Modeling and Optimization of Heterogeneous Vehicle Routing Problem in Emergency Resource Distribution after Disaster

Haibin Zhou
School of safety science and emergency management, Wuhan University of Technology, Wuhan, P.R.China, 430070. Email:1309218390@qq.com

Abstract. In recent years, natural disasters have occurred frequently around the world. There are many kinds of disasters in China, which are diversified in form and widely distributed. How to reduce the damage caused by disasters to humans is one of our urgent tasks. Firstly, a heterogeneous vehicle routing optimization model is constructed, and a genetic algorithm is designed to solve the model. Secondly, the optimal path of heterogeneous vehicle resource transportation is solved by using examples to verify the effectiveness of the model and algorithm. Finally, this paper puts forward the prospect of research on the problem of heterogeneous vehicle routing for emergency resource transportation after disasters.

1. Introduction
China has suffered from natural disasters in the world and the losses are also very heavy. For example, the earthquake in Wenchuan in 2008 caused direct economic losses of more than 800 billion yuan. According to the data of donated resource received by the Sichuan Provincial Health Department, the resource needed after the disaster are mainly daily necessities and food. These kinds of donated resources are complex and huge, which puts high requirements for the disaster relief system. How to transport disaster relief resource to disaster-stricken areas quickly and effectively is a serious challenge for us.

At present, scholars at home and abroad have done abundant research on the distribution and transportation of emergency resource. Albareda-Sambola et al. (2007)[1] proposed the application of two-stage heuristic algorithm to the study of vehicle routing problems. By solving a series of sub-problems, the initial feasible solution was established and improved on this basis. Chang et al. (2012)[2] analyzed the scenario conditions of emergency resource transportation in detail. Based on hybrid shaping planning, an emergency resource transportation model with minimum delay time as the objective grazing function was proposed, and the solution algorithm was proposed. Finally, the example was used to verify the feasibility of the algorithm. Tzeng et al.[3] used fuzzy multi-objective programming to solve a multi-objective model with the shortest time, the lowest cost and the greatest satisfaction. The actual situation of emergency resource transportation after the 1999 Taiwan earthquake in China was analyzed with this method. Jotshi (2009) [4] combined the idea of index data fusion to solve the path selection problem in emergency rescue. Berkoune et al. (2012)[5] defined and formulated the actual transportation problems that crisis managers often encounter in emergencies. Wang et al.(2015)[6] took time and cost minimization as two objectives. Under other uncertain conditions, the LRP model with time window constraints was applied to transform the two objectives into a single objective. The genetic algorithm was applied to analyze the location-routing problem of emergency resource distribution. Considering the complexity and urgency of emergency logistics operation, Li (2016)[7] applied robust discrete optimization to dynamic network theory, established a
new optimization model, and applied improved ant colony algorithm to find a new method for emergency resource transportation. Lu et al. (2017) [8] combined the Fuzzy Impact Map and Fuzzy Comprehensive Evaluation, and used genetic algorithm and BP neural network to plan and analyze the correlation and characteristic parameters of logistics paths based on the above methods, which made up for the omission of traditional methods.

It can be seen from above literature that most of the research focuses on the allocation and transportation of single-stage emergency resource, and classifies emergency vehicle path planning as the vehicle routing problem. At the same time, the research on multi-stage problems is still from the static allocation of resource. Although there has been a lot of research on vehicle routing optimization for resource transportation after disasters at home and abroad, it has not really dealt with the difficulties of long time and high cost of resource transportation for disaster relief. Therefore, this paper intends to study the optimization of heterogeneous vehicle routes in emergency resource transportation, and to plan the allocation of disaster emergency resource by understanding road conditions and vehicle capacity, and to efficiently complete the resource relief after disaster.

2. Model of Heterogeneous Vehicle Routing for Emergency Resource Allocation after Disasters

2.1. Description of the Problem

In the rescue work, the vehicle routing problem is the core link of emergency resource transportation after disaster, and also the key to achieve rapid loosening of emergency resource. In order to design a reasonable vehicle path for a large number of disaster-stricken areas under certain constraints, the rescue vehicle starts from the distribution point, distributes the relief resource quickly and efficiently (with the lowest cost, the least time and the least use of vehicles) and then returns quickly to the next round of rescue. The model constructed below is mainly to study the impact of different loads of heterogeneous vehicles on the results of transportation path planning.

2.2. Construction of Heterogeneous Vehicle Path Problem Model

2.2.1 Model assumptions. (1) It is assumed that the location of the distribution center is known, and the distance between the distribution center and each disaster point and each disaster point is known; (2) The types of resources delivered by each vehicle are the same, and there is no difference in the types of resources distributed by each vehicle. (3) The load capacity of each vehicle can meet the demand for resource at any demand point; (4) The resource at each resource demand point is distributed by only one vehicle; (5) The preferred level of resource demand is the same in each disaster area, and there is no preferred level. (6) Assuming that each vehicle travels at the same speed, the shortest scheduling path length can be used to replace the shortest scheduling time, and the optimization objective function is converted to the shortest scheduling path length.

2.2.2 Variables and symbols Descriptions. Variables and symbols are described in Table 1.

| Parameter (symbol variable) | Implication |
|-----------------------------|-------------|
| \( b_k \)                  | Load of each delivery vehicle, \( k=1,2,\ldots,m \) |
| \( r_i \)                  | Represents resource requirements of each disaster point, \( i=1,2,\ldots,n \) |
| \( d_{ij} \)               | Represents distance from demand point \( i \) to \( j \) |
| \( d_{0i},d_{i0} \)        | Represents distance from distribution center to demand point \( i \) |
| \( v_k \)                  | This is a 0-1 variable. When the value is 1, it means that the \( k \)-th vehicle goes to the demand point \( i \); if the value is 0, it means other cases. |
| \( x_{ijk} \)              | This is a 0-1 variable. When the value is 1, it means that the \( k \)-th vehicle passes through the point \( i \) and directly reaches the point \( j \). If the value is 0, it indicates other conditions. |
2.2.3 Establishment of model. Based on the above assumptions and analysis, the following mathematical models can be established.

(1) The objective function is as follows:

$$\min \sum_{k=1}^{m} \sum_{j=0}^{n} \sum_{i=0}^{n} d_{ij} x_{ijk}$$

(1)

Formula (1) is the objective function of this paper, which indicates that the shortest route length can be used to express the shortest resource distribution time in the whole resource distribution process because of the same speed assumption.

(2) Constraints are as follows:

$$\sum_{k=1}^{m} v_{ik} = 1, i = 1,2,..., n$$

(2)

$$\sum_{j=1}^{n} x_{0,jk} = \sum_{j=1}^{n} x_{j,0k} = 1, k = 1,2,..., m$$

(3)

$$\sum_{j=0}^{n} x_{jk} = v_{ik}, i = 1,2,..., n; k = 1,2,..., m$$

(4)

$$\sum_{i=1}^{n} r_{i} v_{ik} \leq b_{k}, k = 1,2,..., m$$

(5)

$$d_{ij} = d_{ji}, i, j = 0,1,2,..., n$$

(6)

$$x_{ijk} \in \{0,1\}, i, j = 0,1,2,..., n; k = 1,2,..., m$$

(7)

$$v_{ik} \in \{0,1\}, i = 1,2,..., n; k = 1,2,..., m$$

(8)

$$d_{ij} \geq 0, i, j = 0,1,..., n$$

(9)

$$r_{i} > 0, b_{k} > 0, i = 1,2,..., n; k = 1,2,..., m$$

(10)

Formula (2) indicates that the resource at each resource demand point are only distributed by one vehicle. Formula (3) indicates that each distribution vehicle starts from the distribution center and passes through each resource demand point. Formula (4) indicates that there will be a vehicle passing through every resource demand point. Formula (5) indicates that the load capacity of distribution vehicles will be greater than that of the resource demand points visited, and there will be no overload of vehicles. Formula (6) denotes that the path length from point i to point j is the same as that from point j to point i. Formulas (7), (8), (9), (10) respectively indicate the range of values of each variable.

3. Algorithm Design of Heterogeneous Vehicle Routing Problem for Emergency Resource Distribution

In this paper, the genetic algorithm is used to solve the model. The specific steps are as follows: (1) Chromosome coding. The coding method is represented by the arrangement of resource demand points and virtual distribution centers, which transforms the problem into a virtual multi-individual traveling salesman problem. Randomly generate a natural number arrangement of 1 to m+n-1. The natural number greater than n indicates a virtual distribution center. If the distribution center is connected, it means that the vehicle does not participate in the delivery. Thus the non-repetitive natural number permutation of 1 to m+n-1 constitutes a solution and corresponds to a distribution scheme. (2) Initialize the population. Randomly generate N chromosomes, and non-conforming chromosomes were eliminated according to the constraints, and the fitness function of each chromosome was calculated and sorted. (3) Calculate fitness. For each individual's corresponding distribution plan, the fitness value (i.e. the sum of the length of the distribution path) should be determined by whether the
constraint is satisfied or not. A large penalty factor is added to the individual scheme which does not satisfy the restriction for later screening and exclusion. (4) Select the operation. In the selection operation, we use the method of roulette. The selection operation for individuals is to facilitate the following crossover and mutation operations. (5) Crossover operation. In this paper, a matching region such as A1 and A2 is randomly generated by using the quasi-crossover rule. Then, the mating region of A2 is placed before A1, and the mating region of A1 is placed before A2, so A11 and A22 are obtained. After the self-mating region of A11 and A22, the same natural number as the mating area is deleted, and new descendants are obtained. (6) Mutation operation. The method of symmetrical mutation is used for mutation calculation. In the process of using crossover operation to achieve the optimal solution, the mutation operation is used to accelerate the convergence of the algorithm and prevent the algorithm from premature convergence or entering the local optimal cycle.

4. Case Analysis
Suppose there are 5 types of vehicles and 25 demand points, and their specific data are shown in the table 2 and table 3. Where X, Y is the coordinate position, number 0 is the distribution center, 1, 2, ..., 25 represents the resource demand point.

| Serial number | X  | Y  | Demand |
|---------------|----|----|--------|
| 0             | 117| 42 | 0      |
| 1             | 147| 15 | 15     |
| 2             | 139| 64 | 10     |
| 3             | 110| 37 | 23     |
| 4             | 6  | 91 | 13     |
| 5             | 34 | 100| 20     |
| 6             | 10 | 92 | 15     |
| 7             | 120| 37 | 14     |
| 8             | 40 | 97 | 23     |
| 9             | 63 | 34 | 21     |
| 10            | 200| 66 | 15     |
| 11            | 88 | 8  | 14     |
| 12            | 14 | 47 | 10     |
| 13            | 174| 79 | 24     |
| 14            | 92 | 49 | 16     |
| 15            | 37 | 76 | 15     |
| 16            | 14 | 35 | 11     |
| 17            | 146| 0  | 14     |
| 18            | 127| 93 | 12     |
| 19            | 32 | 42 | 25     |
| 20            | 150| 57 | 11     |
| 21            | 106| 21 | 10     |
| 22            | 114| 37 | 20     |
| 23            | 86 | 98 | 21     |
| 24            | 34 | 86 | 11     |
| 25            | 180| 74 | 20     |

Load capacity of each vehicle is shown in table 3.
Table 3. Load capacity of each vehicle

| Distribution vehicle | Load capacity |
|-----------------------|--------------|
| 1                     | 70           |
| 2                     | 80           |
| 3                     | 100          |
| 4                     | 120          |
| 5                     | 95           |

In order to be clear and intuitive, the calculation is omitted. The distance between the resource demand points and the distance between distribution center and resource demand points is calculated by their respective coordinates.

The formula for calculating distance is as follows:

\[ d_{ij} = \sqrt{(y(i) - y(j))^2 + (x(i) - x(j))^2} \]

The genetic algorithm is used for calculation. Suppose that the crossover probability is 0.8 and the mutation probability is 0.08. After 10 simulation operations, the results are shown in Table 4.

Table 4. Simulation results

| Serial number | Shortest path length |
|---------------|----------------------|
| 1             | 331.0492             |
| 2             | 328.1062             |
| 3             | 339.4746             |
| 4             | 333.4255             |
| 5             | 332.4717             |
| 6             | 332.4239             |
| 7             | 346.5063             |
| 8             | 331.6005             |
| 9             | 323.9988             |
| 10            | 352.1364             |

It’s can be seen that the optimal result is 323.9988 from Table 4, and the optimal arrangement is shown in Figure 1.

![Figure 1. Optimization path](image)

The convergence diagram of the optimal solution is shown in Figure 2.
From Figures 1, the optimal scheduling scheme can be obtained as follows: 0-18-13-25-10-20-2, 0-7-1-17-22, 0-3-9-19-12-16-11-21, 0-14-8-5-23, 0-15-4-6-24. And the shortest path length is 323.9988.

5. Conclusion
Emergency rescue time and efficiency directly determine the rescue effect, so it is of great significance to study the heterogeneous vehicle routing problem in emergency rescue. Firstly, a heterogeneous vehicle routing optimization model is constructed, and a genetic algorithm is designed to solve the model. Secondly, the optimal route of heterogeneous vehicle resource transportation is solved by an example, which verifies the effectiveness of the model and algorithm. However, this paper only considers the impact of heterogeneous vehicle load change on emergency resource distribution, but the speed and dynamic optimization of vehicles have not been taken into account, which is also the need for further improvement in future research.

6. References
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