Research on Vehicle Routes Optimization for Emergency Materials Distribution

Jiashan Zhang and Xiaoqun Lin
Chongqing vocational institute of engineering, Chongqing, 402260, China
Corresponding author: E-mail: zh_jiashan@163.com

Abstract. Disasters such as earthquake, flood and diseases are sudden and urgent. In order to improve the efficiency of emergency materials distribution, scientific decision on vehicle routes plays an important role. This article assumes that the emergency materials required by each disaster site are allowed to be delivered in advance but not delayed. Considering vehicle maintenance and driver's continuous working ability, taking the distribution cost as the objective function, a mathematical optimization model for the problem is established. Based on ant colony algorithm, optimization algorithm is designed to solve the model. Then, effects of different optimization algorithms were compared. The application shows that the method operates quickly and the results are rational, which can provide scientific basis for decision-making.

1. Introduction
In recent years, disasters have occurred frequently. Statistics, which is from the China National Ministry of Emergency Management, show that about 130 million people are affected by different degrees by various disasters in China in 2018. Direct economic loss is as much as 264.46 billion RMB. After the disaster occurs, the government's first task is to save people's lives and reduce losses. So, how to distribute emergency materials to the disaster areas timely, accurately and effectively is a major concern. Vehicle routes optimization for emergency materials distribution plays an important role in coping with disasters, which is also an very important research direction in emergency logistics [1-3].

In fact, since vehicle routing problems (VRPs) was put forward, it has drawn great attention from researchers, due to their importance in communications, transportation and logistics. After analyzing the complexity of VRP, Lenstra and Rinnoy Kan (1981) have come to a conclusion that vehicle routing problems are one of typical NP-Hard problems in combination optimization [4]. Hundreds of models and algorithms are applied to different versions of VRPs for optimal solutions.

In the literature, the vehicle routing problem for emergency materials distribution (VRPEMD) is abstracted as a mathematical model and solved by the improved Ant Colony Algorithm prompted.

2. Literature Review
Traditional exact algorithms [3], such as branch and bound algorithm, cutting planes approach and dynamic programming, play a very important role for VRP. Usually, they provide solutions at 10-20 percent above the optimal solutions. Exact algorithms has as well as its limitation. They can only solve VRPs less than 50 nodes, not solve large-scale VRPs. Later, evolutionary algorithms are developed for VRP.

Taking water and food as example, Hamedi et al. (2012) studied the distributing model of humanitarian emergency supplies. They applied genetic algorithm to solve the model. For emergency materials distribution in the aftermath of disasters, Lu et al. (2016) proposed a rolling horizon-based
framework.

Hu et al. (2015) built an Express Mail Service (EMS) model, aiming at the least time and the lowest cost, and applied genetic algorithm to solve the model. For single distribution center (DC) and multiple disaster depots, Ma and Wang (2014) built an EMD model. For multi-criteria optimization in emergency materials last mile distribution, Ferrer et al. (2018) built a compromise programming model.

3. Problem Description and Formulation

There are m vehicles in the distribution center , which are used to delivery cargo for n customers ( v_1, v_2, \ldots, v_n ). Demand level of each customer d_i is known . All vehicles are required to start from distribution center. All vehicles are required to return back to distribution center after finishing distribution. Every customer is serviced by just one vehicle and customer demands are satisfied. The VRPEMD aims to find m or less vehicle routes, i.e. sequences of deliveries to disaster sites no later than time request, to visit each disaster site one time exactly while minimizing the total travel distance.

Set 0-1 variables as follows :

\[ x_{ij}^k = \begin{cases} 
1, & \text{if customer j is supplied after customer i by a vehicle of type k} \\
0, & \text{otherwise}
\end{cases} \]

\[ y_{jk} = \begin{cases} 
1, & \text{if vehicle k visits client j} \\
0, & \text{else}
\end{cases} \]

The objective function can be written as follows:

\[ \min z = \sum_i \sum_j \sum_k d_{ij} x_{ij} \]  

Subjected to

\[ \sum_{i=1}^{n} q_i y_{ik} \leq Q, \quad k = 1, 2, \ldots, m; \]  

\[ RT_i \leq ET_i, \quad i = 1, 2, \ldots, n \]  

\[ \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} \cdot x_{ijk} \leq D, \quad k = 1, 2, \ldots, m \]  

\[ \sum_{k=1}^{m} y_{ik} = 1, \quad i = 1, 2, \ldots, n \]  

\[ \sum_{i=0}^{m} x_{ijk} = y_{jk}, \quad j = 1, 2, \ldots, n; \quad k = 1, 2, \ldots, m \]  

\[ \sum_{j=0}^{m} x_{ijk} = y_{ik}, \quad i = 1, 2, \ldots, n; \quad k = 1, 2, \ldots, m \]

Constraint (2) guarantees that the vehicle is not overloaded. Constraint (3) demands that all supplies must arrive at the site no later than time request. Constraint (4) guarantees that the vehicle will not drive more than single maximum traveling distance. Constraint (5) guarantees that each client is serviced by exactly one vehicle. Constraint (6) and (7) guarantee that only one vehicle arrives at each node. \( y_{jk} \) denotes whether the node j is distributed by vehicle k.
4. Design of Ant Colony Algorithm

4.1. State Transition Probability

Ant Colony Algorithm derived from the study of real ant colonies. Ants deposit pheromone on the trial when they are moving. The subsequent ants decide whether to follow the same path depending on the amount of pheromone, thus establishing a path from ant nest to feed sources. The more the ants following a trail, the more attractive the trail becomes for other ants. For example, there is a path along which ants are walking from A(food source) to E(the nest), shown in Fig. 1 or Fig. 2

In Original Ant Colony Algorithm, the state transition probability from node i to node j for the k-th ant is defined as follows:

\[
P_k^{ij} = \begin{cases} 
\frac{\tau_k^{ij}(t) \eta_k^{ij}(t)}{\sum_{r \in \text{allowed}_k} \tau_k^{ir}(t) \eta_k^{rj}(t)}, & j \in \text{allowed}_k \\
0, & \text{otherwise}
\end{cases}
\]
There are some differences in the vehicle routing problem for emergency materials distribution (VRPEMD). In addition to considering the pheromone intensity and visibility on each path, it is also necessary to consider the preference of hard time window restrictions. The preference is based on the principle that time difference between the time window of disaster site and delivery time of emergency materials.

For the k-th ant in VRPEMD, the state transition probability is defined as follows:

\[
p_{ij}^k = \begin{cases} 
{\frac{\tau_{ij}^k(t) \cdot \eta_{ij}^k(t)}{\sum_{j \text{ allowed}} \tau_{ij}^k(t) \cdot \eta_{ij}^k(t)} + \frac{1}{\sum_{j \text{ allowed}} \sqrt{|RT_{ij}^k - ET_{ij}^k|}},} & j \in \text{allowed}_k \\
0 & \text{otherwise} 
\end{cases}
\]  

(8)

When ants select a path, a new constant \(q_0 \in (0,1)\) is introduced and it denotes the probability when ants choose current possible path. Before selecting, \(q\) is randomly generated and uniformly distributed in \([0,1]\), then the k-th ant chooses the path \(j\) according to the following rule:

\[
j = \begin{cases} 
\arg \max_{j \text{ allowed} k} \{ (\tau_{ij}^a(t) \cdot \eta_{ij}^b(t)), \quad q < q_0 \} \\
(8), \quad q \geq q_0 
\end{cases}
\]  

(9)

If \(q \geq q_0\), it is exploratory search in ACA, then the ant will select the path at the probability of \(1-q_0\) randomly. The algorithm can search more paths by adjusting parameter \(q_0\). If \(q < q_0\), it is deterministic search which selects the maximum probability path, and the ant will select the shortest path according to probability \(q_0\). Deterministic search utilize past experience to guide to selecting paths, thus can make up for the shortcoming of slow convergence rate of exploratory search.

4.2. Pheromone Updating Rules

The ACA combines global and local pheromone updating rules.

4.2.1. Global pheromone updating

\[
\tau_{ij} = (1-\rho)\tau_{ij} + \rho \Delta \tau_{ij}, (i,j) \in T^g 
\]  

\[
\Delta \tau_{ij} = Q / L_{g} 
\]  

(10)

where \(T^g\) is the optimal path and \(L_{g}\) is the length of \(T^g\). The evaporation and release of pheromone is performed on the edge of optimal path, and this can reduce the computational complexity from \(O(n^2)\) to \(O(n)\).

4.2.2. Local pheromone updating

\[
\tau_{ij} = (1-\rho)\tau_{ij} + \rho \cdot \tau_{ij}, 
\]  

(11)

where \(\tau_0\) is the initial value of pheromone. As time goes by, pheromone intensity on the trail diminishes. So the trial becomes less attractive, which is helpful to explore unvisited edges to prevent search from stagnation[10].

5. Experiments

In this section, we report our computational results and compare them with those from the existing
literature. The improved ant colony algorithm proposed has been executed on an Intel Pentium 5 machine, which is equipped with 4GB memory, running 20 times. The example is derived from the original problem A-n33-k5-new by randomly generating the latest delivery time. The nodes are shown in Table 1.

| Site Number | X coordinate | Y coordinate | Request | Latest arrival time | Site Number | X coordinate | Y coordinate | Request | Latest arrival time |
|-------------|--------------|--------------|---------|---------------------|-------------|--------------|--------------|---------|---------------------|
| 1           | 42           | 68           | 0       | 9:00:00             | 18          | 73           | 3            | 24      | 13:42:03            |
| 2           | 77           | 97           | 5       | 10:40:40            | 19          | 59           | 77           | 13      | 15:24:40            |
| 3           | 28           | 64           | 23      | 11:00:10            | 20          | 58           | 97           | 14      | 10:13:00            |
| 4           | 77           | 39           | 14      | 13:23:06            | 21          | 23           | 43           | 8       | 11:07:06            |
| 5           | 32           | 33           | 13      | 9:09:39             | 22          | 68           | 98           | 10      | 10:24:51            |
| 6           | 32           | 8            | 8       | 11:58:18            | 23          | 47           | 62           | 19      | 14:30:14            |
| 7           | 42           | 92           | 18      | 10:06:53            | 24          | 52           | 72           | 14      | 14:43:43            |
| 8           | 8            | 3            | 19      | 11:46:27            | 25          | 32           | 88           | 13      | 9:59:48             |
| 9           | 7            | 14           | 10      | 11:35:00            | 26          | 39           | 7            | 14      | 9:35:10             |
| 10          | 82           | 17           | 18      | 13:33:04            | 27          | 17           | 8            | 2       | 11:50:10            |
| 11          | 48           | 13           | 20      | 9:25:18             | 28          | 38           | 7            | 23      | 9:47:36             |
| 12          | 53           | 82           | 5       | 16:25:19            | 29          | 58           | 74           | 15      | 15:04:42            |
| 13          | 39           | 27           | 9       | 9:15:12             | 30          | 82           | 67           | 8       | 13:05:22            |
| 14          | 7            | 24           | 23      | 11:29:04            | 31          | 42           | 7            | 20      | 9:31:32             |
| 15          | 67           | 98           | 9       | 10:19:00            | 32          | 68           | 82           | 24      | 10:49:23            |
| 16          | 54           | 52           | 18      | 14:03:11            | 33          | 7            | 48           | 3       | 11:16:48            |
| 17          | 72           | 43           | 10      | 13:55:29            |             |              |              |         |                     |

![Figure 3](image-url)  

**Figure 3.** Best solution found for problem

| Table 2. Comparison of different algorithms for A-n33-k5-new |
|-----------------------------------------------------------|
| original ACA[7] | ACA with elite strategy [10] | ACA proposed |
|-----------------|-----------------------------|--------------|
| optimal solution | Iterations | optimal solution | Iterations | optimal solution | Iterations | Average solution |
| 730.34          | 87           | 710.10        | 132         | 677.87           | 157         | 694.31          |

The ant colony algorithm proposed has a good performance in searching optimal solution. Compared with the original ACA or ACA with elite strategy, the optimal solution improve 7.1% or 4.4%. But Iterations increase slightly.
6. Conclusion and Future Work

This paper proposes a new ant colony algorithm for the emergency materials Vehicle Routing Problem. The proposed method can retain optimum in a reasonable time. Compared with the original ACA and ACA with elite strategy, results of the algorithm is improved obviously. In the example, the average of 20 times computing is 694.31, and improve 3.2%~ 6.4% than the original ACA or ACA with elite strategy. Experiments show that the algorithm, Which succeed in solving a variety of VRPEMD, is robust as the optimization method.

Actually, real-life emergency materials vehicle routing application has many uncertain characteristics, such as dynamically changing requirement of customers. We will carry out further research in the future.

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8. References

[1] Gao Hongni, Zhao Yibing, Li Ning. “Study on earthquake disaster emergency supplies scheduling model based on multiple demand points,” China Safety Science Journal, vol.23, no.01, pp.161-165, 2013.
[2] Taylor, D, Pettit, S, “A consideration of the relevance of lean supply chain concepts for humanitarian aid provision,” International Journal of Services, Technology and Management, vol.12, no.4, pp. 430-444, 2009. Advances in Computer Science Research, volume 65192
[3] Murali P, Ordóñez F, Dessouky MM, “Facility location under demand uncertainty: Response to a large-scale bio-terror attack,” SocioEconomic Planning Sciences, vol.46, no.1, pp.78-87, 2012.
[4] Lenstra, J. K., & Rinnoy Kan, A. H. G. (1981). Complexity of Vehicle and Scheduling Problems. Networks, 11, 221–227.
[5] Hamedi, M., Haghani, A., Yang, S., 2012. Reliable transportation of humanitarian supplies in disaster response: model and heuristic. Procediae Social and Behavioral Sciences 54,1205e1219.
[6] Lu, C.C., Ying, K.C., Chen, H.J., 2016. Real-time relief distribution in the aftermath of disasters: a rolling horizon approach. Transportation Research Part E: Logistics and Transportation Review 93, 1e20.
[7] Hu, F., Wang, Y., Ma, B., et al., 2015. Emergency supplies research on crossing points of transport network based on genetic algorithm. In: 2015 International Conference on Intelligent Transportation, Big Data and Smart City, Halong Bay, 2015.
[8] Ma, D., Wang, W., 2014. Logistics distribution vehicle scheduling based on improved particle swarm optimization. Computer Engineering and Applications 50 (11), 246e250.
[9] Ferrer, J.M., Martí-n-Campo, F.J., Ortuno, M.T., et al., 2018. Multi-criteria optimization for last mile distribution of disaster relief aid: test cases and applications. European Journal of Operational Research 269 (2), 501-515.
[10] Huang Xuncheng, Zhuang Yiqi, Power Distribution Network Optimization Planning Based on Improved Ant Colony Algorithm [J];Journal of Xi’an Jiaotong University;2007 (6):73-81.