

Single-level LRP Problem of Emergency Logistics System Considering Demand Priority

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Abstract. Once a public emergency occurs, it will cause serious human casualties and property losses to human society. If timely and effective rescue measures are not adopted, the consequences will be disastrous. Therefore, it is necessary to establish a sound and effective emergency rescue system. In this paper, we establish an open emergency response facility positioning and emergency relief transportation model based on the characteristics of demand points, vehicle service capabilities, soft time windows, damage of road network and other constraints. The non-dominated sorting genetic algorithm was applied in this article. Finally, the simulation verified the rationality and the effectiveness of the model and the algorithm.

1. Introduction

The terrain of China is complex and diverse, when a large-scale natural disaster occurs, such as earthquakes, landslides, mudslides or others, it usually causes huge losses of life and property to people's production and life. For example, the Xinjiang Yutian earthquake of magnitude 7.3 in 2014 had direct economic losses of more than 33 million yuan. On the Aug.8th in 2017, the 7.0 magnitude earthquake in Jiuzhaigou, Sichuan, caused direct economic losses of 1.1446 billion yuan. According to the National Disaster Reduction Office of the Ministry of Civil Affairs (NDRC), 140 million people were affected by natural disasters of various types in 2017, with direct economic losses of 301.87 billion yuan. After the occurrence of disasters, the deployment of emergency materials becomes the key to emergency rescue. The timely launching of emergency rescue work is also a major decision to ensure the safety of people's life and the stability of society. Therefore, it's very important to establish a scientific and effective emergency rescue system and achieve efficient delivery of emergency supplies within the golden 72 hours.

Most of the researches on priority issues focus on the general logistics distribution. Ma (2015) proposed a multi-objective vehicle routing optimization model that considered customer priorities based on the company's LCL logistics and customers' priority, a hybrid multi-objective genetic algorithm was adopted to solve it. Cao (2006) started from the problem of goods loading in logistics enterprises, established a dynamic assembly model for cargo assembly considering the priority of customer needs, and solved it with a two-stage method. The research on priority issues in emergency logistics mainly includes Wang (2010), who considered the feature of multi-stage emergency rescue and established a multi-stage, multi-modal location routing problem (LRP) that taken into account the priority of supplies. According to the characteristics of the model, a multi-stage weight coefficient transformation method based on the improved genetic algorithm was proposed. He (2011) divided the demand points into two categories through the fuzzy clustering and analytic hierarchy process, and then proposed an emergency vehicle dispatch model. Tian (2016) used the CVA management method and the Satty scale's



hierarchical entropy analysis to establish an emergency material priority system and applied it to the emergency allocation of flood disasters. Although all the above models consider priority issues in emergency logistics from different perspectives, the method of determining priorities is too subjective to adequately reflect the characteristics of the needs of the affected people. Therefore, this study establishes an emergency facilities location and material distribution routing problem model considering the priority of the affected areas.

2. Methodology

2.1. The definition of priority

Owing to the attributes of different nodes, the priority in this paper mainly includes the following two aspects: material delivery priority and demand priority.

2.1.1. Material delivery priority.

According to the NDRC, the emergency relief could be divided into 3 categories and 65 small classes. In this paper, we mainly start from urgently needed items and general life items. We define the set of emergency supplies R , the smaller the value is, the earlier the material will be delivered, otherwise, the later delivery.

2.1.2. Demand priority

The demand priority λ_i (i is the affected area, S_1 is set of affected areas, $i \in S_1$) refers to the urgency of relief λ_i^u and the tolerance of time λ_i^t . In this paper, we describe the demand priority as the correlation between the urgency and the time tolerance. The expression is as follows:

$$\lambda_i = a\lambda_i^u - b\lambda_i^t \quad (1)$$

In the expression, a, b is a fixed constant, $0 \leq a \leq 1, 0 \leq b \leq 1, \lambda_i > 0, 0 < \lambda_i^u < 1, 0 < \lambda_i^t < 1$.

2.2. The satisfaction function

In the emergency system, each node has a soft time window $[l_i, ll_i]$, the satisfaction of each point can be expressed by the following formula.

$$\mu_i(T_i^k) = \begin{cases} 1 & 0 \leq T_i \leq l_i \\ \left[\frac{ll_i - T_i^i}{ll_i - l_i} \right]^\alpha & l_i \leq T_i \leq ll_i, \forall i \in S_1 \\ 0 & \text{others} \end{cases} \quad (2)$$

In the above, α is the time sensitive coefficient of different demand points, it determines the shape of the function, different values reflect different curve shapes. In this paper, the value of α is related to λ_i , and we take it as $\alpha = 1/(1 - \lambda_i)$.

$$\mu_i(T_i^k) = \begin{cases} 1 & 0 \leq T_i \leq l_i \\ \left[\frac{ll_i - T_i^i}{ll_i - l_i} \right]^{1/(1-\lambda_i)} & l_i \leq T_i \leq ll_i, \forall i \in S_1 \\ 0 & \text{others} \end{cases} \quad (3)$$

3. Modelling

To facilitate model formulation, several assumptions are made.

- The number of affected areas and distribution centers are known.

• There are three different type vehicles, and this paper only consider the ground transportation. Unlike commercial logistics, vehicles don't have to return to depots, they wait at their last stop until receive the next order.

• The distance between each pair of nodes is a weighted distance when the road network is damaged.

Sets and parameters.

S_1 -set of affected areas.

S_2 -set of distribution centers, $\forall g, h \in I, I = S_1 \cup S_2$.

K -set of vehicles, Q_k -the capacity of different vehicles.

R -set of emergency reliefs, U_r -the volume of different reliefs.

ρ_l -the impedance coefficient of damaged road.

V_{gh}^k -the average speed of different vehicle.

q_{gi}^{kr} -amount of relief r that vehicle k dispatch to node i .

X_{ir} -relief demand for affected area i .

T_g^k -if the vehicle departs from the DC for the first time $T_g^k = 0$, and otherwise $T_g^k \neq 0$.

x_j -if a DC is located at eligible site j $x_j = 1$, and 0 otherwise.

y_{gh}^k -if vehicle k departs from demand point g to h $y_{gh}^k = 1$, and 0 otherwise.

VF_{ik} -if point i is the last node of the route serviced by vehicle k $VF_{ik} = 1$, and 0 otherwise.

$$\text{Max} \sum_{i \in S_1} \sum_{k \in K} \lambda_i \mu_i (T_i^k) \quad (4)$$

$$\text{Min} C_1 \sum_{i \in S_1} \max [(T_i^k - l_i, 0)] \quad (5)$$

S.t.

$$\sum_{i \in S_1} \sum_{k \in K} y_{ji}^k - x_j \geq 0, \forall j \in S_2, k \in K \quad (6)$$

$$\sum_{i \in S_1} y_{ji}^k - x_j \leq 0, \forall j \in S_2, k \in K \quad (7)$$

$$\sum_{k \in K} y_{gh}^k = 0, \forall g, h \in S_2 \quad (8)$$

$$\sum_{g \in I} \sum_{k \in K} \sum_{r \in R} q_{gi}^{kr} \geq X_{ir}, \forall i \in S_1 \quad (9)$$

$$\sum_{i \in S_1} \sum_{r \in R} U_r q_{gh}^{kr} \leq Q_k, \forall g, h \in I, k \in K \quad (10)$$

$$\sum_{h \in I} y_{hg}^k - \sum_{h \in I} y_{gh}^k = \begin{cases} 1 & VF_{ik} = 1, g \in S_1 \\ 0 & VF_{ik} \neq 1, g \in S_1, \\ -1 & \text{else} \end{cases} \quad \forall k \in K \quad (11)$$

$$T_h^k = T_g^k + t_{gh}^k y_{gh}^k, \forall g, h \in I, k \in K \quad (12)$$

$$t_{gh}^k = \frac{\rho_l d_{gh}}{V_{gh}^k}, \forall g, h \in I, \rho_l > 0 \quad (13)$$

The above model includes two objective functions equation (4) and equation (5). Equation (4) seeks to maximize the satisfaction of every disaster area. Equation (5) aims to minimize the punishment cost that when the affected area doesn't service within the time window. Constraint set (6) and (7) indicate that the selected distribution center can dispatch vehicles. Constraint set (8) restricts that there is no

traffic between the same facilities. Constraint (9) enables the needs of the affected area should be met. Constraint (10) enforces the total amount of materials transported by vehicles do not exceed its' capacity. Constraint (11) enables vehicles do not have to return to DC and they may wait at their last stop until the next dispatching order. Constraint set (12) and (13) define the calculation of time.

4. Algorithm

In this section we use the NSGA-II that coding based on roulette and random keys to verify the effectiveness of considering priority.

Before the solution, we transform the first objective function into the following form to simplify the operation and the analysis.

$$Max \frac{\sum_{i \in S_1} \sum_{k \in K} \lambda_i \mu_i (T_i^k)}{\sum_{i \in S_1} \lambda_i} \quad (14)$$

In the coding process, we use a two-layer mechanism. The first layer is used for the selection of the distribution center, and the second layer is used to determine the order of delivery. The coding dimension of the first layer is from 1 to k , the second layer is from 1 to $(n+k-1)$, n is the number of demand points. And the following chart vividly describes the process of coding and decoding.

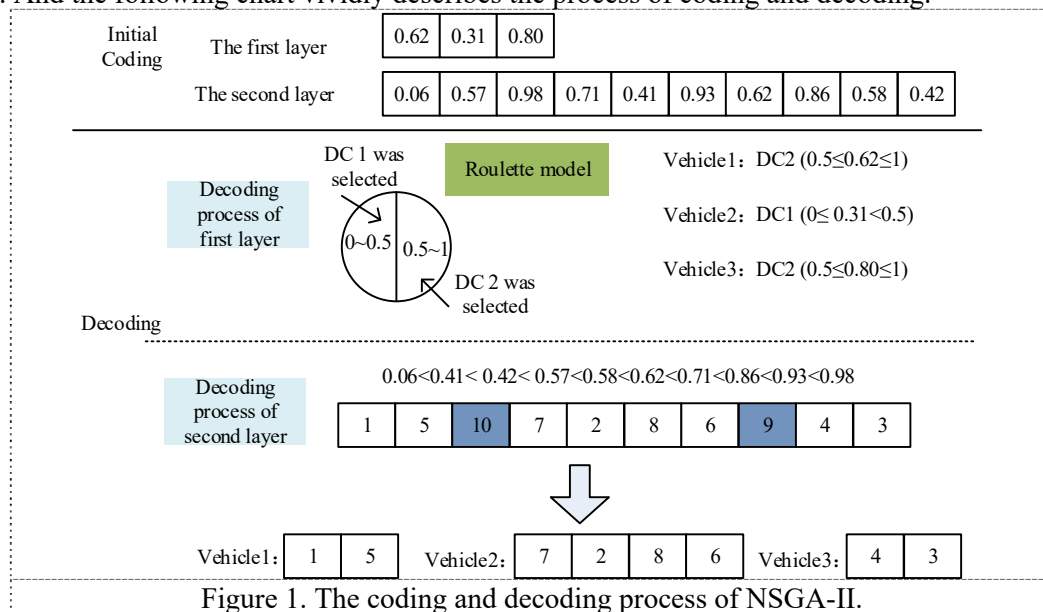


Figure 1. The coding and decoding process of NSGA-II.

5. Simulation

The main purpose of this section is to demonstrate the efficiency of the proposed method that can be used in practical operations of emergency scenario during the large-scale disasters. The case study includes 20 demand nodes, 2 materials, 5 DCs and the data is chosen from the typical Solomon RC-208 by Solomon. In order to verify the effectiveness of considering priority, we compare the system that consider the priority with the other one that do not consider it. We mark A1 as the system that consider priority, and A2 that do not consider it. The parameter of the algorithm is $N = 50$, $MaxIt = 200$, $P_m = 0.05$, $P_c = 0.9$.

Through the NSGA-II, we get the Pareto solutions and one of the routing plan of this two systems, which is presented in the following figure and table.

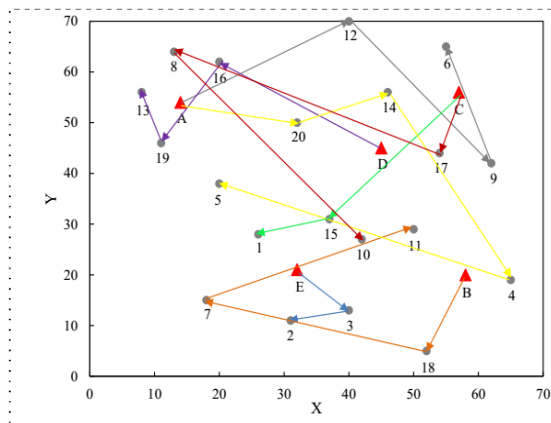


Figure 2. Routing of A1.

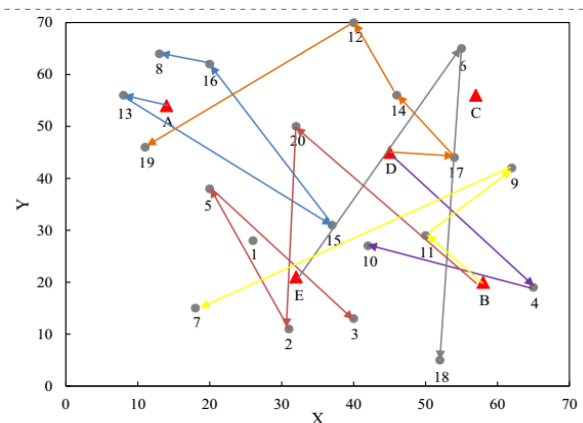


Figure 3. Routing of A2.

Table1. Routing of two systems

Scenario	Vehicle	Routing	Total time (min)
A1	2	C-15-1	119.59
	3	D-16-19-13	161.03
	4	E-3-2	38.66
	5	B-18-7-11	162.21
	6	C-17-8-10	200.37
	7	A-20-14-4-5	152.06
	9	A-12-9-6	100.93
A2	2	D-4-10	151.78
	4	A-13-15-16-8	168.39
	5	B-11-9-7	156.50
	6	E-6-18	239.28
	7	B-20-2-5-3	189.53
	8	D-1	37.48
	9	D-17-14-12-19	97.65

There are four columns in table 1 which indicate the routing plan and the total time when their demands were met. The first column is the two systems that mentioned in the above, the second one is the vehicle collection which is dispatched to the emergency areas, the third column present the routing plan of different vehicle and the fourth column is the total time when the demand of every affected area is met. The total time of this two systems is 934.85minutes and 1040.61minutes, obviously, the former is smaller than the later one. Therefore, it is necessary to consider the priority in the emergency logistics system. In time to meet the needs of the affected points, the total service time of the system is shortened and the rescue rate is effectively improved.

Through the calculation of satisfaction, we get the value of the above two systems. And then transform it into $[0,1]$ interval, the following graph is the specific results.

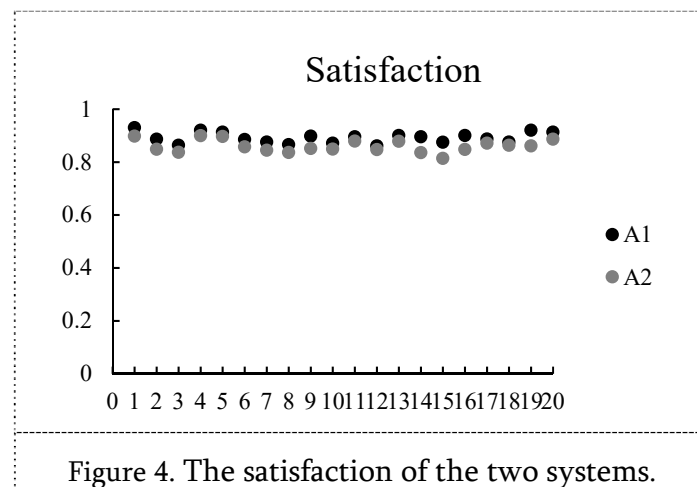


Figure 4. The satisfaction of the two systems.

In figure 4, we find that the satisfaction of A1 is higher than that of A2, which indicates that considering priority of the demand point can improve the satisfaction of the demand point and the overall performance of the emergency logistics system.

6. Conclusions

Based on the characteristics of relief and demand points, this paper studies the emergency logistics site selection and material distribution problem with time window after the open road network is blocked, and establishes an LRP model with the shortest system total time and the lowest penalty cost, and we design a two-layer coding NSGA-II algorithm to solve it. Finally, the Solomon data is used as an example to verify the rationality of the model and the effectiveness of the algorithm. It further shows that it is necessary to consider the priority in the emergency rescue work in the early post-disaster period. It can shorten the overall service time of the system and reduce the losses caused by the lack of timely satisfaction of material needs. In addition, although the research has added the priority of the demand point, only the emergency material distribution under the static network is considered, and the multi-stage dynamic problems of the emergency material distribution after the disaster need further study.

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