Research on Two-stage Multi-objective Integer Programming Model of Helicopter Distribution Materials in Emergency Logistics

Haiwang Guo*, Chaojing Peng*
School of Management, Shanghai University, Shanghai 200444, China

*Corresponding author e-mail: 18301951937@163.com, *1521116407@qq.com

Abstract. Based on the earthquake disaster, this paper introduces the JIT just-in-time thinking of logistics management, and builds a three-level supply chain network consisting of helicopters, warehouses and material demanders. On this basis, aiming at maximizing the seismic performance, radiation range and optimal helicopter dispatching plan of the material reserve, and establishing the warehouse location and material distribution as the decision variables, a two-stage multi-objective integer programming model is established. The feasibility and effectiveness of the model are verified by specific case analysis, and the efficiency and effect of material distribution in the earthquake disaster reduction system are improved. In addition, according to the actual earthquake disaster area, the model was improved by the ant colony optimization algorithm.

1. Introduction
Earthquakes have been active in a wide range, high intensity and high frequency in China [1]. In 2018, a total of 542 earthquakes above grade 3 occurred in China, and the impact on people's lives and environmental changes cannot be ignored, which shows that the improvement of emergency logistics is urgent [2]. Due to its rapid delivery of supplies, high safety, strong adaptability, can accept flexible deployment, in the earthquake relief obvious advantages. Therefore, it is of great significance to consider the problem of helicopter dispatching in the process of emergency logistics.

At present, researches on emergency logistics can be divided into three parts: first, research on the location of emergency logistics facilities. Ming Zhao et al. designed and developed a user-friendly decision support tool [3]. Nick et al. established a mathematical model to determine the location of emergency logistics distribution points and inventory distribution after disasters [4]. Sudipta et al. & Zhang Min et al., studied a continuous approximation (CA) model to optimize the location of distribution center and its corresponding service area [5] [6]. Second, the emergency logistics resource scheduling model was studied. Yuan et al. constructed a distribution path selection model based on the travel salesman problem, and adopted heuristic algorithm to solve and analyze it [7]. Qian et al. solved the emergency vehicle scheduling problem by using the linear programming model based on the improved idea of maximum flow and minimum cost [8]. Huang et al. proposed an emergency logistics distribution path model based on uncertainty theory and designed a cellular genetic algorithm to calculate it [9]. Dan Ya et al. proposed a network flow model [10] for the dynamic selection of temporary distribution facilities and resource allocation in the emergency plan. Shan Erfang et al. established a
two-stage multi-objective model to optimize the site selection of storage warehouses before the earthquake and the transportation route of vehicles after the earthquake, and also considered the optimization of carbon emission [11]. Zheng Bin et al. established a two-layer programming dynamic model with the upper layer maximizing the satisfaction of material delivery time and the lower layer maximizing the fairness of material distribution [12].

When domestic and foreign scholars study the facility location and material distribution of emergency logistics, most of them build models for these two problems respectively, but rarely combine them [13] [14]. However, as two functional sub-modules in the emergency logistics system, they affect each other, and it is inevitable that the overall optimization strategy cannot be obtained by studying part of them alone [15]. And multi-objective problem, this paper studies the two stages for the facility location and distribution of two stage and two stages of multiple objective, comprehensive analysis of the influence of various factors, both two phase multi-objective decision model is established, the emergency service facility location strategy formulation and effective rapid emergency resource scheduling system, thus it is concluded that with the aim of minimizing the total cost, and disaster mitigation system positioning strategy - distribution problem.

2. Problem description and notation

2.1. Problem description

Emergency logistics is divided into two stages according to time: (1) before the disaster. This includes evacuation within a short period of time, site selection of emergency facilities and advance distribution of relief supplies. (2) After the disaster. This includes the distribution of relief supplies, the transport of the wounded and the evacuation of refugees. The model in this paper is also divided into two stages according to time sequence, namely pre-earthquake and post-earthquake. Before or immediately after a disaster, the location of the material storage warehouse as the heart of emergency logistics should be determined first, and then the distribution plan of helicopters should be arranged based on the known location and storage capacity of the material storage warehouse [16]. Therefore, there are two models in this paper, which are constructed in two stages of emergency logistics to achieve the optimal site selection target of material storage warehouse and the optimal distribution plan target of helicopter.

2.2. Model 1

(1) Assumptions

The paper makes the following assumptions: 1. Due to the tight construction time, the area only allows one site to be used as a material reserve; 2. The indicators for measuring the seismic performance of the material reserve are: geological condition score, topographic condition score and scored far and wide from the epicenter. After considering the influence degree of the three earthquake resistance performances, the weighting coefficients of the three indicators are: 0.2, 0.3 and 0.5 respectively. 3. For the convenience of calculation, the location of the material reserve is selected from the alternative addresses.
(2) Related parameters (symbolic description)

**Table 1. Model 1 parameter table**

| Parameter name | Meaning |
|----------------|---------|
| \( M \)       | Alternative address set for the material repository (\( M = 1, 2, \ldots, m \)) |
| \( J \)       | Collection of emergency demand points (\( J = 1, 2, \ldots, j \)) |
| \( G_m \)     | Geological condition score of the alternative address \( m \) of the material reserve; \( G_m \in [0, 10] \) |
| \( O_m \)     | Topographic condition score of alternative address \( m \) of material reserve; \( O_m \in [0, 10] \) |
| \( A_m \)     | The alternative address \( m \) of the material reserve is from the epicenter of the epicenter; \( A_m \in [0, 10] \) |
| \( Y_{mj} \)  | The value range is \{0, 1\}, 1 means that the emergency demand point \( j \) can be covered by the material reserve \( m \), otherwise it is 0. |

(3) Decision variables

\[ H_m = \begin{cases} 1 & \text{Hm} = 1 \text{ means that the material reserve } m \text{ is built, otherwise } H_m = 0. \\ 0 & \end{cases} \]

(4) Objective function

\[
\text{Max } F_1 = \sum_m H_m \cdot (0.2G_m + 0.3O_m + 0.5A_m) \\
\text{Max } F_2 = \sum_m \sum_j Y_{mj} \cdot H_m
\]

(5) Constraints

\[
\sum_m H_m = 1 \quad \forall m \in M \\
H_m = \{0, 1\} \quad \forall m \in M \\
Y_{mj} = \{0, 1\} \quad \forall m \in M
\]

Use the weight method to convert the double target into a single target (6):

\[
\text{Max } F_3 = \alpha \sum_m H_m \cdot (0.2G_m + 0.3O_m + 0.5A_m) + (1-\alpha) \sum_m \sum_j Y_{mj} \cdot H_m
\]

The objective function \( F_1 \) represents the seismic performance of the material repository. (In seismic rescue, the seismic performance of the material reserve is very important, and the factors determining the seismic performance are often composed of geological conditions, topographic conditions and earthquake resistance. The weighted average maximum is the most robust); the objective function \( F_2 \) represents the maximum material reserve coverage (radiation) range, and the radiated area is the largest; the formula (3) ensures that only one will be selected as Material reserve; both (4) and (5) are non-negative constraints.
2.3. Model 2

(1) Assumptions
In order to better study the model, the paper further makes the following assumptions: 1. Eliminate the interference factors caused by the weather caused by helicopter grounding; 2. Helicopter loading and unloading time is negligible; 3. Due to time urgency, materials are only allowed to be delivered once; The location is known, the demand is random, but does not exceed the helicopter capacity, and is serviced by only one helicopter.

(2) Related parameters (symbolic description)

| Parameter name | Meaning |
|----------------|---------|
| $i$            | Material reserve, also the starting point and end point of the helicopter |
| $D_i$          | Maximum capacity of the material reserve (unit: kg) |
| $K$            | Helicopter collection ($k=1,2,...,k$) |
| $J$            | A collection of emergency demand points in the disaster area ($J=1,2,...,j$) |
| $d_{ij}$       | The shortest distance between any emergency demand point and the material reserve (Euler distance) is $d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$, $\forall j \in J$ |
| $C_k$          | Helicopter $k$ the maximum weight of materials that can be loaded (unit: kg) |
| $V_k$          | Average speed of helicopter $k$ (unit: km/h) |
| $E_k$          | Maximum range of helicopter $k$ (unit: km) |
| $Max V_k$      | Maximum speed of helicopter $k$ |
| $R_j$          | Emergency demand point $j$ demand for materials (unit: kg) |
| $N_j$          | Emergency demand point $j$ The specified arrival time of the material (unit: h) |
| $L_j$          | Emergency demand point $j$ The unit out-of-stock cost of the material (unit: RMB) |
| $M_j$          | Emergency demand point $j$ The unit time delay cost of the material (unit: RMB) |
| $T_j$          | Rescue time limit for emergency demand point $j$ (unit: h) |

(3) Decision variables
$P_{kj}$: the weight of the material transported by the helicopter $k$ to the material demand point $j$ (the weight of a single transport, unit: kg);

$Z_{kj} = \begin{cases} 1 & \text{If helicopter } k \text{ complex material demand point } j \text{ material transportation, } Z_{kj}=1, \\ 0 & \text{otherwise, } Z_{kj}=0 \end{cases}$

(4) Objective function

\[
\begin{align*}
\text{Min} F_4 &= \sum_k \sum_j L_j \sqrt{(R_j - Z_{kj} \cdot P_{kj})^2} \\
\text{Min} F_5 &= \sum_k \sum_j M_j \sqrt{(Z_{kj} \cdot \frac{d_{ij}}{V_k} - N_j)^2}
\end{align*}
\]

(5) Constraints

\[0 \leq C_k \leq 2000 \quad \forall k \in K\]
\begin{align*}
0 \leq V_k & \leq \text{Max}V_k \quad \forall k \in K \tag{10} \\
\sum_j \sum_k P_{kj} \cdot Z_{kj} & \leq D_i \quad \forall k \in K, j \in J \tag{11} \\
\sum_j P_{kj} \cdot Z_{kj} & \leq C_k \quad \forall k \in K, j \in J \tag{12} \\
\sum_k Z_{kj} \cdot \frac{d_{ij}}{V_k} & \leq T_j \quad \forall k \in K, j \in J \tag{13} \\
\frac{d_{ij}}{E_k} & \leq T_j \quad \forall k \in K, j \in J \tag{14} \\
Z_{kj} & = \{0,1\}, \quad \forall k \in K, j \in J \tag{15} \\
\sum_k Z_{kj} & = 1 \quad \forall k \in K, j \in J \tag{16} \\
\sum_j Z_{kj} & = 1 \quad \forall k \in K, j \in J \tag{17}
\end{align*}

Using weights to convert double goals into single goals (18):

\begin{equation}
\text{Min} F_4 = \beta \sum_k \sum_j L_j \sqrt{(R_j - Z_{kj} \cdot P_{kj})^2} + (1 - \beta) \sum_k \sum_j M_j \sqrt{(Z_{kj} \cdot \frac{d_{kj}}{V_k} - N_j)^2} \tag{18}
\end{equation}

The objective function F4 is the minimum material out-of-stock cost and the surplus material opportunity cost; F5 is the minimum material delay cost and the storage cost due to the early arrival of the material; the formula (9) is the maximum loadable weight of the helicopter; (10) for each helicopter to achieve the maximum speed; (11) for the total amount of material cannot exceed the capacity of the material repository i; (12) for each helicopter total number of delivery cannot exceed the maximum capacity of the helicopter; (13) indicates that the time when the goods arrive at the demand point j should not exceed the rescue time limit of the demand point j, that is, each disaster area demand has a time window, which will bring very much when the demand does not arrive at the upper limit of the time window. Large loss; (14) means that the distance from the starting point to any emergency demand point cannot exceed the maximum range of the helicopter; Equation (15) is a non-negative constraint; Equation (16) ensures that each demand point has one and only one Helicopter service once, (17) ensures that each helicopter serves only one emergency demand point at a time.

3. Case analysis

This paper uses LINGO11.0 to solve the model. The relevant parameters of each emergency demand point are shown in Table 3.
Table 3. coordinates and requirements of disaster points

| No. | Position (coordinate) | Demand / kg | Nj/h | Lj/RMB | Mj/RMB | Tj/h |
|-----|-----------------------|-------------|-------|--------|--------|------|
| 1   | (98,100)              | 331         | 2     | 5      | 10     | 2    |
| 2   | (45,107)              | 340         | 2.7   | 6.5    | 11.1   | 2    |
| 3   | (134,39)              | 262         | 2.6   | 3.5    | 12.3   | 2    |
| 4   | (4,96)                | 341         | 2.3   | 5.6    | 15.6   | 2    |
| 5   | (62,93)               | 313         | 3     | 6.5    | 12.8   | 2    |
| 6   | (54,23)               | 259         | 1.8   | 5.5    | 16.4   | 2    |
| 7   | (108,16)              | 277         | 1.7   | 4.7    | 15.9   | 2    |
| 8   | (112,70)              | 304         | 2.8   | 6.8    | 13.8   | 2    |
| 9   | (26,136)              | 345         | 1.5   | 10     | 14.7   | 2    |
| 10  | (69,48)               | 346         | 4     | 3.7    | 12.2   | 2    |
| 11  | (63,83)               | 265         | 1.2   | 4.6    | 14.4   | 2    |
| 12  | (91,31)               | 347         | 3.8   | 4.3    | 9.9    | 2    |

Note: \(N_j\) represents the demand arrival time of emergency demand point \(j\) for emergency materials (unit: h), \(L_j\) represents emergency demand point \(j\), the unit out-of-stock cost of emergency materials (unit: RMB), \(M_j\) represents emergency demand point \(j\) The unit time delay cost of materials (unit: RMB).

In order to balance the firmness and coverage of the warehouse, this paper sets the weight coefficient \(\alpha\) to 0.5. By solving the model 1, the location of the material reserve under the given conditions is obtained. The results are shown in Table 4. By solving the model 2, the helicopter distribution and material transportation plan are shown in Table 5. The corresponding objective function optimal value, that is, the lowest cost is 117530.5 RMB. It can be seen from the table that the demand for each emergency demand point under the final plan is met, and it is basically in line with the economic principle. The target target's first target delivery quantity is accurate, and the second target delivery time accuracy is satisfied. Therefore the program can be accepted.

Table 4. Location coordinates and final objective function values of material reserves

| Material storage location | Final objective function value |
|---------------------------|--------------------------------|
| (129,35)                  | 7.65                           |

Table 5. The final plan of helicopter distribution and material delivery

| Helicopter Demand point | Serial number | Supply/kg |
|-------------------------|---------------|-----------|
| 1                       | 8             | 331       |
| 2                       | 2             | 340       |
| 3                       | 5             | 262       |
| 4                       | 11            | 341       |
| 5                       | 4             | 313       |
| 6                       | 9             | 259       |
| 7                       | 6             | 277       |
| 8                       | 10            | 304       |
| 9                       | 1             | 345       |
| 10                      | 7             | 346       |
| 11                      | 3             | 265       |
| 12                      | 12            | 347       |
4. Conclusion
Based on the earthquake disaster, this paper establishes a two-stage multi-objective integer programming model, which solves the problem of material reserve storage site selection and helicopter dispatching plan in earthquake relief, and provides a scientific basis for decision makers in emergency rescue to formulate quick emergency plans. Theoretical support. The main advantages and innovations of this model are:

(1) The two-stage model is systematic, continuous, and holistic compared to the ordinary single-stage optimization model.

(2) Introducing JIT (Just in Time) thinking, which not only minimizes the delay cost of emergency materials but also avoids additional storage costs and material waste [18].

(3) Integrated research on the application of helicopters in emergency logistics;

This model also has shortcomings such as not considering information uncertainty factors and discrete external disturbance factors. Therefore, this study can introduce “demand information update mechanism” and interference management methods to further optimize the model.

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