Robust Optimization Research on Multi-objective Distribution of Emergency Supplies under Geological Disasters

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Abstract. This study focuses on the emergency material distribution problem in a geologic disaster scenario, and proposes a multi-objective ant colony optimization method to plan the distribution path of rescue materials. In the event of geologic disasters, critical logistics distribution points may suffer damages, and the model proposed in this paper is dedicated to maximizing the satisfaction of the emergency rescue time while minimizing the total cost of the system, including the construction cost of the logistics facility points, the loading cost of the vehicles, the transportation cost, and the cost of the time penalty for the time window that exceeds the point of demand for the emergency supplies. To deal with this NP-Hard problem, the variability among the optimization objectives is eliminated by a percentage normalization method, and a weighting factor is introduced to balance the time satisfaction and cost.

Keywords: emergency supplies distribution path; robust optimization; uncertainty

1 INTRODUCTION

Our country has a complex geological structure and is located at the boundary between the Asian-European plate, the Indian Ocean plate and the Pacific plate, so the frequency of geological disasters is quite high.[1] such as the Wenchuan earthquake in 2008 and the Yutian earthquake in 2014, both of which brought great losses to the lives and property safety of our people, so saving people's lives and restoring people's normal life after the disaster as soon as possible is the top priority after a geological disaster, and it is urgent to establish a complete set of distribution path optimization methods after a geological disaster to realize the supply of emergency supplies in the shortest possible time, in order to minimize the losses and negative impacts of geological disasters on people.

In emergencies such as geologic disasters, efficient and reliable distribution of materials is crucial, so many scholars take into account the uncertainty of demand and complex decision-making environment to plan distribution paths or facility points, and for the multimodal distribution problem of multilevel nodes Deng Mingjun, Dai

V. Vasilev et al. (eds.), *Proceedings of the 2024 5th International Conference on Management Science and Engineering Management (ICMSEM 2024)*, Advances in Economics, Business and Management Research 306,
https://doi.org/10.2991/978-94-6463-570-6_15

Yuzhen et al.[2] Optimization of multimodal transportation scheme for emergency supplies under consideration of demand uncertainty and solved by improved genetic algorithm. Li Shuanglin, Ma Zujun et al.[3] Simulation of material demand at the initial demand points after the earthquake by triangular fuzzy numbers, and obtaining the integrated decision of distribution center location and multimodal transportation according to the decision maker's preference.DI GANG[4] Multi-objective distribution model for emergency materials under emergency geologic disasters, solved by ant colony algorithm. SHI Chuwei, MA Changxi et al.[5] For the case that there are nodes and roads damaged in the network, a reliable logistics network design method based on two-stage robust optimization is proposed and solved by hybrid evolutionary algorithm with two-layer coded structural chromosomes,Zemin WANG et al.[6] Establishing a two-layer planning set up multi-objective model to solve the path network optimization of medical supplies.

Most scholars have considered the influence of other key factors such as cost, time, carbon emission on the optimization objective in the emergency facility siting-path problem (LRP), but in emergency logistics, Wang Yong et al.[7] established a multi-objective function to ensure the robustness of the system by improving the heuristic algorithm. Long Haibo, Yang Jiaqi et al.[8] A bias robust optimization approach for risk avoidance in the case of demand uncertainty. Su Bing, Zhou Jiaqi[9] Combining the demand characteristics of individual emergency material demand points to create a probability density function, so as to eliminate uncertainty and configure a reasonable distribution path. Cheng Xingqun[10] Jin Chun[11] et al. Constructed a robust adjustable path selection model and combined it with multiple low-carbon policies, and solved the robust model with pairwise transformation.

In summary, most of the scholars only consider the relevant cost or the benefits of a single efficiency, but ignore the two should be integrated planning in emergency logistics, and should take into account the emergency logistics due to some unexpected conditions caused by the disaster caused by road damage and demand uncertainty and other issues, so this paper in the previous scholars of the research results below, by fully taking into account the above situation, the unity of a variety of objectives, and algorithms for solving the problem, to validate the validity of the model.

2 PROBLEM DESCRIPTION AND MODELING

2.1 Description of the Problem

The multi-objective distribution problem of emergency supplies under geologic disasters studied in this paper can be formulated as follows: there are i candidate first-level emergency logistics distribution points, j candidate second-level emergency logistics distribution points, k emergency supplies demand points, and o rescue vehicles in the geologic disaster area. a material distribution path that meets the above conditions is planned. The logic diagram is shown in Figure 1. In response to the above statement, the paper makes the following assumptions:

The fuzzy number a_k is introduced to denote the emergency distribution time of the emergency material demand point K, which obeys the skewed small parabolic distribution[12] , and the affiliation function is as follows. Most of the previous scholars only considered the deterministic situation or single-objective path optimization, while in the emergency logistics many situations are with uncertainty, to sum up the above to get the model description of this paper is as follows.

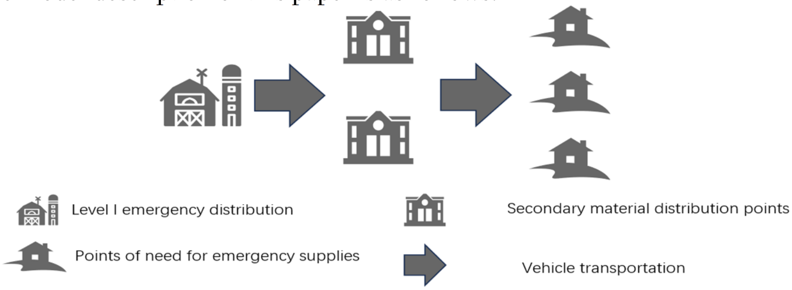

Fig. 1. Logic diagram of logistics nodes

$$f_k(a_k)=\begin{cases} 1 & a_k < a \\ \left(\dfrac{b-a_k}{b-a}\right)^m & a \le a_k \le b \\ 0 & b < a_k \end{cases} \tag{1}$$

The faster the emergency response, the better, so when the arrival time of emergency supplies is greater than a after a geologic disaster, the satisfaction of rescue time shows a nonlinear relationship decreasing gradually[13] .

2.2 Model Parameters and Variables

According to the need of constructing the model, the parameters and sets are defined as follows Table 1 are shown.

Table 1. Description of model parameters

parameters	hidden meaning
D_{ab}	Indicates primary and secondary emergency distribution points
d_{cd}	Indicates the distance between the secondary emergency logistics distribution point and the point of demand
q_k	Requirements at point of need k for emergency supplies
R_i	Fixed cost of building distribution points i , j
R_o	Vehicle o loading cost per unit of cargo capacity

Since the network design includes three logistics nodes, the primary emergency logistics distribution point, the secondary emergency logistics distribution point, and the emergency material demand point, the decision variables are set as follows in order to represent the network circulation relationship.

2.3 Model Building

Based on the above assumptions as well as parameter variables, the multi-objective distribution model of emergency supplies under geologic disasters is constructed as follows:

$$\max Z_1 = \sum_{k \in K} f_k \left(a_k \right) \tag{2}$$

$$\min Z_2 = \sum_{i \in I} X_i R_i + \sum_{j \in J} X_j R_j + \left(\sum_{j \in J} Q_j + \sum_{j \in J} \sum_{k \in K} Y_{jk} O_k \right) RO + \sum_{j \in J} RO_2 Q_j LG_j + \sum_{k \in K} Q_K LG_k RO_2 + Q_k \alpha_1 \max \left[0, T_{2d} - T_d \right] \tag{3}$$

$$s.t. \quad \sum_{k \in K} \left(\sum_{j \in J} P_{ojk} \right) \times \sum_{j \in J} X_j Y_{jk} Q_j + \sum_{k \in K} \left(\sum_{j \in J} P_{ojk} \right) \varpi_i \geq \sum_{k \in K} \left(\sum_{j \in J} P_{ojk} \right) q_k \quad \mathrm{k} \in \mathrm{K} \tag{4}$$

$$\sum_{i \in I} \sum_{o \in O} Z_{oij} X_i \leq C_{i,} \ i \in I, o \in O \tag{5}$$

$$\sum_{o \in O} \sum_{j \in J} P_{oij} X_j \leq C_o \ o \in O, j \in J \tag{6}$$

$$\sum_{i \in I} X_{ij} = \sum_{o \in O} \sum_{j \in J} Z_{ojk} = 1 \ i \in I, o \in O \tag{7}$$

$$\sum_{j \in J} Y_{jk} = \sum_{o \in O} \sum_{k \in K} P_{ojk} = 1 \ j \in J, o \in O \tag{8}$$

$$\sum_{i \in I} Z_{oij} \leq \sum_{j \in J} Z_{oij} \ i \in I, j \in J \tag{9}$$

$$\sum_{j \in J} Z_{oij} \leq \sum_{k \in K} P_{ojk} \ j \in J, k \in K \tag{10}$$

$$\sum_{i \in I} \sum_{j \in J} Z_{oij} \leq 1 \ i \in I, j \in J \tag{11}$$

$$\sum_{j \in J} \sum_{k \in K} P_{ojk} \leq 1 \ j \in J, k \in K \tag{12}$$

$$C_o < C_j < C_i \tag{13}$$

$$f_k(a_k)=\begin{cases}1 & a_k<a\\ \left(\dfrac{b-a_k}{b-a}\right)^m & a\le a_k\le b\\ 0 & b<a_k\end{cases} \tag{14}$$

$$X_{ij}, Y_{jk}, Z_{ojk}, P_{ojk}, X_j, X_j \in \{0,1\} \tag{15}$$

Equation (1) in the model is to maximize the emergency relief time satisfaction, and Eq.(1) is to minimize the total cost of the system, which mainly includes the construction cost of the logistics facility point, the loading cost of the vehicle, the transportation cost of the logistics operation, and the cost of the time penalty for exceeding the time window of the emergency material demand point.

2.4 Multi-objective Weighting

The above multi-objective distribution model of emergency supplies under geological disasters considers maximizing the time satisfaction of emergency rescue and minimizing the total cost of the system, which belongs to the NP-Hard problem in the model solution, so in order to facilitate the solution, and because more emphasis is placed on time satisfaction in the distribution of emergency supplies, the weighting factors of time satisfaction and cost are set to $\beta_1=0.6, \beta_2=0.4$, and the minimum value of the objective function under the deterministic demand, Z_1^*, Z_2^* is used to obtain the optimized multi-objective function after linear weighting as follows

$$\min Z=\beta_1\left(\frac{Z_1}{Z_1^*}\right)+\beta_2\left(\frac{Z_2}{Z_2^*}\right) \tag{16}$$

2.5 Robust Optimization Model Optimization

Robust optimization model is an uncertain optimization method that can get better results based on the current situation even if the value range of uncertain parameters and probability distribution function are not known by using the idea of robust control. The robust optimization method can solve the problem of optimizing the distribution path of materials in emergency logistics due to the uncertain demand of the disaster-stricken places.

In order to describe the simplicity, the interval type set is used to describe the material demand situation of the emergency material demand point:

$$Q_{qk}=\left\{q_k \,\middle|\, q_k\in\left[q_{1k}-q_{2k}, q_{1k}+q_{2k}\right]\right\}\quad k\in K \tag{17}$$

In the above equation, q_{1k} is the nominal value of the demand for emergency supplies at the demand point k , which is mainly selected according to the grade of the geologic disaster and the impact of the population density and other indicators in the actual applicatione. The control coefficient can be obtained by bringing it into equation (3) and performing a pairwise transformation:

$$\sum_{k\in K}\left(\sum_{j\in J}P_{ojk}\right)\times\sum_{j\in J}X_jY_{jk}Q_j+\sum_{k\in K}\left(\sum_{j\in J}P_{ojk}\right)\varpi_i\geq\sum_{k\in K}\left(\sum_{j\in J}P_{ojk}\right)\times q_k \quad (18)$$
$$+\eta_o+\rho_{ok},k\in K,o\in O$$

Due to the uncertainty of the demand at the emergency logistics demand point after the occurrence of the geologic disaster, the LRP problem is handled based on the deviation robust optimization method, for which the scenario set $W=\{W_k,k=1,2......\}$ is defined, when $C\geq 1$ represents the scenario in which the distribution of materials from the vehicle ready to be transported from the second-level emergency logistics distribution point to the demand is unable to be accomplished due to the damage of the demand at the emergency logistics demand point due to the geologic disaster. So the set of scenarios defined for decision making under the scenario W_k is R ,i.e., $R=\{R_k,k=0,1,......\}$, the objective function value under the R scenario is $Z_{R_k}^{W_k}$, and the optimal objective function value under the scenario is Z^* , and the deviation robust optimization model is established according to the maximum regret value as follows:

$$F=\min_{W}\max\left(Z_{R_k}^{W_k}-Z^*\right) \quad (19)$$

Therefore, a robust optimization model with Eq.(2) ~(2) as the objective function and Eqs. (3)~(14) as the constraints of the robust optimization model under the uncertainty of demand at the demand point of emergency supplies.

3 ANT COLONY ALGORITHM DESIGN

Since the emergency material distribution problem belongs to the NP-hard problem It is difficult to get the exact solution of this problem, so heuristic algorithms are used to solve this kind of problem. The ant colony algorithm simulates the behavior of ants in the process of searching for food in nature, and finds the shortest path through the change of pheromone concentration, and the flow of the algorithm is as follows Figure 2 The flow of the algorithm is shown in Fig.

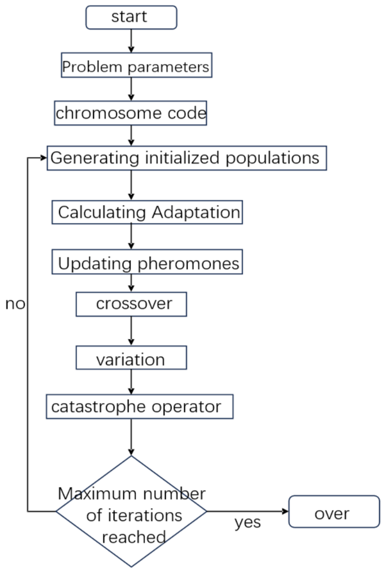

Fig. 2. Data flow diagram of ACO algorithm

Since the ant colony algorithm has a better global search ability, but it is easy to fall into the local optimum, it is more difficult to realize the accurate search of the global optimum, so in order to improve the algorithm's ability to explore and develop, the disaster operator is added to improve the algorithm, the specific operation of the disaster operator is as follows: after the ant colony algorithm reaches a certain number of iterations or when the algorithm's improvement of the optimal solution of the ten consecutive generations is less than 1%, the disaster operator will be triggered and the pheromone matrix will be reset, so that the algorithm will be forced to jump out of the local optimum.

3.1 Selection and Fitness Functions

Calculate the fitness value of an individual to provide a basis for the retention of subsequent individuals, since the optimization objective of this paper is to minimize the total cost of the system, the fitness function is set to $f(x) = \frac{1}{Z(x)}$, calculate the fitness value of the ants' search paths, and update the optimal paths if the fitness of the new paths is greater than the original fitness value.

4 EXAMPLE VERIFICATION AND ANALYSIS

In order to verify the feasibility of the multi-objective robust optimization model for emergency material distribution in this paper, three first-level emergency material distribution points, four second-level emergency material distribution points, 20 emergency material demand points, and eight cars are set in conjunction with the relevant data of recent geologic disasters. the demand perturbation value is set to be 10%, the driving speed of the emergency distribution vehicles is 30km/h, the maximum loading capacity of the vehicles is 8t, and the unit loading cost of the vehicles is $100, and Matlab is utilized to R2019a program programming and run on a computer with CPU Core(TM) i5-9300H to realize it.

4.1 Robust Optimization Analysis

In order to verify the effectiveness of the model, change the size of the control coefficients in the robust optimization model of multi-objective distribution of emergency supplies, in which the larger the control coefficient represents the greater the uncertainty of the demand point of emergency supplies in the model, and the control coefficient of 0 represents that there is no scenario of uncertainty of the demand, and respectively, compare the changes to the mean value of the total objective function under the consideration of the scenario of uncertainty in the demand for emergency supplies and the scenario without the consideration of the uncertainty in the demand for emergency supplies, as shown in Table 2.

Table 2. Mean values of the objective function with different control coefficients

factor	objective function value		
0	344.96	344.96	356.65
3	356.69	356.58	356.59
5	378.68	385.54	396.26
7	312.36	326.36	305.36
10	376.56	396.45	485.68

By Table 2. Mean values of the objective function with different control coefficients It is known that as the control coefficient increases, that is, the system uncertainty increases, the objective function value also presents a larger value, in which when $\sigma \in [5,7]$, the total objective function mean value basically remains stable and the economic cost is low, so it also proves that the model is effective in the optimization of robustness, but when $\sigma \in [7,10]$, as the control coefficient continues to increase, the economic cost of the system continues to increase, so as to achieve the optimal transportation efficiency and operating cost.

5 REACH A VERDICT

This paper studies the multi-objective distribution robust optimization model of emergency supplies after geologic disasters, establishes a robust optimization model with maximized time satisfaction and minimized economic cost, and solves it with deviation robust optimization. Through empirical analysis, this study verifies the effectiveness and robustness of the proposed method in dealing with the distribution of emergency supplies under geologic disasters, and the corresponding parameters can be set up according to the decision maker's preference, thus providing a reference for the decision maker to achieve the purpose of rapid rescue. Thus, it can provide reference for decision makers to achieve the purpose of rapid rescue.

Through empirical analysis, this study demonstrates the effectiveness and robustness of the proposed method in dealing with the emergency material distribution problem under geologic disasters, which provides a valuable reference for future disaster response and logistics management in related fields.

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