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Research Article

Research on the Model and Algorithm for Multimodal Distribution of Emergency Supplies after Earthquake in the Perspective of Fairness

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After the earthquake, it is important to ensure the emergency supplies are provided in time. However, not only the timeliness, but also the fairness from different perspectives should be considered. Therefore, we use a multilevel location-routing problem (LPR) to study the fairness of distribution for emergency supplies after earthquake. By comprehensively considering the time window constraints, the partial road damage and dynamic recovery in emergency logistics network, the stochastic driving time of the vehicle, and the mixed load of a variety of emergency materials, we have developed a multiobjective model for the LRP in postearthquake multimodal and fair delivery of multivariety emergency supplies with a limited period. The goal of this model is to minimize the total time in delivering emergency supplies and to minimize the maximum waiting time for emergency supplies to reach demand points. A hybrid heuristic algorithm is designed to solve the model. The example shows that this algorithm has a high efficiency and can effectively realize the supply of emergency supplies after the earthquake within the specified period. This method might be particularly suitable for the emergency rescue scenarios where the victims of the earthquake are vulnerable to mood swings and the emergency supplies need to be fairly distributed.

1. Introduction

Earthquake is one of the most devastated natural disasters to human beings. Earthquakes usually affect a large area including the local infrastructure and a huge population. Various emergency supplies are needed and quantity is usually high. One of the common obstacles is the lack of supplies in the initial stage of the rescue. Moreover, the duration of the earthquake rescue is long. The demand of type and quantity of emergency supplies is also various depending on the stage of rescue [1]. In order to save the lives of the people in disaster areas and minimize the losses caused by the earthquake, emergency supplies must be distributed to the rescue points in disaster areas as soon as possible after the earthquake, especially in the initial stage of rescue. Therefore, ensuring the supply of emergency materials is the key to effectively carry out the rescue work after the earthquake.

The paroxysm and destructiveness of earthquake disaster and the urgency of emergency rescue caused the serious situation of emergency logistics work. From the actual feedback information of disaster rescue work, the following problems should be solved in the emergency logistics system of earthquake disaster: How to locate emergency facilities? How to optimize the transport route of emergency supplies? Specifically, the first problem is to determine the number, the location, and the size of emergency facilities (emergency supplies distribution points, emergency logistics centres, etc.), as well as the division of upstream and downstream nodes. The second problem is to select the appropriate transport route and distribute all kinds of emergency supplies from the emergency logistics centres to the rescue points, to meet the urgent needs of the disaster areas. The former mainly solves the location-allocation problem (LAP) of emergency facilities and determines the mode and structure

of the whole emergency logistics system. The latter mainly solves the rescue vehicle routing problem (VRP). There are two interdependent and interactional key issues in the optimization of the earthquake disaster emergency logistics system. Therefore, it is necessary to study the location-routing problem (LRP) in the earthquake disaster emergency logistics system.

At present, the research on LRP in the emergency logistics system has made fruitful achievements [2–9]. However, there are still some research imperfectness in the following areas: the research results on multivariety emergency supplies and multimodal supply are relatively few; the research results on comprehensive consideration of postearthquake emergency logistics network reliability and emergency materials supply are relatively few; the research results aiming at the fairness of emergency materials supply and the maximum satisfaction of rescue points are relatively few; the research results using real data of postearthquake emergency supplies supply are relatively few. In this paper, we mainly improve this research imperfectness.

Next, the fair supply problem of emergency supplies is analysed. If the total demand for supplies at demand points is greater than the total supply of materials, a reasonable dispatch should be carried out to make the limited emergency supplies reach the maximum rescue effectiveness. In addition, if some demand points receive emergency supplies in a longer period than others, it is possible that panic and high psychological tensions arise due to the adverse effect and related public opinion from the unfair supply distribution, which might affect the social stability. Therefore, emergency supplies should not only focus on timeliness, but also consider fairness [10].

Zhan [11] proposes that earthquake disasters and other emergencies are low-probability events, and many emergency supplies (such as plasma and medicines) are nondurable goods and cannot be stored for a long time. Thus, it is difficult to maintain a large inventory of emergency supplies for low-probability events. Due to unfavourable factors such as communication inconvenience and mass panic, it is difficult for the information of emergency supply demands in earthquake-stricken areas to be accurately obtained in a short time. In addition, earthquake aftershocks may damage the original unimpeded road, and emergency delivery vehicles cannot travel effectively. Therefore, after a sudden earthquake disaster, it is likely that the demand for emergency supplies in some disaster-stricken areas will be oversatisfied, while the demand points in other areas will still be waiting for emergency supplies. This led to the fairness problem of emergency supplies after the earthquake.

In order to solve the fairness issue of emergency supplies after the earthquake, Ruan et al. [12] propose two assessment indicators: average waiting time and maximum waiting time. The average waiting time indicates the average time for emergency supplies to arrive at the demand point. The shorter the time is, the greater the effectiveness of emergency supplies is, especially for medical devices and medicines. The maximum waiting time reflects the gap between the actual time and the expected time of the emergency supplies arriving at the demand points. The shorter the maximum waiting time is, the more fair the distribution of emergency supplies is.

There are four types of fairness models: absolute average, mini-max or max-min, and fair sequence and multiobjective optimization with fairness as demonstrated [13]. The supply problem of the emergency materials is divided into sufficient and insufficient conditions. In particular, a multiobjective programming model is established by introducing the fair index based on the Gini coefficient, and a variable neighbourhood ant colony algorithm is designed to solve the problem.

Zhan [11] argues that, in order to solve the fairness problem of emergency supplies after the earthquake, emergency logistics should have multiple objectives: minimizing the loss waiting function of emergency supplies, minimizing the logistics cost of emergency supplies, minimizing the total time for delivery of emergency supplies, and minimizing the proportion of unmet need to the total demand. Zhan [11] constructs a multiobjective optimization model under the different supply scenarios of emergency materials, which combines the fuzzy objective programming method and Bayesian method to solve the model.

In this article, we claim that the main reasons cause unfair supply of emergency materials are the shortage of emergency supplies in a short time, the inaccurate demand information of some demand points in the disaster area, the time for the emergency supplies arriving at demand points far beyond the time limit, the limited psychological endurance of some injured people in the extreme environment, and disturbance events occurring during the delivery of emergency supplies.

In view of this, based on the perspective of fairness, the multilevel location-routing problem (LRP) for the multimodal distribution of emergency supplies after the earthquake is studied in this paper. Considering the time window constraints, the partial road damage and dynamic recovery in emergency logistics network, the stochastic driving time of the vehicle, the mixed load of a variety of emergency materials, and the multimodal supply, we have developed a multiobjective model for the LRP in postearthquake multimodal and fair delivery of multivariety emergency supplies with a limited period. The goal of this study is to minimize the total time in delivering emergency supplies and to minimize the maximum waiting time for emergency supplies to reach demand points. A hybrid heuristic algorithm is designed to solve the model. And the Wenchuan earthquake emergency supplies distribution data are used to verify the validity of the model and the algorithm.

2. Problem Description

After the earthquake, in order to meet the needs of various emergency supplies in the disaster area, several appropriate quantity and scale of emergency supplies distribution points should be built on the periphery of the disaster area. These points function as logistics centres for storing and transferring emergency supplies to the disaster area. Then, the emergency materials are supplied from emergency logistics centres to various demand points using suitable supply methods according to the situation of road network.

To clarify the scope of application, the following assumptions are made:

(1) The distribution points use vehicles to transport emergency supplies to logistics centres.

(2) The emergency supplies at demand points can only be supplied by the logistics centres.

(3) If the demand point belongs to "unconnected islands", the demand point is supplied by helicopters; otherwise it is supplied by vehicles.

(4) There may be some demand points in the disaster area, whose demand for emergency supplies exceeds the vehicle capacity. These demand points are called large demand points; otherwise they are called small demand points. The "demand split" strategy is adopted at the large demand points, and full-load direct distribution and tour distribution are carried out at the same time. That is to say, the demand for emergency supplies at the large demand points is divided into two parts. Firstly, the part that meets full-load direct distribution is treated as a virtual large demand point and carried out by full-load direct distribution. Then the remaining part that are less than the minimum capacity of the delivery vehicles is treated as a virtual small demand point and carried out by tour distribution with other small demand points.

(5) The demand point can be served many times, and all kinds of emergency supplies can be mixed delivery.

(6) The speed of the vehicle traveling on the damaged road is random, and the speed of the helicopter is constant.

(7) The number of the supply equipment for the emergency supplies is unlimited.

(8) The supply equipment for the emergency supplies starts from the starting point and returns to the starting point after completing the mission.

Decision-making problems: choose the appropriate emergency supplies distribution points and logistics centres, and plan the helicopter flight route and vehicle route, to meet the needs of the demand points within the specified time limit and minimize the total time in delivering emergency supplies and minimize the maximum waiting time for emergency supplies to reach demand points.

3. Model Building

3.1. Symbolic Description. The mathematical formulation of the problem and the notation are given below.

(i) A: set of emergency supplies distribution points, $A = \{a \mid a = 1, 2, \cdots, |A|\}$;

(ii) AQ_a: supply of emergency supplies at distribution point a;

(iii) B: set of alternative emergency logistics centres, $B = \{b \mid b = 1, 2, \cdots, |B|\}$;

(iv) BQ_b: capacity of emergency logistics centre b;

(v) V: set of distribution vehicles, $V = \{r \mid r = 1, 2, \cdots, |V|\}$;

(vi) VQ_r: capacity of distribution vehicle r, and $VQ_{\min}$ represents the minimum capacity;

(vii) VS_r: speed of distribution vehicle r under normal road conditions;

(viii) H: set of helicopters, $H = \{k \mid k = 1, 2, \cdots, |H|\}$;

(ix) HQ_k: capacity of helicopter k, and $HQ_{\min}$ represents the minimum capacity;

(x) HS_k: flight speed of helicopter k;

(xi) BC: set of large demand points whose demand exceeds $VQ_{\min}$ or $HQ_{\min}$, and $BC = \{f \mid f = 1, 2, \cdots, |BC|\}$;

(xii) SC: set of small demand points whose demand are less than $VQ_{\min}$ or $HQ_{\min}$, and "virtual small demand points" generated by large demand points through segmentation strategy, $SC = \{m \mid m = 1, 2, \cdots, |SC|\}$;

(xiii) C: set of rescue points in the disaster area, $C = BC \cup SC = \{c \mid c = 1, 2, \cdots, |BC| + |SC|\}$;

(xiv) N: set of all nodes in the emergency logistics network, $N = A \cup B \cup C$;

(xv) η_{ij}: road connectivity between node i and node j, $\eta_{ij} \in \{0, 1\}$, $\eta_{ij} = 0$ means unconnected, and $\eta_{ij} = 1$ means connected;

(xvi) E: set of varieties of emergency supplies, and $E = \{w \mid w = 1, 2, \cdots, |E|\}$;

(xvii) d_{jw}: demand of emergency supplies w at rescue point j;

(xviii) d_j: demand of all varieties of emergency supplies at rescue point j, and $d_j = \sum_{w \in E} d_{jw}$;

(xix) G: set of demand points in the disaster area that are not connected to any node at present, $G = \{g \mid g = 1, 2, \cdots, |G|\}$ and $G \subseteq C$;

(xx) q_{ij}: distance from node i to node j;

(xxi) VT_{ijr}: time for distribution vehicle r to reach node j from node i;

(xxii) HT_{ijk}: time for helicopter k to reach node j from node i, and $HT_{ijk} = q_{ij}/HS_k$;

(xxiii) VT_{ri}^{ab}: time for distribution vehicle r to reach emergency logistics centre i from distribution points, and when $i \in A$, $VT_{ri}^{ab} = 0$;

(xxiv) VT_{rj}^{bc}: time for distribution vehicle r to reach demand point j from emergency logistics centres, and when $j \in B$, $VT_{rj}^{bc} = 0$;

(xxv) HT_{kj}^{bc}: time for helicopter k to reach demand point j from emergency logistics centres, and when $j \in B$, $HT_{kj}^{bc} = 0$;

(xxvi) T: supply time limit for emergency supplies.

Decision variables:

(i) x_a: establish an emergency supplies distribution point at alternative point $a(a \in A)$;

(ii) y_b: establish an emergency logistics centre at alternative point $b(b \in B)$;

(iii) z_{ba}: emergency logistics centre b is assigned to distribution point a;

(iv) β_{bj}: demand point $j(j \in C)$ is assigned to emergency logistics centre b;

(v) e_{bjk}: logistics centre b uses helicopter k service demand point j;

(vi) φ_{bjr}: logistics centre b uses distribution vehicle r service demand point j.

3.2. Multiobjective LRP Model for Fair Distribution of Emergency Supplies. The multiobjective LRP model for multimodal and fair distribution of emergency supplies with a limited period is established as follows:

$$\min \quad \sum_{r\in V}\sum_{i\in B} VT_{ri}^{ab} + \sum_{r\in V}\sum_{j\in C} VT_{rj}^{bc} + \sum_{k\in H}\sum_{j\in C} HT_{kj}^{bc} \tag{1}$$

$$\min \quad \left\{\max\left[\max_{r\in V}\left(\sum_{r\in V}\sum_{i\in B} VT_{ri}^{ab} + \sum_{b\in B}\sum_{j\in C}\varphi_{bjr}\cdot VT_{ijr}\right), \max_{k\in H}\left(\sum_{r\in V}\sum_{i\in B} VT_{ri}^{ab} + \sum_{b\in B}\sum_{j\in C} e_{bjk}\cdot HT_{ijk}\right)\right]\right\} \tag{2}$$

$$\text{s.t.} \quad d_j = \sum_{w\in E} d_{jw} \tag{3}$$

$$\sum_{b\in B} BQ_b y_b \le \sum_{a\in A} AQ_a x_a \tag{4}$$

$$\sum_{j\in C} d_j \le \sum_{b\in B} BQ_b y_b \tag{5}$$

$$\sum_{j\in C} d_j \beta_{bj} \le BQ_b, \quad \forall b \in B \tag{6}$$

$$\sum_{b\in B}\sum_{j\in C} d_j \varphi_{bjr} \le VQ_r, \quad \forall r \in V \tag{7}$$

$$\sum_{b\in B}\sum_{j\in C} d_j e_{bjk} \le HQ_k, \quad \forall k \in H \tag{8}$$

$$\sum_{j\in B\cup C} e_{ijk} = \sum_{i\in B\cup C} e_{jik}, \quad \forall j \in B\cup C,\ \forall k \in H \tag{9}$$

$$\sum_{j\in B\cup C} \varphi_{ijr} = \sum_{i\in B\cup C} \varphi_{jir}, \quad \forall j \in B\cup C,\ \forall r \in V \tag{10}$$

$$\sum_{i\in B}\sum_{j\in C} \varphi_{ijr} \ge 1, \quad \forall r \in V \tag{11}$$

$$\sum_{i\in B}\sum_{j\in C} e_{ijk} \ge 1, \quad \forall k \in H \tag{12}$$

$$\sum_{b\in B} z_{ba} \ge x_a, \quad \forall a \in A \tag{13}$$

$$z_{ba} \le x_a, \quad \forall b \in B,\ \forall a \in A \tag{14}$$

$$\sum_{i\in B}\sum_{j\in C}\sum_{k\in H} e_{ijk} \le 1 \tag{15}$$

$$\sum_{i\in B}\sum_{j\in C}\sum_{r\in V} \varphi_{ijr} \le 1 \tag{16}$$

$$\sum_{b\in B}\sum_{j\in C}\sum_{r\in V} \varphi_{bjr} \ge y_b \tag{17}$$

$$\sum_{j\in C}\varphi_{bjr} \le y_b, \quad \forall b \in B,\ \forall r \in V \tag{18}$$

$$\sum_{b\in B}\sum_{j\in C}\sum_{k\in H} e_{bjk} \ge y_b \tag{19}$$

$$\sum_{j\in C} e_{bjk} \le y_b, \quad \forall b \in B,\ \forall k \in H \tag{20}$$

$$VT_{ri}^{ab} = VT_{ri}^{ab} + VT_{ijr}, \quad \forall j \in B,\ \forall i \in A \cup B,\ \forall r \in V \tag{21}$$

$$VT_{rj}^{bc} = VT_{rj}^{bc} + VT_{ijr}, \quad \forall j \in C,\ \forall i \in B \cup C,\ \forall r \in V \tag{22}$$

$$HT_{kj}^{bc} = HT_{kj}^{bc} + HT_{ijk}, \quad \forall j \in G,\ \forall i \in B \cup C,\ \forall k \in H \tag{23}$$

$$\begin{aligned} &VT_{rj}^{bc} \le T, \\ &HT_{kj}^{bc} \le T \end{aligned} \tag{24}$$

$$\begin{aligned} &x_a \in \{0,1\}, \\ &y_b \in \{0,1\}, \\ &z_{ba} \in \{0,1\}, \\ &\beta_{bj} \in \{0,1\}, \\ &e_{bjk} \in \{0,1\}, \\ &\varphi_{bjr} \in \{0,1\} \end{aligned} \tag{25}$$

The objective function (1) indicates that the total time in delivering emergency supplies is the shortest, including the time for transporting emergency supplies from the distribution points to the logistics centres, and the time for delivering emergency supplies from the logistics centres to the demand points using vehicles/helicopters. The objective function (2) indicates that the maximum waiting time for emergency supplies to reach demand points is the shortest. The maximum waiting time is used to represent the fairness in delivering emergency supplies in this paper.

Constraint (3) represents the total demand for multivariety emergency supplies at demand points. Constraint (4) indicates that the total supply of emergency supplies for the selected distribution point must meet the total demand of the selected logistics centre. Constraint (5) represents that the total capacity of the selected logistics centre must meet the demand of all demand points. Constraint (6) indicates that the sum of demand for all demand points allocated to the selected logistics centre does not exceed the capacity of the logistics centre. Constraint (7) represents that the sum of the demand for all small demand points allocated to the tour vehicle does not exceed the capacity limit of the vehicle. Constraint (8) indicates that the sum of the demand for all small demand points allocated to the tour helicopter does not exceed the capacity limit of the helicopter. Constraints (9) and (10) represent the path continuity constraints of the helicopters/vehicles, i.e., the helicopters/vehicles entering the node must leave from the same node. Constraints (11) and (12) are a subloop elimination constraint, which means that each path is connected to at least one emergency logistics centre. Constraints (13) and (14) show that logistics centres are assigned to a distribution point only when it is open, and logistics centres are assigned only to open distribution points. Constraint (15) indicates that each tour helicopter can only be assigned to at most one logistics centre. Constraint (16) represents that each tour vehicle can only be assigned to at most one logistics centre. Constraints (17) and (18) show that vehicles are assigned to a logistics centre only when it is open, and vehicles are assigned only to open logistics centres. Constraints (19) and (20) show that helicopters are assigned to a logistics centre only when it is open, and helicopters are assigned only to open logistics centres. Constraint (21) indicates the time that the vehicle arrives at the logistics centres from the distribution points. Constraint (22) represents the time when the vehicle reaches the demand points. Constraint (23) indicates the time when the helicopter reaches the demand points. Constraint (24) represents the time constraint of vehicle/helicopter arriving at the demand points. Constraint (25) is 0-1 decision variables constraint.

3.3. Calculation of Demand for Multiple Varieties of Emergency Supplies. There are very few research results on the calculation of the demand for multiple varieties of emergency supplies. Tzeng et al. [14] studied the calculation method of the demand for different types of emergency supplies. Here, we use the method mentioned by Tzeng et al. [14].

Table 1: The volume equivalent calculation of emergency supplies.

Item	Measurement unit	Volume[cm^3]	Volume equivalent
Sleeping bag	EA	12375	1
Tent	EA(6-8 people)	27300	2.21
Mineral water	Box(1410ml, 12 bottles)	28080	2.27
Rice	Pack(5kg)	5225	0.42
Instant noodles	Box(12 bowls)	21199	1.71
Biscuits	Box(30 packs)	18468	1.49
Canned food	Box(12 cans)	3532	0.29

Table 2: The capacity equivalent calculation of vehicles.

Vehicle type	Capacity[cm^3]	Capacity equivalent
Military vehicle(10.5 tons)	26250000	2121
Civilian truck(1.5 tons)	4504500	364

The calculation results of the volume equivalent of emergency supplies and the capacity equivalent of vehicles are shown in Tables 1 and 2, respectively.

3.4. Road Network Connectivity Processing of Demand Points. Assuming that the road is repaired after the earthquake, the connectivity of damaged roads will be dynamic in different time periods. This paper synthesizes and expands the methods proposed as demonstrated [15–21]. Let θ denote earthquake central point; p denote logistics centre. According to the distance $dd_{i\theta}$(unit: km) between the demand point $i(i \in G)$ and earthquake central point θ, the topography dx_i of the demand point i (ma represents the mountain area, pa represents the plain), the time span kt_i (unit: day) between the distribution time and the occurrence time of the earthquake, and the initial value of η_{ij}, the road connectivity a_{ipt} of the demand point i in the period t is predicted as follows:

$$a_{ipt} = \begin{cases} 0, & if\ dd_{i\theta} \le 10,\ kt_i \le 15,\ dx_i \in ma \\ 0, & if\ 10 < dd_{i\theta} \le 20,\ kt_i \le 10,\ dx_i \in ma \\ 1, & else \end{cases} \quad (26)$$

That is, when $a_{ipt} = 0$, demand point i belongs to "unconnected islands", and it is supplied by helicopters; otherwise it is supplied by vehicles.

3.5. Calculation of the Random Driving Time for Vehicles. Because it is difficult to determine the driving speed of vehicles running on damaged roads, we synthesize and expand the methods proposed as demonstrated [10, 15, 17, 19, 20, 22]. According to the terrain dx_j of the demand point j, the road damage degree index zb_{ij} between node i and node j, the driving time ξ_{ijr} of the vehicle r from node i to node j under normal state of the road, and so on, the driving time VT_{ijr} of the vehicle r from node i to node j is predicted as follows:

$$VT_{ijr} = \begin{cases} \vartheta \cdot \xi_{ijr}, & if\ dx_j \in ma,\ 0.2 < zb_{ij} \le 0.3 \\ \sigma \cdot \xi_{ijr}, & if\ dx_j \in ma,\ 0.1 < zb_{ij} \le 0.2 \\ \beta \cdot \xi_{ijr}, & if\ dx_j \in ma,\ 0.01 < zb_{ij} \le 0.1 \\ \varepsilon \cdot \xi_{ijr}, & if\ dx_j \in pa,\ 0.2 < zb_{ij} \le 0.3 \\ \mu \cdot \xi_{ijr}, & if\ dx_j \in pa,\ 0.1 < zb_{ij} \le 0.2 \\ \varpi \cdot \xi_{ijr}, & if\ dx_j \in pa,\ 0.01 < zb_{ij} \le 0.1 \\ \xi_{ijr}, & else \end{cases} \quad (27)$$

where ma represents the mountain area, pa represents the plain. $zb_{ij} > 0.3$ indicates that the road is completely damaged (using helicopters for distribution), $0.2 < zb_{ij} \le 0.3$ indicates seriously damaged, $0.1 < zb_{ij} \le 0.2$ indicates moderately damaged, $0.01 < zb_{ij} \le 0.1$ indicates slightly damaged, and $zb_{ij} < 0.01$ indicates basically undamaged. The decision maker determines the value of the coefficient ϑ, σ, β, ε, μ, ϖ according to the actual situation of the road network after the earthquake.

4. Design of Hybrid Heuristic Algorithm

The algorithms for solving LRP are mainly divided into two-stage algorithm and global algorithm. The former has a shorter running time, while the latter has a slightly longer running time. However, the LRP planning scheme obtained is better as discussed [23, 24]. In order to obtain a higher quality solution, the hybrid heuristic algorithm based on the idea of overall solution and the characteristics of the model is designed in this paper. The design idea of the hybrid heuristic algorithm is shown in Figure 1.

The concrete steps of the hybrid heuristic algorithm designed in this paper are as follows:

(1) Initialize the Variables. Input the coordinates of all distribution point a_{xy}, the coordinates of all logistics centre coordinates b_{xy}, the coordinates of all demand point c_{xy}, the number of distribution points A_n and logistics centres B_m to be selected, AQ_a, BQ_b, VQ_r, VS_r, $VQ_{\min}$, HQ_k, HS_k, $HQ_{\min}$, d_{jw}, T, η_{ij}, and the value of maximum iterations $MAXiter$. Let the total time $ZT = \infty$ in delivering emergency supplies, the maximum waiting time $ZS = \infty$ for emergency supplies

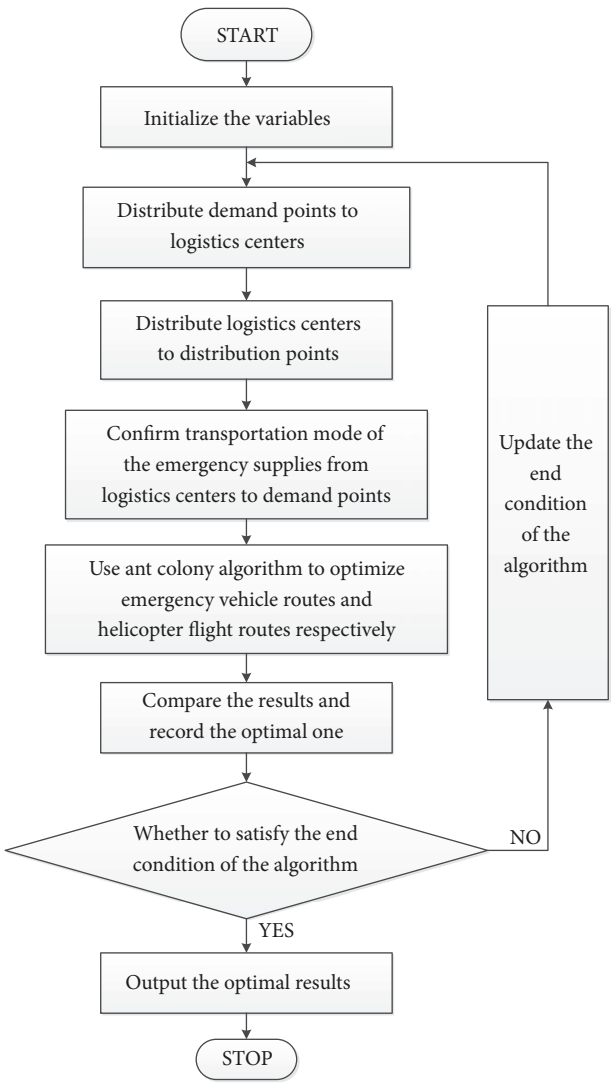

Figure 1: The design idea of the hybrid heuristic algorithm.

to reach demand points, and the number of current iterations $iter = 1$.

(2) Distribute Demand Points to Logistics Centres

Step 1. According to d, calculate the demand d_j of each demand point j, then calculate the demand D_{all} of all demand points.

Step 2. Let XB denote the set of selected logistics centres, and $XB = \phi$.

Step 3. From the set B of alternative logistics centres, randomly select B_m logistics centres into XB, and calculate the total capacity $\sum_{b\in XB} BQ_b$ of XB. If $D_{all} \leq \sum_{b\in XB} BQ_b$, go to Step 4; otherwise let $XB = \phi$ and go to Step 3.

Step 4. Let WC denote the set of unassigned demand points $j(j \in WC)$. Select the logistics centre $b(b \in XB)$ at random, and let its current total distribution demand $FP_b = 0$. Let JP_{bj} denote the set of demand points $j(j \in C)$ assigned to the logistics centre $b(b \in XB)$, and $JP_{bj} = \phi$.

Step 5. Calculate the distance between all demand points $j(j \in WC)$ and b, and arrange them in ascending order. First select the demand point j with minimum distance; let $FP_b = FP_b + d_j$. If $FP_b \leq BQ_b$, remove j from WC, j is assigned to b, that is, $j \in JP_{bj}$ and $j = j + 1$; otherwise $b = b + 1$.

Step 6. If all the demand points have been allocated, go to Step 3. Otherwise, allocate the remaining demand points to the nearest selected logistics centre $b(b \in XB)$ that meets the capacity constraint.

(3) Distribute Logistics Centres to Distribution Points

Step 1. Let XA denote the set of selected distribution points and $XA = \phi$.

Step 2. From the set A of alternative distribution points, randomly select A_n distribution points into XA, and calculate the total capacity $\sum_{a\in XA} AQ_a$ of XA. If $\sum_{b\in XB} BQ_b \leq \sum_{a\in XA} AQ_a$, go to Step 3; otherwise let $XA = \phi$ and go to Step 2.

Step 3. Select the distribution point $a(a \in XA)$ at random, and let its current total distribution capacity $FQ_a = 0$. Let AB_{ab} denote the set of logistics centres $b(b \in XB)$ assigned to the distribution point $a(a \in XA)$, and $AB_{ab} = \phi$.

Step 4. Calculate the distance q_{ab} between the distribution point a and all selected logistics centres $b(b \in XB)$, and arrange them in ascending order. First select the logistics centre b with minimum q_{ab}, let $FQ_a = FQ_a + FP_b$. If $FQ_a \leq AQ_a$, remove b from XB, b is assigned to a, that is, $b \in AB_{ab}$; otherwise $b = b + 1$.

Step 5. If $XB = \phi$, go to Step 4. Otherwise, let $a = a + 1$ and go to Step 3.

(4) Calculate the Vehicle Transportation Time between Distribution Points and Logistics Centres

Step 1. Let the total vehicle transportation time $\sum_{r\in V}\sum_{i\in XB} VT_{ri}^{ab} = 0$ between distribution points and logistics centres.

Step 2. Select any distribution point $a(a \in XA)$, calculate the total demand $\sum_{b\in AB_{ab}} FP_b$ of AB_{ab}, and calculate the demand equivalent DL_{ab} according to Table 1.

Step 3. According to the vehicle capacity VQ_r^a of the distribution point $a(a \in XA)$, calculate the vehicle capacity equivalent VD_a^r, and calculate the number $NV_r^a = DL_{ab}/VD_a^r$ of transport vehicles required for a.

Step 4. According to the speed VS_r of the vehicle r and the distance q_{ab} between the distribution point a and the logistics centre $b(b \in AB_{ab})$, calculate the vehicle transportation time

Table 3: The data of candidate emergency supplies distribution points.

Number	Distribution point	Food(pack)	Quilt
1	Mianyang Railway Station	1000000	90000
2	Chengdu Shuangliu Airport	800000	100000
3	Chengdu North Railway Station	1200000	130000

$TR_{ab} = \sum_{r\in V}((NV_r^a \cdot q_{ab})/VS_r)$ between the distribution point a and the logistics centre b.

Step 5. Let $\sum_{r\in V}\sum_{i\in XB} VT_{ri}^{ab} = \sum_{r\in V}\sum_{i\in XB} VT_{ri}^{ab} + TR_{ab}$, remove b from AB_{ab}, and let $b = b + 1$.

Step 6. If $AB_{ab} = \phi$, let $a = a + 1$; otherwise go to Step 4.

Step 7. If all the distribution points have been calculated, go to Step 5; otherwise go to Step 2.

(5) Confirm Transportation Mode of the Emergency Supplies from Logistics Centres to Demand Points

Step 1. Let VJB_{bj} and HJB_{bj}, respectively, represent the sets of the emergency supplies transported by vehicles and helicopters, and $VJB_{bj} = \phi$, $HJB_{bj} = \phi$.

Step 2. Select the logistics centre $b(b \in XB)$ at random; find the demand point j of JB_{bj}.

Step 3. ① Determine the value of η_{ij} $(i \in B \cup C, j \in C)$. If $\eta_{ij} = 1$, transport emergency supplies by vehicles, that is, $j \in VJB_{bj}$. Otherwise transport emergency supplies by helicopters, that is, $j \in HJB_{bj}$. ② Determine the value of VT_{ijr} $(i \in B \cup C, j \in C)$. If $VT_{ijr} \le T$, it means that the vehicle can transport emergency supplies to the demand point j within the time limit T, then use vehicles, that is, $j \in VJB_{bj}$. Otherwise use helicopters, that is, $j \in HJB_{bj}$.

Step 4. If all the logistics centres have been calculated, go to Step 6; otherwise go to Step 2.

(6) Determine the Supply Scheme of Emergency Supplies for Logistics Centres

Step 1. According to Table 1, calculate the demand equivalent of demand points, vehicle capacity equivalent, and helicopter capacity equivalent. Select any allocated logistics centre $b(b \in XB)$ and its corresponding JB_{bj}.

Step 2 (schedule vehicle routes). ① Use ant colony algorithm as demonstrated (Chen, 2010) to schedule the vehicle routes of demand points $j(j \in VJB_{bj})$. ② Calculate the vehicle driving time $VZP_{bc} = \sum_{r\in V}\sum_{j\in VJB_{bj}\cap BC} VT_{rj}^{bc}$ of full-load direct transportation at large demand point $j(j \in VJB_{bj} \cap BC)$. ③ Calculate the vehicle driving time $VXH_{bc} = \sum_{r\in V}\sum_{j\in VJB_{bj}\cap SC} VT_{rj}^{bc}$ of tour distribution at small demand point $j(j \in VJB_{bj} \cap SC)$.

Step 3 (schedule helicopter routes). ① Use ant colony algorithm as demonstrated (Chen, 2010) to schedule the helicopter routes of demand points $j(j \in HJB_{bj})$. ② Calculate the helicopter flight time $HZP_{bc} = \sum_{k\in H}\sum_{j\in HJB_{bj}\cap BC} HT_{kj}^{bc}$ of full-load direct transportation at large demand point $j(j \in HJB_{bj} \cap BC)$. ③ Calculate the helicopter flight time $HXP_{bc} = \sum_{k\in H}\sum_{j\in HJB_{bj}\cap SC} HT_{kj}^{bc}$ of tour distribution at small demand point $j(j \in HJB_{bj} \cap SC)$.

Step 4. Calculate the total time ZT_{iter}^{bj} in delivering emergency supplies of the logistics centre b, and $ZT_{iter}^{bj} = VZP_{bc} + VXH_{bc} + HZP_{bc} + HXH_{bc}$.

Step 5. According to the objective function (2), calculate the maximum waiting time ZC_{iter}^{bj} of the logistics centre b for emergency supplies to reach demand points.

Step 6. If all the logistics centres have been calculated, go to Step 7; otherwise go to Step 1.

(7) Record Results and Judge the End of the Algorithm.

Step 1. Calculate the total time ZT_{iter} in delivering emergency supplies, and $ZT_{iter} = \sum_{r\in V}\sum_{i\in XB} VT_{ri}^{ab} + ZT_{iter}^{bj}$.

Step 2. If $ZT_{iter} \le ZT$ and $ZC_{iter}^{bj} \le ZS$, then $ZT = ZT_{iter}$ and $ZS = ZC_{iter}^{bj}$.

Step 3. Let $iter = iter + 1$, if $iter < MAXiter$; go to Step 2; otherwise the algorithm ends.

5. An Example Analysis from the Wenchuan Earthquake Emergency Supplies Distribution Data

We use the data from the Zheng [25] study as a case study here. We selected three candidate emergency supplies distribution points, eight candidate emergency logistics centres, and 24 demand points. The specific data are shown in Tables 3, 4, and 5, respectively. The emergency supplies are mainly food and quilts. The unit weight of food and quilts is 0. 82kg and 5kg, respectively, which is equivalent to 0.18 equivalents and 1 equivalent. There are two types of emergency vehicles. Their capacities are 2000 equivalents and 16000 equivalents, respectively. The running speed on normal road is 60km/hour and 70km/hour, respectively. The flight speed of the helicopter is 600km/hour, and the capacity is

Table 4: The data of candidate emergency logistics centres.

Number	Emergency logistics center	Capacity(ton)
1	Dujiangyan	800
2	Mao Country	800
3	Pengzhou	800
4	Wenchuan	500
5	Deyang	1500
6	Chongzhou	800
7	Dayi	1200
8	Shifang	1000

3000 equivalents. The coordinates of the earthquake centre are (31.04560 N, 103.45560 E).

The program parameters are set as follows: $A_n = 2$, $B_m = 3$, $VQ_{\min} = 1600$, $MAXiter = 500$, $\vartheta = 5$, $\sigma = 4$, $\beta = 3$, $\varepsilon = 2.5$, $\mu = 3$, $\varpi = 1.5$, $kt_j = 2$, and $T = 480$min.

The Matlab R2013a language is used to program the hybrid heuristic algorithm designed in this paper. The calculations are performed 10 times on notebook on condition of Intel Core™ 2 Duo T8300 2.4GHz with 4G RAM, and the average running time of this program is 323.76 seconds. It shows that this algorithm has high efficiency and can implement LRP scheme effectively and quickly. In Table 6, it lists the optimal location of emergency supplies distribution points, the optimal location of logistics centres, emergency vehicle routes, and helicopter flight routes in the 10 results. In Table 6, "h" denotes the vehicle routes of tour distribution, "fh" indicates the helicopter flight routes of tour distribution, "f" indicates the helicopter flight routes of full-load direct transportation, and the rest denotes the vehicle routes of full-load direct transportation. The total supply time of emergency supplies is 101,256.22 minutes, and the total number of helicopters and vehicles dispatched is up to 264. The average time for emergency supplies to arrive at the demand points is 383.55 minutes, and the maximum waiting time for demand points is 460.73 minutes. The results show that this algorithm can effectively achieve the supply of emergency supplies within the specified time limit, meet the need of emergency supplies at various demand points in the earthquake-stricken area, and effectively ensure the fair supply of emergency supplies. The simulation results also indicate the necessity and rationality of multimodal supply of emergency supplies. If only vehicles are used for the supply of emergency supplies, it is difficult for vehicles to supply emergency supplies in time to the demand points which belong to "unconnected islands" in the initial period of rescue. These demand points cannot receive emergency supplies within the prescribed time limit, which may result in heavy casualties and property losses. Decision makers should choose reasonable supply mode of emergency supplies according to the actual road network connectivity of the demand points in the disaster area in different time periods.

The schematic diagram of multimodal supply of emergency supplies obtained by this program is shown in Figure 2, where the coordinate data are from Baidu map. For a clear display, the coordinate data is enlarged 100 times and the origin of the coordinate system is (3100, 10300). Figure 2(a) shows the LRP planning results with a time span of 2 days and a time window of 480 minutes. Figure 2(b) shows the LRP planning results with a time span of 11 days and a time window of 680 minutes. Figure 2 shows that different time span and time window constraint will lead to different LRP facility location schemes. It can also be seen that, in the early period after the earthquake, the road to the demand points near the earthquake centre is seriously damaged, and the emergency supplies must be supplied by helicopter. After a period of time for repair, only a few demand points must be supplied by helicopter, which proves that the connectivity of damaged roads is changing with time.

Under the premise of invariable parameters such as the ant population, the running time of the algorithm in this paper is tested by expanding the scale parameters of the distribution points, logistics centres, and demand points in the above example. The results in Table 7 show that the computational efficiency of this algorithm is relatively high.

6. Conclusion

After the earthquake, a large amount of various emergency supplies is urgently needed in the disaster area. The most important task for rescue work is to ensure the delivery of emergency supplies in time. Therefore, the multilevel LRP for the multimodal distribution of multivariety emergency supplies after the earthquake is studied in this paper. With a comprehensive consideration of the time window constraints, the partial road damage and dynamic recovery in emergency logistics network, the stochastic driving time of the vehicle, and so on, a multiobjective model for the LRP in postearthquake multimodal and fair delivery of multivariety emergency supplies with a limited period is developed. The goal is to minimize the total time in delivering emergency supplies and to minimize the maximum waiting time for emergency supplies to reach demand points. A hybrid heuristic algorithm is designed to solve the model. The results of the example show that this algorithm has a high efficiency and can effectively realize the supply of emergency supplies after the earthquake within the specified period. This method is particularly suitable for the emergency rescue scenarios where the victims of the earthquake are vulnerable to mood swings and the emergency supplies need to be distributed from a fair perspective.

Of course, the proposed model and algorithm also have limitations. In the postearthquake emergency logistics process, it is very easy to generate some disruptions. For example, the distribution vehicles suddenly suffer with some breakdowns during transportation, the originally unimpeded roads are suddenly seriously damaged, the demand points require emergency supplies to arrive in advance, and so on. Under the influence of these disruptions, whether the proposed model and algorithm can achieve the optimal effect and how to improve them still need further discussion. Moreover, we will further research the dynamic scheduling algorithm of emergency vehicles, the cooperative rescue of emergency vehicles, and other issues.

Table 5: The data of emergency supplies demand points.

Number	1	2	3	4	5	6
Demand point	Guankou Town	Qingchengshan Town	Zipingpu Town	Hongkou Village	Xiushui Town	Mao Country
Food(pack)	53000	48600	44000	48000	36000	216500
Quilt	5300	4860	4400	4800	3600	21650
Number	7	8	9	10	11	12
Demand point	Li Country	Putou Village	Muka Village	Tonghua Village	Yingxiu Town	Shuimo Town
Food(pack)	214000	32000	20000	48000	40000	36000
Quilt	21400	3200	2000	4800	4000	3600
Number	13	14	15	16	17	18
Demand point	Wolong Town	An Country	Luoshui Town	Shuangsheng Town	Mianyuan Town	MianzhuCity
Food(pack)	34000	239500	38000	52000	31200	290500
Quilt	3400	23950	3800	5200	3120	29050
Number	19	20	21	22	23	24
Demand point	Luojiang Country	Zhongjiang Country	Baolin Town	Yanmen Village	Xiaojin	Sanjiang Village
Food(pack)	87000	106000	42000	34800	25000	30800
Quilt	8470	9600	4200	3480	3400	3080

Table 6: Decision results of facility location and route arrangement.

Distribution point	Logistics centre	Route arrangement
Mianyang Railway Station	Mao Country	Mao Country—Li Country; Mao Country—Mao Country; Mao Country—Putou Village; Mao Country—Muka Village; Mao Country—Tonghua Village; Mao Country—Yanmen Village; Mao Country—Muka Village—Li Country—Mao Country(h); Mao Country—Putou Village—Tonghua Village—Mao Country(h)
	Pengzhou	Pengzhou—Qingchengshan Town; Pengzhou—Hongkou Village; Pengzhou—Wolong Town; Pengzhou—Shuangsheng Town; Pengzhou—Qingchengshan Town—Hongkou Village—Pengzhou(h); Pengzhou—Guankou Town(f); Pengzhou—Zipingpu Town(f); Pengzhou—Shuimo Town(f); Pengzhou—Xiaojin(f); Pengzhou—Sanjiang Village(f); Pengzhou—Yingxiu Town(f); Pengzhou—Yingxiu Town—Zipingpu Town—Pengzhou(fh); Pengzhou—Sanjiang Village—Shuimo Town—Pengzhou(fh);
	Shifang	Shifang—Luojiang Country
Chengdu Shuangliu Airport	Deyang	Deyang—Xiushui Town; Deyang—An Country; Deyang—Mianyuan Town; Deyang—Mianzhu City; Deyang—Luojiang Country; Deyang—Zhongjiang Country; Deyang—Baolin Town; Deyang—An Country—Luojiang Country—Deyang(h); Deyang—Xiushui Town—Mianyuan Town—Deyang(h)

Table 7: The effect of the problem scale on the performance of the algorithm.

Number of distribution points	Number of logistics centres	Number of demand points	Algorithm running time(second)
2	4	30	337.84
2	5	40	346.72
3	6	50	389.95
4	6	70	420.16
4	7	80	458.63

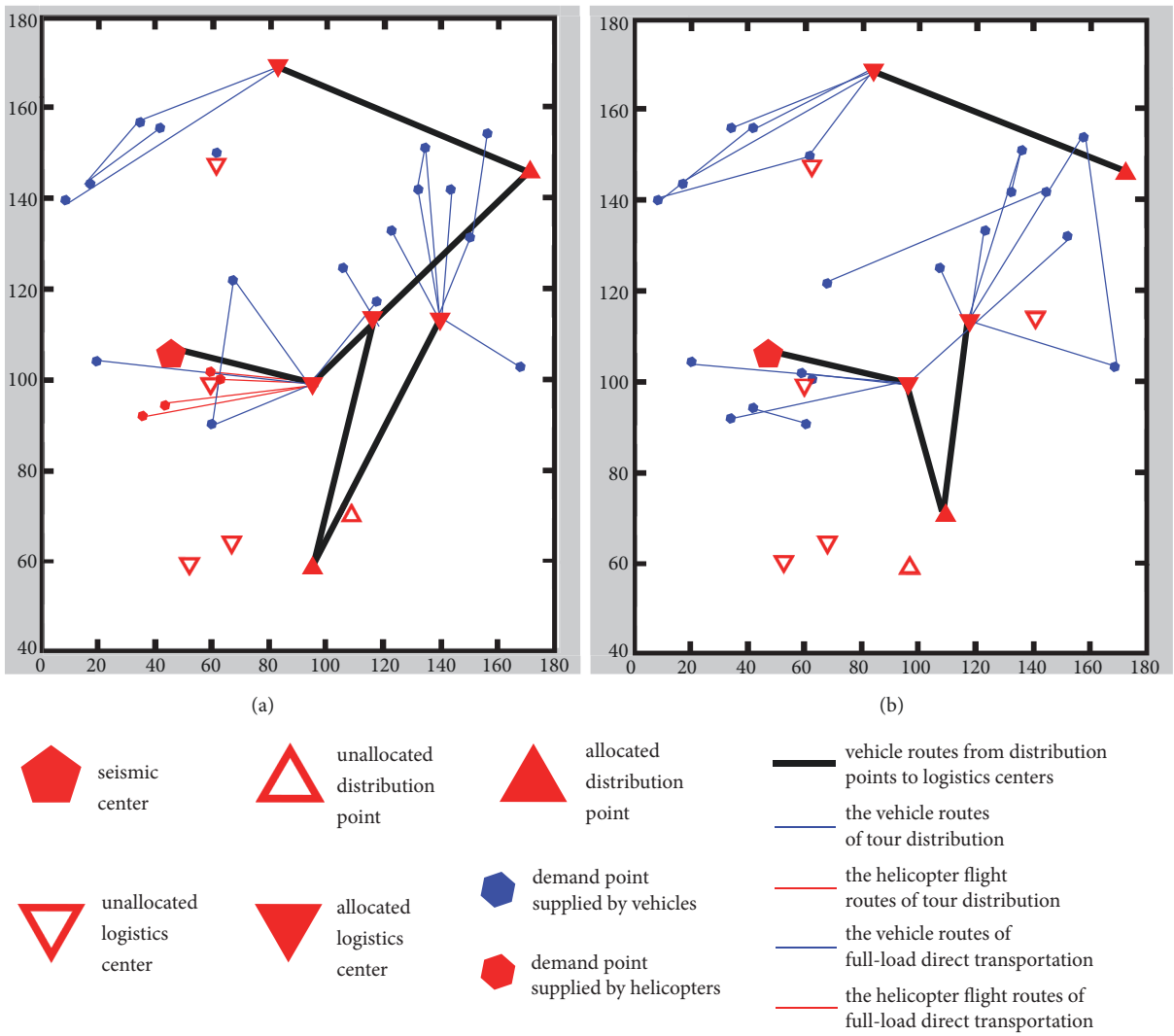

Figure 2: The LRP planning results of multimodal supply of emergency supplies.

Data Availability

The authors declare that all experimental date can be obtained by winnie101206@126.com.

Conflicts of Interest

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

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