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Research Article

Path Choice of Emergency Logistics Based on Cumulative Prospect Theory

Chang-feng Zhu,[1] **Zheng-kun Zhang**,[1] **and Qing-rong Wang**[2]

[1]*School of Traffic and Transportation, Lanzhou Jiaotong University, Lanzhou 730070, China*
[2]*School of Electronic and Information Engineering, Lanzhou Jiaotong University, Lanzhou 730070, China*

Correspondence should be addressed to Zheng-kun Zhang; zzklzjtu@163.com

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We study the problem of path choice for emergency logistics in this paper. Based on the uncertainty environment during the path choice from emergency logistics network and the bounded rationality of decision makers, cumulative prospect theory is introduced to study the problem of emergency logistics path choice with comprehensive consideration of path properties and risk attitude of decision makers. In addition, the decision behavior of decision maker with the attitude of risk seeking and risk aversion under limited rationality is comprehensively analyzed respectively. Based on the choice behavior, a strategy to demarcate the value of reference point value is also proposed, and an optimization model is used to obtain the combined weight based on the moment estimation. Finally, both the theory and model are verified by calculation and compared analysis in a case study. In addition, perturbation analyses of related parameter are carried out to further reveal the influence mechanism between the prospect value of each path and related parameters. The result shows that the decision-making model can make emergency logistics path choice with higher efficiency and reliability under different complex interference conditions.

1. Introduction

Various emergency events, such as natural disaster, have exerted serious influences on human life and socioeconomic development [1]. Disaster is any occurrence that causes damage, destruction, ecological disruption, loss of human life, and the deterioration of health and health services on a scale, which is sufficient to warrant an extraordinary response from outside the affected community or area [2]. Such situations may include natural disasters, such as drought, earthquake, flood or storm, and epidemic. Besides, man-made disruptions, such as nuclear and chemical explosions, are also included [3].

Frequent natural disasters, especially the unexpected emergency events, are not only a test of the government's emergency response but also a challenge for emergency logistics. When a disaster occurs, emergency materials, such as food, medicine, and water, must be sent to the affected area as soon as possible to help wounded people and support rescue operation. Therefore, emergency logistics support is one of the major activities in emergency response [4], and related personnel or decision makers are firstly required as soon as possible to make a reasonable emergency response and select a desirable emergency action to reduce the consequent negative effect [5]. Generally speaking, emergency decision making is typically characterized by the limited time pressure and lacking of information, both of which may lead to potentially serious consequences. To further analyze, the decision-making problems in emergency response are complicated due to the evolutions of the disaster scenario and uncertainty of decision information [6]. Therefore, the study on decision-making method in emergency response is an important topic, and it is becoming a very active and important research field [7].

2. Literature Review

With the number of emergency events taken place, more and more researchers pay their attention to the problem about emergency logistics path choice. In existing related researches, some theory and methods, like optimization [8,

9], decision making [10, 11], and simulation [12, 13], are proposed from different viewpoints.

2.1. Research Based Network Optimization. From the perspective of traditional optimization of emergency logistic network, Haghani et al. [1] have presented a multicommodity and multimodal network flow model for disaster relief operations. In order to further reflect the dynamic of the network, Zhu et al. [14] propose an optimization model of the emergency logistics dynamic network by using super-network theory, in which the information network is specially taken into consideration. Based on the optimization of emergency network, an optimization model has been constructed to vehicle routing in emergency logistics context [12]. The paper shows a point that a reasonable vehicle routing plays an important role in emergency logistics. With respect to the solving algorithm, the improved genetic algorithm is frequently introduced to solve the optimization of emergency logistic network due to the advantage of parallelism. Specially, Jamuna and Swarup [15] propose an improved genetic algorithm for the emergency logistics path choice, in which the time allocation table is dynamically adjusted in terms of different supply points according to the requirements of the demand point. Besides, Chang et al. [16] propose an improved genetic algorithm based on greedy search strategy, by which the efficiency of the algorithm is obviously improved.

Those researches provide an essential reference value, like the emergency rescue operation and material dispatch, to further study the optimization of emergency logistic networks. However, the majority of those researches neglect the complexity and dependency of emergency system, and it may loss the research value in some degree to practical application in real world.

2.2. Research Based System Uncertainty. In order to make up those shortcomings, some scholars take synergy of emergency rescue system into consideration. Specially, Zhu and Li [17] have analyzed the operation mechanism of virtual emergency logistics coupled collaborative system. With the consideration of evolution mechanism of emergency material requirement, Afshar and Haghani [18] propose an integrated model about emergency supply chain based on real-time large-scale disaster relief operations. Based on the complexity of logistic network after the earthquake, a bilevel programming is proposed by Zheng et al. [19]. In addition, some scholars have done some researches from the perspective of robust optimization, such as [20, 21].

There is no doubt that those kinds of achievements have laid further foundation for emergency rescue research. Especially, the consideration of complexity and dependency makes the research more valuable. However, the weakness still exists in the decision behavior without taking them into consideration. As we all know, emergency event usually has property of uncertainty, and the destruction caused by the emergency event is also unpredicted. It means that the emergency logistic environment has not only complexity but also uncertainty. How to reflect decision behavior during the decision maker choices the emergency vehicle routing is also significant to a reasonable decision. But the regret is that this topic is seldom related in existing research.

2.3. Research Based Decision Theory. In fact, the path choice of emergency logistics is a classical problem of stochastic decision making under uncertainty conditions, in which the natural states faced by decision makers are randomly appeared and predicted. With respect to stochastic decision making, some decision rules have been proposed, including elimination by choice strategy [22], fuzzy logistic [23, 24], and stochastic multicriteria decision [25, 26]. However, all of those researches are based on the expected utility theory and assume that decision makers are completely rational. What is more, there is only one emergency decision maker considered in the model. Obviously, those decision models cannot reflect decision behavior under limited rationality, and the decision result cannot match the requirement in real world in that the decision environment is influenced by complex factors, such as lacking of knowledge, degradation of capacity, uncertainty of requirement and travel time.

In recent years, more and more research has taken the decision maker's psychology into consideration in the research of decision making, especially like prospect theory [27] and cumulative prospect theory [28]. The prospect theory is firstly proposed to reflect the decision behavior of decision maker under limited rationality. Based on the original prospect theory, cumulative prospect theory is lucubrated to make the decision result more reasonable and available, especially in the problems of departure time choice, risk perception, and path choice. However, in the emergency logistics system, they are seldom involved.

2.4. Contribution and Organization of This Paper. Based on the aforementioned analysis of existing researches, this paper focuses on the path choice of emergency materials with the consideration of uncertainty of transportation timeliness and volume. In order to make the decision result more corresponding to the decision behavior of decision maker under limited rationality, the prospect theory, especially cumulative prospect theory, is introduced. The main contributions of this paper are the following.

(1) According to analysis of the decision property of emergency materials with the prospective of decision behavior in prospect theory, the value function with heterogeneous reference point is developed by considering time reliability and reconfigurability of transportation volume on emergency logistics path. The significance of value function with heterogeneous reference point is to well mimic the decision attitude under limited rationality towards gains and losses about transportation timeliness and transportation volume.

(2) By analyzing the time probability of any path, the weight function is specially structured based on the probability strategy that a discrete probability distribution is formulated to fit the continuous distribution of transportation time and volume. The significance of weight function with reasonable probability is to describe the decision behavior such that decision maker usually pays more attention to the event with small probability but neglects the higher one.

(3) Based on the value function and weight function, a comprehensive cumulative prospect value is exhibited to reflect the evaluation of decision maker to each path. Especially, in order to obtain the more reasonable prospect value, a weight optimization model is exhibited based on the moment estimation. And also the sensitivity of the related parameters in cumulative prospect theory is lucubrated and analyzed in the case study by dividing the decision makers into the risk preference and the risk aversion.

Furthermore, the optimization model and choice strategy proposed in this research can also be applied to related fields with similar operation characteristics to improve the efficiency. It is hoped that the choice strategy may be applied in further research into path choice modeling for stochastic networks.

The rest of this paper is organized as follows. Section 3 offers a brief analysis and description of the problem about emergency stage and emergency materials. Section 4 proposes path choice modeling based on cumulative prospect theory, and an optimization combined weight model based on the moment estimation is given in this section. A case study is carried out in Section 5. Finally, the conclusions and suggestions for future study are given in Section 6.

3. Problem Analysis and Description

As we all know that some emergency rescue measures must be taken after the emergency events occur, and it is usually different with the rescue time changed. Generally speaking, the emergency rescue process can be divided into four stages which include emergency preparedness, emergency primary response, expand emergency, and emergency recovery [4]. From those four stages, the emergency preparedness and emergency primary response are extremely significant to emergency rescue system in that the necessary emergency materials must be prepared. Besides, the reasonable path selected for transporting emergency materials from emergency storage center to disaster area is also preplanned.

3.1. Requirement Volume of Emergency Materials. As having mentioned above, the category of emergency material is various, such as food, water, and medicine. Without doubt, the demand of emergency material required by the disaster area is also variable with the rescue changed. The urgent variation of emergency material demand at different time is shown in Figure 1.

From Figure 1 we can see that the requirement of emergency materials increases sharply, once the emergency event takes place. It means that the difficulty of organization of emergency materials is in the requirement volume of emergency materials, and it is one of the most important reasons that the majority of related existing researches focus their attention on those topics.

With respect to the requirement volume of emergency materials, some of existing researches regard transportation volume on path as the amount of known, which is obviously unreasonable because of various requirements. In fact, each path has its maximum capacity $q_{\max}$. If the transportation volume q distributed by decision maker is bigger than $q_{\max}$, the timeliness may poor. On the contrary, the timeliness becomes higher, but the transportation ability of the path is wasted. Obviously, these two conditions mean losses to decision maker; otherwise, they mean gains.

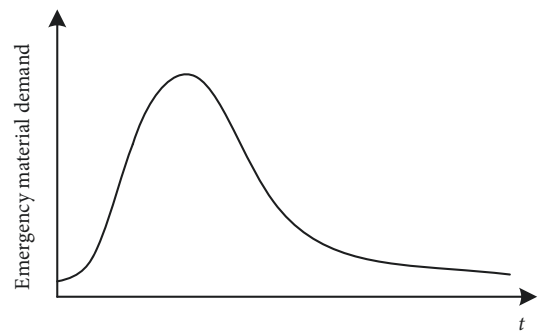

Figure 1: Urgent variation of emergency materials demand at different time.

3.2. Transportation Timeliness of Emergency Materials. Timeliness is another important property to emergency materials. Usually, the best rescue time is within 72 hour. Once the best rescue time is lost, the meaning of the rescue will be dramatically reduced. In addition, if the transportation time of emergency materials is delayed, the plan of rescue may be interrupted, which also can cause the additional damage.

With respect to the transportation timeliness of emergency materials, most existing researches regard it as a determinant attribute in emergency transportation network. The differences are that some researches deal with transportation time with a fixed value t_i on each path p_i. However, with taking care of disturbance caused by secondary disaster or traffic congestion, others grant a deviation time Δt_i on transportation time t_i to improve the robustness and adaption. Just as explained above, the shortage of those researches is that the influence caused by the decision maker is not taken into consideration. For a wise and experienced decision maker, there is an expected and neutral time t_0, which can be called reference point. If $t_i > t_0$, it means loss to decision maker; otherwise, it means gains.

3.3. Decision Process Based Reference Points. According to the analysis of volume and timeliness of emergency materials, both transportation volume reference point and timeliness reference point are prominent to decision maker. In order further analyze the decision process, the decision process of decision makers based reference point is shown as Figure 2.

Based on the analysis of decision process, the reference point is extremely significant for decision makers. However, just as exhibited by prospect theory [27], decision maker usually holds an attitude of risk seeking when he faces gains outcome with small probability to occur. On the contrary, the attitude will turn to risk aversion when it faces loss outcome with higher probability. The decision attitude based gains and loss can be expressed as in Figure 3, and the decision attitude based probability can be expressed as in Figure 4

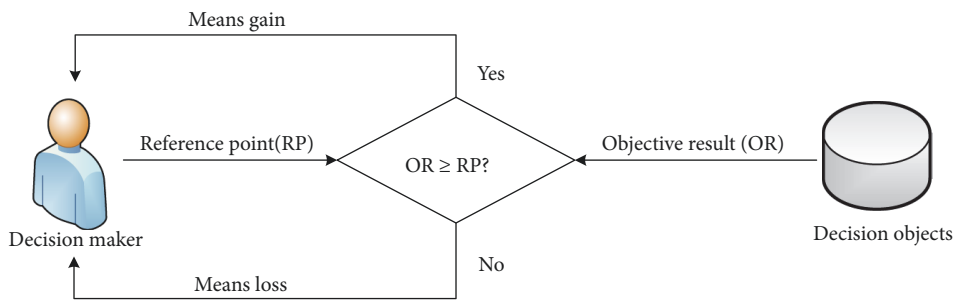

Figure 2: The decision process of decision makers based reference point.

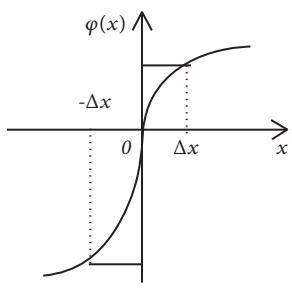

Figure 3: The decision attitude based gains and loss.

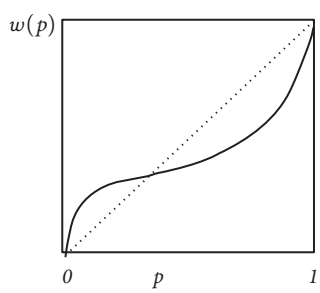

Figure 4: The decision attitude based probability.

Obviously, according to Figures 3 and 4, the attitude violates the expected utility theory. Therefore, with the consideration of comprehensive decision process, cumulative prospect theory can be used to research the path choice problem.

4. Path Decision Model Based on Cumulative Prospect Theory

Similar to prospect theory, both value function and weight function are the particular contents in cumulative prospect theory. Specially, they are also the key points that reflect the decision behavior of decision makers under limited rationality. For the value function, the selection of reference point is extremely important. For the weight function, the probability of event is an important one.

4.1. Strategy of Reference Point and Value Function. The reference point is a measurement standard of the gain and loss, the value of reference point is the core for cumulative prospect theory. Considering that the research problem in this paper is the stages of emergency preparedness and emergency primary response, this paper chooses transportation time and transportation volume of emergency materials as the main factors; namely, CPT model of two heterogeneous reference points is transportation time and transportation volume of emergency materials.

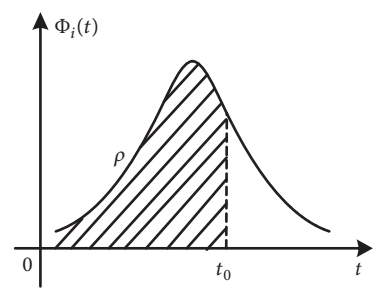

Figure 5: Transportation time reliability.

(1) Reference Point of Transportation Time. In an emergency event, the earlier the materials arrive at the affected area, the smaller the loss will be. Consequently, transportation time is the first problem to be considered, especially in the choice of emergency logistics path. For reference point of transportation time, decision makers should not only consider transportation time but also consider the reliability. Therefore the time reference point based on time reliability is defined as follows.

Definition. Define that the minimum transportation time whose reliability $\Psi_i(t_i)$ is not less than ρ in all alternative paths as transportation time reference point t_0.

Based on this, the reference point of transportation time is defined as follows:

$$t_i^{\min} = \min\{t_i \mid \psi_i(t) \geq \rho\} \tag{1}$$

$$t_0 = \min\{t_i^{\min}\} \tag{2}$$

Moreover, we assumed that the transportation time distribution of each path approximates normal distribution $N_1 \sim (\mu_i, \sigma_i^2)$ [29]. Reliability of transportation time is shown as in Figure 5.

Based on the normal distribution $N_1 \sim (\mu_i, \sigma_i^2)$, the solution process of formula (1) is shown as

$$t_i = \min\left\{\Phi^{-1}(\rho)\sigma_i + \mu_i\right\} \tag{3}$$

where $\Phi^{-1}(\cdot)$ is the inverse function of the normal function. μ_i is the mean value of the transportation time for the i-th path. σ_i is the standard deviation.

According to the analysis and description, $t_i \le t_0$ means gains to decision maker, otherwise, means loss.

(2) Reference Point of Transportation Volume. The more quantity of emergency materials is transported to disaster area, the smaller loss will be. Nevertheless, the more the transportation volume of emergency materials, the fewer the road section satisfied conditions, the less the flexibility of path choice, and the worse the reconfigurability of path choice.

Consequently, reference point of transportation volume includes minimum acceptable transportation volume q_0 and maximum acceptable transportation volume q_1. If the transportation volume of emergency materials is less than q_0 or higher than q_1, we consider it as a loss to decision maker. On the contrary, if the transportation volume of emergency materials is between q_0 and q_1, it can be regarded as gains to decision maker. Select the minimum acceptable transportation volume q_0 and maximum acceptable transportation volume q_1 as two reference points; the main purpose is to transport as much emergency materials as possible to the affected areas to reduce casualties and property damage.

Many factors affect the reconfigurability of the emergency logistics path. In this paper we only consider the factor that leads to the reconfigurability decline of the emergency logistics path, yet the remaining capacity of the section is the key factor that affects the emergency logistics path reconfigurability.

When the path reconfigurability is not considered, the gain is $q_i \ge q_0$ and the loss is $q_i < q_0$. However, when path reconfigurability is considered, the value function is defined as follows.

$$\varphi(q_i) = \begin{cases} -\lambda_1 (q_0 - q_i)^{\beta_1} & q_i < q_0 \\ (q_i - q_0)^{\alpha} & q_0 \le q_i \le q_1 \\ -\lambda_2 (q_i - q_1)^{\beta_2} & q_i > q_1 \end{cases} \tag{4}$$

where α is the parameter to sensibility of gains. β_1, β_2 are the parameters to sensibility of loss. λ_1, λ_2 are the loss aversion coefficients.

According to the research [25], we also assumed that the remaining capacity of i-th path approximates normal distribution $N_2 \sim (\upsilon_i, \xi_i^2)$. Then, the probability distribution of the remaining capacity for any path is shown as in Figure 6.

On i-th path, the probability $\phi_i(q_i^{\min})$ of the minimum transportation volume $q_i^{\min}$ to be delivered is required not smaller than the reliability ρ'. That is

$$q_i^{\min} = \min\left\{q_i \mid \phi_i(q) \ge \rho'\right\} \tag{5}$$

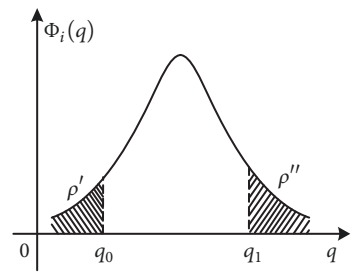

Figure 6: Probability distribution of any path remaining capacity.

Select the largest $q_i^{\min}$ of paths as q_0, that is,

$$q_0 = \max\left\{q_i^{\min}\right\} \tag{6}$$

On i-th path, the probability $\phi_i(q_i^{\max})$ of the maximum transportation volume $q_i^{\max}$ to be delivered is required not smaller than the reliability ρ''.

$$q_i^{\max} = \max\left\{q_i \mid 1 - \phi_i(q) \ge \rho''\right\} \tag{7}$$

In order to meet reliability, select the smallest $q_i^{\max}$ of paths as q_1, which can be expressed as

$$q_1 = \min\left\{q_i^{\max}\right\} \tag{8}$$

4.2. Weight Function and Probability Strategy. In prospect theory, the decision weight function is to simulate the psychological activity. In general, people will pay attention to smaller probability events, while ignoring the larger probability events [29]. In other words, the decision maker has more sensitivity to event with the smaller probability than the higher one. In the face of loss, decision maker keeps risk preference, otherwise, keeps risk aversion.

Get a gain for any reference point:

$$\omega^+(p) = \frac{p^\gamma}{\left[p^r + (1-p)^\gamma\right]^{1/\gamma}} \tag{9}$$

Get a loss for any reference point:

$$\omega^-(p) = \frac{p_j^\delta}{\left[p^r + (1-p)^\delta\right]^{1/\delta}} \tag{10}$$

where $\omega(p)$ indicates the probability of occurrence of an event.

With respect to the travel time probability of any path in weight function, it is directly given in most of existing researches, like [30, 31], and the limitations are very obvious. Based on this weakness, a strategy improved is proposed in this paper to compute travel time probability. Technically, a discrete distribution is formulated to fit the continuous distribution of t_i. The following notations are defined to describe the discrete distribution:

$p\%$: close to but not bigger than 1, taking 98% as an example

$\phi(\cdot)$: the standard normal cumulative distribution function

$$a_i = t_i - \sigma_i^t \phi^{-1}\left(0.5 + 0.5p\%\right) \tag{11}$$

$$b_i = t_i + \sigma_i^t \phi^{-1}\left(0.5 + 0.5p\%\right) \tag{12}$$

$\Theta_i = [a_i, b_i]$: a confidence interval of t_i with a reliability of $p\%$.

Divide Θ_i into equal spaces with a number of K, which are denoted as $\Delta_i^1, \cdots, \Delta_i^j, \cdots, \Delta_i^K$, thereinto, $j = 1, \cdots, K$. x_i^j and p_i^j respectively denote the median of space Δ_i^j and the probability that travel time happens to be in Δ_i^j.

According to the discretization strategy mentioned above, transportation time (transportation volume) outcomes of emergency material on i-path can be described as a discrete distribution denoted by pair (x_i, p_i).

$$\begin{aligned} x_i &= \left(x_i^1, \cdots x_i^K\right), \\ p_i &= \left(p_i^1, \cdots p_i^K\right) \end{aligned} \tag{13}$$

4.3. Comprehensive Cumulative Prospect Value. Based on the description of value function and weight function, this section will further give the formulation of comprehensive cumulative prospect values. For convenient application, it will be arranged in ascending order of x_i. In addition, the cumulative decision weight π_{ij}^+ and π_{ij}^- for any reference point j can be obtained respectively as

$$\pi_{ij}^+ = \omega^+\left(\sum_{\tau=j}^{n} p_\tau\right) - \omega^+\left(\sum_{\tau=j+1}^{n} p_\tau\right) \tag{14}$$

$$\pi_{ij}^- = \omega^-\left(\sum_{\tau=1}^{j} p_\tau\right) - \omega^-\left(\sum_{\tau=1}^{j-1} p_\tau\right) \tag{15}$$

Then, the prospect value of any reference point j ($j = 1, 2$) for i-th path can be denoted as

$$U_{ij} = \sum_{j=1}^{n} \pi_{ij}^+ \varphi\left(x_{ij}\right) + \sum_{j=-m}^{0} \pi_{ij}^- \varphi\left(x_{ij}\right) \tag{16}$$

Nevertheless, transportation time and transportation volume are the two heterogeneous reference points; they have different dimensions; therefore, use the following equation to make them dimensionless.

$$\overline{U}_{ij} = \frac{U_{ij}}{\max\left|U_{ij}\right|} \tag{17}$$

Based on formulation (17), the comprehensive cumulative prospect value of any path, which is also the evaluation basis of decision maker to decide which path to choose, can be expressed as

$$\widehat{U} = \sum_{j=1}^{n} \omega_j \overline{U}_{ij} \tag{18}$$

where ω_j is the weight to $\overline{U}_{ij}$.

With respect to the weight ω_j in formula (18), existing researches have done similar research, such as fuzzy theory [32], TOPSIS theory [33], interval grey number theory [34], and rough set theory [35]. Nevertheless, most of above researches only consider the subjective weight or objective weight. In this paper, a model of optimal combination weighting is proposed based on moment estimation theory.

(1) Subjective Weight Based on G1 Method. According to G1 theory, the subjective weight ω_j is denoted as

$$\omega_j = \prod_{k=j+1}^{m} r_k \omega_m \tag{19}$$

$$\omega_m = \left(1 + \sum_{j=2}^{m} \prod_{k=j}^{m} r_k\right)^{-1} \tag{20}$$

where proportion criteria of r_j are denoted according to literature [36].

(2) Objective Weight Based on Maximum Entropy Model. Maximum entropy weight can effectively avoid decision errors caused by incomplete information. According to the improved TOPSIS method, correlation between scheme and positive ideal point, negative ideal point is denoted as

$$\chi_{ij} = \frac{d\left(\widehat{U}_{ij}, \widehat{U}_j^-\right)}{\left[d\left(\widehat{U}_{ij}, \widehat{U}_j^+\right) + d\left(\widehat{U}_{ij}, \widehat{U}_j^-\right)\right]} \tag{21}$$

$$\theta_{ij} = \frac{\chi_{ij}}{\sum_{i=1}^{p} \chi_{ij}} \tag{22}$$

The constraint conditions for weight based maximum entropy model are denoted as

$$\omega_j \in \left[\min \theta_{ij}, \max \theta_{ij}\right] \tag{23}$$

The objective weights based maximum entropy model is shown as

$$\begin{aligned} \max \quad & F = -\sum_{j=1}^{m} \omega_j \ln \omega_j \\ \text{s.t} \quad & \sum_{j=1}^{m} \omega_j = 1 \\ & \omega_j \in \left[\min \theta_{ij}, \max \theta_{ij}\right] \\ & \frac{1}{m}\sum_{j=1}^{m}\left(\omega_j - \frac{1}{m}\right)^2 \in \left(\min_j D_j, \max_j D\right) \\ & D_j = \frac{1}{p}\sum_{i=1}^{p}\left(\theta_{ij} - \frac{1}{p}\right)^2 \end{aligned}$$

$$\theta_{ij} = \frac{\chi_{ij}}{\sum_{i=1}^{p} \chi_{ij}}$$
$$\chi_{ij} = \frac{d\left(\widehat{U}_{ij}, \widehat{U}_j^-\right)}{\left[d\left(\widehat{U}_{ij}, \widehat{U}_j^+\right) + d\left(\widehat{U}_{ij}, \widehat{U}_j^-\right)\right]}$$
$$i = 1, 2, \cdots, p; \quad j = 1, 2, \cdots, m \tag{24}$$

(3) The Optimal Combined Weight Based on the Moment Estimation. The optimal combined weight method based the moment estimation theory can avoid the multiplier effect of the general combined weight method.

Suppose that $\omega_s^* = (\omega_{s1}^*, \omega_{s2}^* \cdots \omega_{sn}^*)$ is subjective weight vector based on G1 method and $\omega_o^* = (\omega_{o1}^*, \omega_{o2}^* \cdots \omega_{on}^*)$ is the objective weight vector based on maximum entropy model.

Then, an optimization model for the combined weight is presented as

$$\begin{aligned}
\min \quad & H = \sum_{j=1}^{m} \vartheta' \left(\omega_j - \omega_{sj}\right)^2 + \sum_{j=1}^{m} \vartheta'' \left(\omega_j - \omega_{oj}\right)^2 \\
\text{s.t.} \quad & \vartheta' = \frac{\sum_{j=1}^{m} \vartheta_j'}{m} \\
& \vartheta'' = \frac{\sum_{j=1}^{m} \vartheta_j'}{m} \\
& \vartheta_j' = \frac{\omega_{sj}}{\left(\omega_{sj} + \omega_{oj}\right)} \\
& \vartheta_j'' = \frac{\omega_{oj}}{\left(\omega_{sj} + \omega_{oj}\right)} \\
& \sum_{j=1}^{m} \omega_j = 1, \quad \omega_j \in (0, 1)
\end{aligned} \tag{25}$$

where ϑ_j', ϑ_j'' are the relative importance coefficients of the subjective weight and objective weight for any reference point.

5. Empirical Case Study

In order to testify validity and objectivity, a simple emergency logistics network is used to validate the above emergency path choice decisions. A simple emergency logistics network is shown as in Figure 7.

As shown in Figure 6, this emergency logistics network consists of five nodes, six sections, and three paths, which connect one OD pair, v_1-v_5.

Path 1: v_1-v_5.

Path 2: v_1-v_2-v_3-v_5.

Path 3: v_1-v_2-v_4-v_5.

Because of the uncertainty of emergency logistics network, decision maker cannot decide the perfect transportation time and transportation volume of emergency material beforehand.

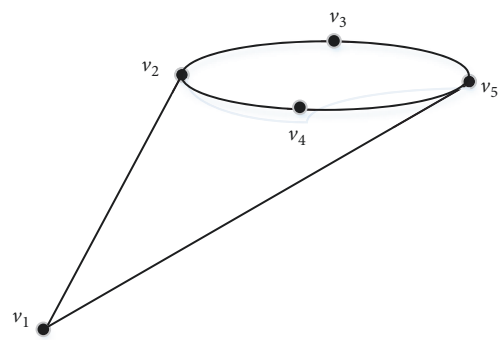

Figure 7: A simple emergency logistics network.

Table 1: Route parameters value.

path	t/min		q/pcu	
	μ	σ	υ	ξ
1	260	60	680	80
2	280	12	630	60
3	300	20	650	40

Therefore, the perceived transportation times and the remaining capacity for any path are all assumed to be random variables with approximately normal distribution.

$$\begin{aligned}
N_1 &\sim \left(u_i, \sigma_i^2\right), \\
N_2 &\sim \left(\upsilon_i, \xi_i^2\right)
\end{aligned} \tag{26}$$

The paths parameters value are shown as in Table 1.

In order to compare the influence of transportation time reliability and path reconfigurability on the path choice result, the decision makers are divided into risk preference (RP) and risk aversion (RA).

For reference point of transportation time, suppose that RP decision maker and RA decision maker select reliability of transportation time with not less than 0.3, 0.8 as the reference point, respectively.

For reference point of transportation volume, suppose that RP decision maker selects the remaining capacity reliability with not less than 0.2 as a reference point and does not consider the reconfigurability of path, while the RA decision maker considers the path reconfigurability and selects minimum and maximum transportation volumes with reliability of not less than 0.2.

5.1. Cumulative Prospect Value Based on Single Reference Point. If only we consider any single reference point, the result of cumulative prospects for each path is shown in Table 2.

It can be seen from the results in Table 2, whether the reference point is transportation time or transportation volume, that the RP decision makers always choose path 1.

Nevertheless, for RA decision maker, if only we consider the reference point of transportation time, the best choice result is path 2, but if only we consider the reference point of transportation volume, the best choice result is path 3.

Table 2: The result of cumulative prospect value for each path.

path	t/min		q/pcu	
	The value based RP	The value based RA	The value based RP	The value based RA
1	−53.767	1.447	9.317	−71.240
2	−82.324	2.000	−17.452	−52.760
3	−91.958	−26.940	6.499	−21.369

Table 3: The optimal result of weight.

ω_s	ω_o	ω_c
(0.4591,0.5409)	(0.4034,0.5966)	(0.4139,0.5861)

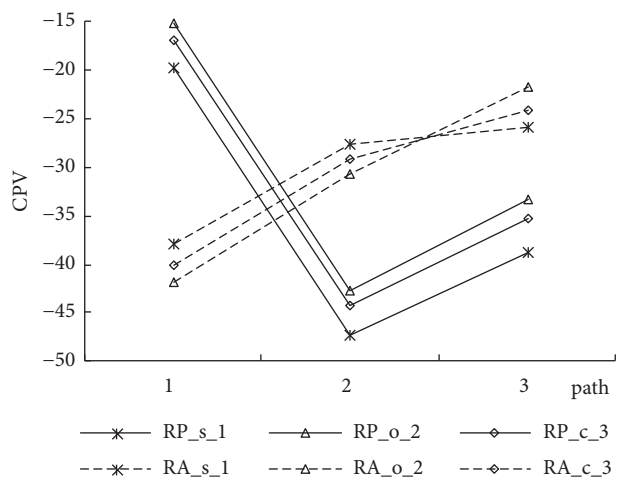

Figure 8: The comprehensive CPV of each path under different conditions.

5.2. Cumulative Prospect Value Based on Double Reference Points. According to the optimal combined weight model proposed in this paper, we use matlab based on ant colony algorithm to solve the results of subjective weight ω_s, objective weight ω_o, and the combined weight ω_c shown in Table 3.

As shown in Table 3, the weight obtained by the optimal combined is between that by G1 method and the maximum entropy model. It shows that it not only considers the subjective psychology of decision maker, but also embodies relevance between the reference points.

The comprehensive cumulative prospect values of each path under different conditions are shown in Figure 8. In Figure 8, RP_s_1 denotes CPV calculated by ω_s of path1 for RP decision makers, and the others have the same denotation.

As shown from Figure 8, if RA decision makers comprehensively consider double reference point, the best choice is path 3; nevertheless, for RP decision makers, the best choice is path 1. Generally, the weight has little impact on the CPV of RP decision makers, while it has larger impact on the CPV of RA decision makers. Consequently, the type of decision makers and weight has a certain impact on the decision results.

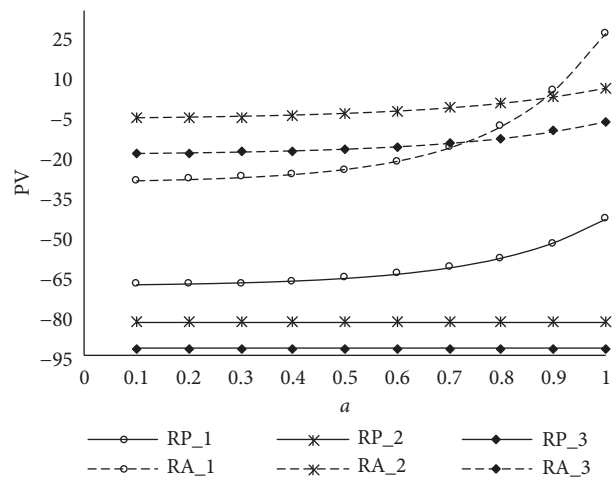

Figure 9: The PV variation of reference point with α.

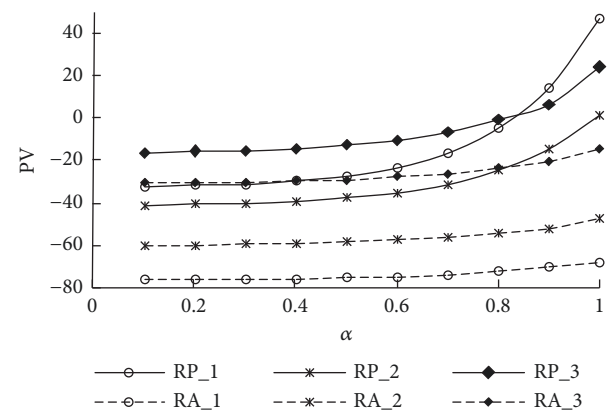

Figure 10: The PV variations of reference point q with α.

5.3. Perturbation Analysis of Parameter. Furthermore, different values of the parameters α,β also have different PV; the variation of the above parameters value has different effect on different types of decision makers. For this purpose, perturbation analysis of the above parameters is carried out by using matlab 7.0 to further reveal the mechanism of the influence of parameter perturbation on PV to any path.

The PV variations of reference point t, q with α are shown in Figures 9 and 10, respectively.

As shown in Figures 9 and 10, the PV of most paths is increasing with the increase of gain sensitive parameter α, but there is a certain differences trend.

Firstly, for reference point t, PV of RA decision makers is all larger than that of RP decision maker, because the

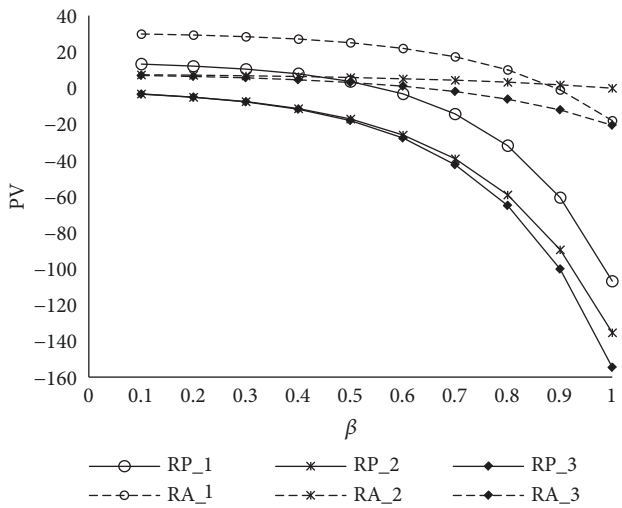

Figure 11: The PV variation of reference point t with β.

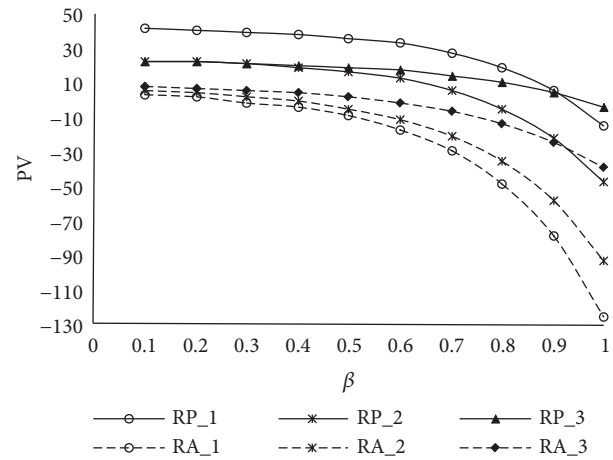

Figure 12: The PV variation of reference point q with β.

value of reference point t is large for RA decision makers, and the gain is larger. Moreover, the PV variation of RA decision maker is more obvious. The reason is that as the value of parameter increases, the diminishing degree of the value function sensitivity in the gain region becomes smaller. When the transportation time is less than the reference point, the decision maker will gain more income.

Secondly, for reference point q, PV of RP decision maker is all larger than that of RA decision maker, because RA decision maker considers the reconfigurability of path, regarding the part of the large capacity but low reliability as a loss. Moreover, PV variation r is more obvious. The reason is that RA decision maker chooses two reference points and the gain interval is smaller than RP decision maker, so parameter α has a weak impact on it.

Thirdly, Figure 9 shows that PV of RP decision maker has almost no change with the increase of parameter α. The reason is that the value of reference point t is relatively smaller and the gain is near to 0, so the gain sensitive parameter α has a small impact on it.

The PV variation of reference point t, q with β is shown as Figures 11 and 12 respectively.

As shown in Figures 11 and 12, PV of all paths decreases with the increasing of β value. For the reference point t in Figure 11, PV variation of RP decision maker is more obvious. The reason is that with the β value increasing, the diminishing degree of value function sensitivity in the gain region becomes smaller. When the transportation time is greater than the reference point, the loss turns to increase.

Nevertheless, for the reference point q in Figure 12, PV variation of RA decision maker is more obvious. The reason is that q_0 is the same as two types of RP and RA decision makers, but the RP decision maker considers the constraints of maximum capacity; therefore, when the transportation volume is higher than q_1 and the diminishing degree of the value function sensitivity in the gain region becomes smaller with increasing of β, the loss increases.

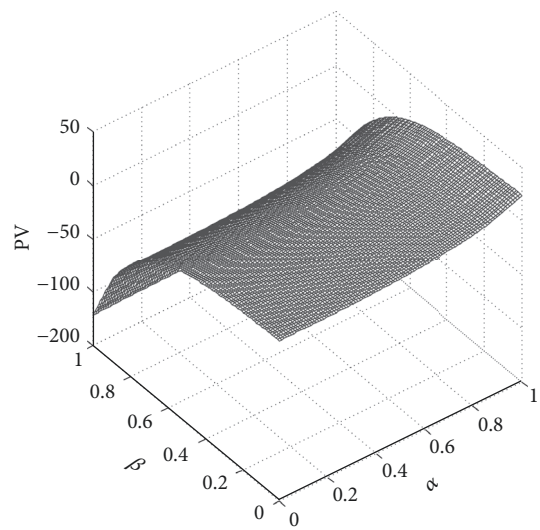

Figure 13: The influence of α, β on PV of RP decision maker for path 1.

In order to analyze the influence of combined perturbation of parameters on PV, path1 is analyzed as an example. The influences of α, β and γ, δ on PV of RP decision maker for path1 are shown as in Figures 13 and 14, respectively.

As shown in Figure 13, PV variation is smaller with the increasing of the gain sensitivity coefficient α, but PV variation is larger with the loss sensitivity coefficient β. It reflects that PV is more sensitive to the loss sensitivity coefficient β than the gain sensitivity coefficient α.

As shown in the Figure 14, PV variation is smaller with the increasing of loss perception coefficient γ value, but PV variation is larger with the increasing of gain perception coefficient δ. It reflects that decision maker is more sensitive to the loss than the gains.

6. Conclusion and Further Work

The path choice of emergency logistics plays a key role in disaster response and recovery. In recent years, various

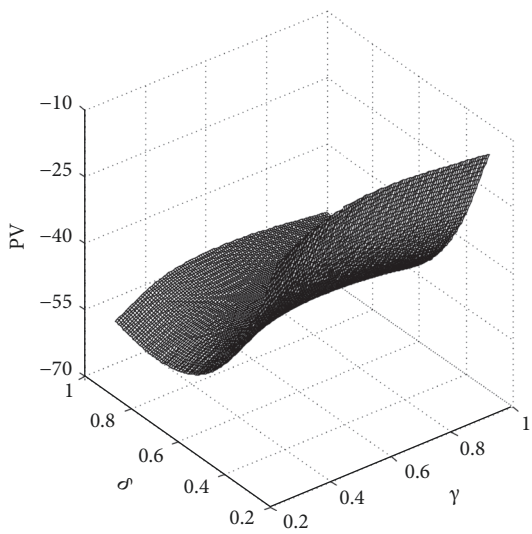

Figure 14: The influence of γ, δ on PV of RP decision maker for path 1.

transport related phenomena and experimental data that could not be explained by EUT have been well explained by PT and CPT. With respect to path choice behavior, CPT offers a pattern of risk attitude, which is different from that of EUT. In CPT, common psychological aspects of decision maker can be incorporated into normative research by using the values of α, β, γ, and δ.

In this paper, a strategy to confirm the reference point value is proposed by considering the path properties and risk attitude of decision makers comprehensively, and an optimization model is proposed to obtain the combined weight based on the moment estimation. The proposed method has also been implemented in a case by calculating and comparing, and also perturbation analysis of related parameter is carried out by using matlab 7.0 to further reveal the mechanism of the influence of parameter perturbation on prospect value of any path. The aim of this paper is to describe the path choice pattern of emergency logistics for various types of decision makers under the complex condition and limited rationality.

It can be reflected from the case study that two types of decision makers have different perception values for the same path, and the final choice path result is different. The result is consistent with the reality and also reflects the applicability of the cumulative prospect theory for the path choice study of emergency logistics.

The path choice of emergency logistics is influenced by multitudinous complicating factors. However, only two reference points and one OD pair are considered in this paper. Next step, we will spend more effort on the multiple reference points and multiple OD pairs. In addition, we will study the value function and the cumulative probability of the multiple reference points by comprehensively analyzing the physical characteristics of the emergency logistics network. These are only a few topics for future research in this important area.

Data Availability

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

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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