Research on the optimization of logistics vehicle routing under multimode transportation strategy based on ant colony algorithm

Haining Qi\(^1,3\), Yanqiu Liu\(^2\) and Shida Xu\(^2\)
\(^1\)Shenyang University of Technology, School of Science, Shenyang 110870, China
\(^2\)Shenyang University of Technology, School of Management, Shenyang 110870, China
\(^3\)Email: 912403904@qq.com

Abstract. The transformation of multiple transport tools which the multimode transportation process involves, and the split transportation brought by the third-party logistics makes the problem more complicated. At present, a large amount of research on the multimode transportation problem remains at the decision-making level, lacking quantitative comparative analysis of vehicle path combinatorial optimization problem. The common genetic algorithm adopts the method of generating an initial solution randomly, which will lead to a large number of infeasible solutions in the population and reduce the solving speed. In view of the above problems, this paper proposes using ant colony algorithm to solve the multimode transportation problem. The solution of ant colony algorithm is generated according to the pheromone concentration and the state transfer probability of nodes, so the feasibility of spatial connection is ensured in the generation stage of solution. The concept of virtual node is introduced to reduce the difficulty coefficient of the problem. Finally, an example is given to prove the validity of the proposed model and algorithm.

1. Introduction
Vehicle Routing Problem (VRP) was proposed by Dantzig and Ramser in 1959 to study the vehicle routing problem from Atlanta refinery to various gas stations [1]. Vehicle Routing Problem is a classical NP-hard problem, whose model and the Travel Salesman Problem (TSP) have many similarities. So the corresponding solution of Vehicle Routing Problem can also be used in solving such similar problem model. In the following decades, scholars have conducted in-depth studies from different aspects and continuously expanded and developed the VRP problem. [2-4]

With the globalization of economy and trade, the traditional transportation mode has been unable to provide feasible transportation solutions for the complex logistics and transportation market now. More and more enterprises and researchers try to use multiple transportation modes to cooperate in the logistics and transportation process to complete enterprise logistics and transportation orders. In the existing studies, transportation problems of multiple modes are mainly divided into four categories: Multimodal transportation [5], Inter-modal transportation [6], Co-modal transportation [7] and Synchro-modal transportation [8]. Among them, two transportation strategies of multimodal transportation and Intermodal transportation both adopt two or more transportation modes in the transportation process, but there are essential differences. The multimodal transportation strategy mainly emphasizes that two or more means of transportation are adopted in the transportation process,
while the intermodal transportation strategy requires that the goods in the vehicle cannot be combined or split during the process from the starting point of cargo loading to the end point of transportation. Therefore, multimodal transportation is more used in container transportation research and practice.

Due to multimodal transportation problems in the logistics network structure compared with traditional VRP problem solution space more large scale and complex, business solving tools such as exactly algorithm, CPLEX are difficult to give a satisfactory solution in a limited time. So most of the scholars in this kind of problem in using the intelligent optimization algorithm to solve. Gen, Li and Ida proposed a genetic algorithm based on a spanning tree for multi-objective transportation problems [9, 10]. Jia Xiao qiu established the three-dimensional transportation model under rough environment and designed the genetic algorithm to solve it [11]. Zhang Chun mei established a two-criterion three-dimensional transportation model and designed an adaptive genetic algorithm to solve it. At last, experiments verified that this method could produce a solution suitable for requirements [12]. Ojha proposed a multi-species transportation problem with fuzzy tolerance and designed a genetic algorithm to solve it [13]. Lotfi proposed a genetic algorithm based on priority coding to solve the fixed-fee transportation problem [14]. In addition to genetic algorithm, some researchers have designed a variety of optimization algorithms to solve the problem. Juman has designed a heuristic algorithm to solve the transportation model of changes in product supply and demand [15]. Kaur introduced the general trapezoidal fuzzy number and proposed a new solution method to solve the fuzzy transportation problem [16]. Wang Yi jing studied the joint transportation mode and path selection problem, established the path optimization model based on the variable network transportation capacity, and designed the simulated annealing algorithm to solve the problem [17]. Lu Tong transformed the path optimization problem of multimodal transportation into a generalized shortest path problem. Taking cost and time as the optimization objective, she established a mathematical model for the path optimization of multimodal transportation to adapt to the change of traffic volume, and selected ant colony algorithm to solve the practical problem. [18]

At present, a lot of researches on multimodal transportation are mainly aimed at the decision-making level, and there is the absence of quantitative comparative analysis on the complex combinatorial optimization problem of path optimization. Genetic algorithm is utilized to solve the existing path optimization problems. As a classical group heuristic algorithm, genetic algorithm is widely used for solving combinatorial optimization problems. However, for the research of multimode transportation path optimization, as the multimode transportation path optimization problem involves the transformation of multiple means of transportation, the random generation of initial solutions adopted by genetic algorithm will lead to a large number of infeasible solutions in the population and reduce the solving speed. However, ant colony algorithm performs probabilistic selection operation according to pheromone concentration and node state transition probability in the generation stage of solution. Therefore, all generated solutions are ensured to be feasible solutions. In the process of algorithm optimization iteration, the algorithm is guaranteed to conduct optimization in the feasible solution space. Therefore, ant colony algorithm is adopted to solve the problem of multimodal transportation. In this paper, aiming at the optimization problem of logistics vehicle path under multimode transportation, based on the existing research, the consideration of third-party logistics assistance for branch transportation is increased, and an improved ant colony algorithm is proposed for simulation and solution according to the characteristics of the established mathematical model.

2. Problem description and model establishment

Multimodal transportation problem is primarily for general cargo transportation, in this paper it is defined as: the goods from one or more starting point through a variety of modes of transportation (such as railway, highway, waterway, etc.) more than served directly or after transit demand, problems of the objective function can be a total transportation cost minimum, transportation time shortest or carrier to obtain maximum profits, and so on. Among them, the choice of transportation mode is based on a number of criteria, such as the limitation of the supply capacity of the starting point, the limitation of the transportation capacity of the transportation mode, the demand for freight volume of the destination, the
requirement for the delivery period, the limitation of operating capacity in transit, the requirement of capital budget and so on.

Figure 1. Multimodal transportation problem composed of 11 nodes.

As showed in Figure 1, it is a schematic diagram of multimode transportation problem composed of 11 nodes. There are three modes of transportation, namely land, water and air. As can be seen from the figure, the structure of the solution under the multimode transportation strategy generates branch structure on the main trunk line, namely the cloverleaf topology [19].

Multimodal transportation problem model

\[
\begin{align*}
\min Z &= \sum_{s=1}^{l} \sum_{i=0}^{n-1} \sum_{j=1}^{n} x_{ij}^s c_{ij}^s + \sum_{k=1}^{n} \sum_{i=0}^{l} \sum_{s_1=1}^{n-1} \sum_{j=1}^{n} x_{ij}^{s_1} c_{ij}^{s_1} x_{jk}^{s_2} + \sum_{s=1}^{l} \sum_{i=0}^{n} \sum_{j=1}^{n} y_{ij}^s c_{ij}^s \\
&\quad \forall i \to j \text{ are transportationed by } s \text{ mode} \\
y_{ij}^s &= \begin{cases} 
1, & \text{from } i \text{ to } j \text{ is transportationed in } s \text{ mode and split} \\
0, & \text{others} 
\end{cases} \\
\end{align*}
\]

\(x_{ij}^s\) \(\{0, 1\}\)

Among them, \(0 \leq y_{ij}^s \leq x_{ij}^s \leq 1\)

\[
\sum_{i=0}^{n-1} \sum_{s=1}^{l} x_{ij}^s \leq \omega x_{ij}^s \leq \omega_{ij}^s 
\]

\(\sum_{j=1}^{n} x_{ij}^s = \sum_{k=1}^{n} x_{jk}^s \leq 1\)

\(\sum_{j=1}^{n} x_{0j}^s = 1\)

(1)

(2)

(3)

(4)
Table 1. Symbol in multimodal transportation problem model.

| symbol | meaning                      | symbol | meaning                      |
|--------|------------------------------|--------|------------------------------|
| s      | The mode of transportation   | c_{ij} | Path transportation cost coefficient |
| l      | Total mode of transportation | c_{ij}^{*} | Transshipment cost coefficient |
| i      | Node (site)                  | c_{ij}^s | Split the transportation cost coefficient |
| n      | The total number of nodes    | Q      | Aggregate demand for goods   |
| q_{ij} | The amount of goods transported between node i and node j |

The symbols used in the multimodal transportation problem model are listed in Table 1. Type (1) is the objective function of the model, the objective function consists of three parts, the first part of the path cost, the cost of producing the goods in transit, the second section show that the cost of transportation, namely in the nodes of transshipment cost, the third part of said split cost, namely the goods by the third party logistics providers of transportation cost. Formula (2) represents node load constraint; Formula (3) indicates that if the goods must leave the station if they enter the station at a node other than the starting point or the ending point, that is, the entry degree is equal to the exit degree; Formula (4) indicates that the station must exit when it is determined; Equation (5) represents the elimination of constraints in the path loop, and represents that the loop is not allowed to exist in the process of cargo transportation; Formula (6) represents the constraint of transportation capacity.

3. Ant colony algorithm and algorithm description

3.1. Ant colony algorithm
Ant Colony Optimization (ACO) is a heuristic algorithm abstract by Italian scholar Dorigo et al. according to the foraging behavior of Ant Colony, which is widely used in combinatorial Optimization. It is simply described as follows: during the foraging process of ant population, pheromones are left on the search path, and the path with higher pheromone concentration is more likely to be selected. Pheromone concentration volatilizes with time, and ants on shorter paths can complete more cycles, so higher pheromone concentration prompts more ants to choose this path, which is positive and negative feed mechanism is the core of ant colony optimization. Ant colony algorithm itself has good robustness, which guarantees the feasibility of understanding the solution in space in the generation stage of the solution.

In ant colony algorithm, the selection of the next node is probabilistic selection, which involves the probability transfer formula.

If the collection \( J(i) \neq \emptyset \) to be accessed for node \( I \), So the probability of node \( I \) going to the next node \( j \) is \( p_{ij}^{k} = \frac{\tau_{ij}^{k} \eta_{ij}^{k}}{\sum_{j \in J(i)} \tau_{ij}^{k} \eta_{ij}^{k}} \) (7)

In formula (7), the pheromone intensity of the path from \( i \) to \( j \) is denoted by \( \tau_{ij} \). Also known as the track intensity of path \((i,j)\), the initial value is generally set to 1. When the ant completes \( t+1 \) cycle, the track intensity changes to \( \tau_{ij}(t + 1) = \rho \tau_{ij}(t) + \Delta \tau_{ij}(t) \). \( \rho \) donates the pheromone hair coefficient.
\( \tau_{ij}(t) \) represents the amount of pheromones added in \( t \) sub-cycles. \( \eta_{ij} \) is illuminating information, which represents the path visibility of path \((i,j)\). \( \eta_{ij} = \frac{1}{d_{ij}} \). \( \alpha, \beta \) mean weight.

3.2. Introduction of virtual nodes

The objective function of multimodal transportation problem is divided into path cost, transfer cost and split cost. The concept of virtual node is introduced in the calculation of transportation cost and split cost.

In the calculation of switching costs, if there are \( l(l \geq 2) \) modes of transportation for point \( J \) in the decision point \( I \) and the feasible set \( J(i) \), then \( j \) can be virtualized into \( l \) nodes and encoded as \( j_1, j_2, \cdots, j_l \).

In the process of split cost calculation, if stay decision points \( i \) and \( j \) in the feasible set \( J(i) \) there are \( l'(l' \leq l) \) mode of transportation, and in \( a \) or \( l'(l' \leq l) \) in the process of the mode of transportation of the need to split a transportation, you can in this kind of or \( l'(l' \leq l) \) virtual into a mode of transportation of the transportation process and coding as \( j_{l+1}, j_{l+2}, \cdots, j_{l+l'} \).

The distance between the virtual node \( j_{in} \) and its corresponding original node \( j \) is 0, and the number of original nodes does not change. By introducing virtual nodes, the choice of transportation mode at nodes and the choice of splitting transportation between nodes are transformed into the choice of transportation path. While simplifying the problem, the multimode transportation problem and ant colony algorithm can be better integrated.

In order to more vividly and concretely express the definition of virtual node, we respectively describe the traditional transportation problem, multimodal transportation problem and multimodal transportation problem with illustrations. Four nodes are used in the legend.

In traditional transportation problems, a single mode of transportation is often adopted, starting from the starting point and passing through several nodes to reach the destination.

![Figure 2. Traditional transportation problems.](image)

In Figure 2, A, B, C and D represent four nodes. There is only one mode of transportation between A and B, B and C, and C and D.

In the problem of multimodal transportation, two or more modes of transportation can be adopted between two nodes. We introduce virtual nodes to represent the choice of modes of transportation.

![Figure 3. Multimodal transportation problem.](image)

In Figure 3, there are two modes of transportation between node A and node B, node B and node C, and node C and node D. Where \( B_1, B_2, C_1, C_2, C_3, D_1, D_2, D_3 \) represent virtual nodes, corresponding to the first type in the concept of virtual nodes.
Figure 4. Multimode transportation problem introducing virtual nodes.

Compared with the intermodal transportation problem in Figure 3, C₄ and D₄ are two more points in the multimode transportation problem in Figure 4. C₄, D₄ represents the virtual node, corresponding to the second type in the concept of virtual node, C₄ represents that B node and C node can be split in the first mode of transportation, and D₄ represents that C node and D node can be split in the third mode of transportation.

From the comparison between Figure 1, Figure 2 and Figure 3, we can intuitively see that the model of multimode transportation problem is more complex than the traditional transportation problem and intermodal transportation problem. With the introduction of virtual nodes, both the choice of transportation mode and the split transportation problem are transformed into the path selection problem, which simplifies the problem in difficulty.

3.3. Algorithm description

Step 1. Input the node parameters, initialize the distance matrix, calculate the polar coordinates of other logistics nodes from the starting point and arrange them according to polar coordinates and polar diameter ascending power, set the maximum iteration times $H_{max}$, population size $M$ and decision times $P$ of the algorithm, and set $h=1$, $M=1$ and $P=1$.

Step 2. Initialize Tabu(m) set, determine the visited set visited(m) and unvisited set unvisited(m) according to Tabu(m) set, and add the starting point 0 to the visited set visited(m).

Step 3. Without access to a collection of unvisited(m)$\neq \emptyset$, in step5. Otherwise, in unvisited (m) in the first node I to be decision point, traverse the unvisited (m), get to decision node I to node j feasible set of $J(i)$. if $J(i) = \emptyset$, in Tabu (m) to add i , visited (m) add i, unvisited removes the $J(m)$ and $p=p+1$, turn to step 3. Otherwise, the $J(i) \neq \emptyset$, then into step4.

Step 4. Randomly generate the next node j to be decided according to the probability transfer formula, and add node j in Tabu(m). If $j < n$, make $i = j$, repeat step 3. Otherwise, $j = n$, visited (m) = $\emptyset$, into step5.

Step 5. $m=m+1$, if $m<M+1$, then step2. Otherwise, step6.

Step 6. If $h< H_{max}$ that is, the number of iterations is not reached, then update pheromone according to the travel path of cyclic ant colony $h$, then $h=h+1$, and transfer to step2; If $h$ is greater than or equal to $H_{max}$, the optimal result of the last loop is output.

4. Simulation experiment and result analysis

4.1. Numerical example

Suppose there is a batch of goods from the node 0 to 9(Figure 5), eight pass transportation nodes can be chosen. The path between transportation nodes can be chosen is specified. The whole process of the transport process has railway, highway and waterway three kinds of transportation modes to choose. The transportation mode of each path which can be chosen is known. Whether in the process of transportation can be split and split costs are known else. It is required to choose a more appropriate
route and mode of transportation, and confirm whether to split the transportation, with the minimum economic cost, the goods from the beginning to the end of the transportation.

Figure 5. Multimodal transportation problem composed of 9 nodes.

Table 2. Cost data during transportation.

| the path   | railway | highway | waterway |
|-----------|---------|---------|----------|
| (0, 1)    | 2       | 0       | 0.78     |
| (1, 2)    | 20      | 28      | 0.78     |
| (1, 4)    | 76/54   | 110     | 0.78     |
| (1, 6)    | 40      | 51/37   | 0.78     |
| (2, 3)    | 13      | 18/12   | 0.55     |
| (3, 4)    | 71      | 80      | 2.5      |
| (4, 5)    |         |         | 105      |
| (4, 7)    |         |         | 151      |
| (5, 8)    | 562     | 901/693 | 99       |
| (6, 5)    |         |         | 117      |
| (6, 7)    |         |         |          |
| (7, 8)    | 227     | 343/283 | 14       |
| (8, 9)    |         |         |          |

Note: / represents the cost of split transportation of this mode of transportation.

Table 3. Transportation costs.

| the path   | railway | highway | waterway |
|-----------|---------|---------|----------|
| railway   | 0       | 2.4     | 5.4      |
| highway   | 2.4     | 0       | 3.4      |
| waterway  | 5.4     | 3.4     | 0        |

4.2. Result analysis

Ant colony algorithm program developed on MATLAB to solve the problem (Table 2, Table 3), parameter $M=30, \alpha = 1, \beta = 1, \rho = 0.1, H_{C_{max}} = 200$, get the optimal transportation scheme: 0 to 1 choose the highway, 1 to 4 choose the railway and split transportation, 4 to 7 choose waterways, 7 to 8 choose the railway, 8 to 9 choose the highway, the total cost of transportation is 408.2 yuan. If this
model is an intermodal transportation problem, there is no split transportation. Ant colony algorithm is still used to solve it. With the same parameter setting, the optimal transportation scheme is obtained as follows: 0 to 1 choose the highway, 1 to 6 choose the railway, 6 to 7 choose the waterway, 7 to 8 choose the railway, 8 to 9 choose the highway, and the total transportation cost is 415.6 yuan.

On the cost, we can see that multimodal transportation is less cost than intermodal transportation in the same model from the result. And the former is more in line with actual needs than the latter.

5. Conclusions
Multimodal transportation is a problem of comprehensive transportation path planning, combining multiple transportation modes and introducing third-party logistics, which is more in line with the needs of the current transportation environment. By introducing the concept of virtual node, this paper effectively reduces the difficulty of combining multimode transportation problem with ant colony algorithm. Ant colony optimization algorithm has good robustness and avoids the problem of multimode transportation path optimization falling into local optimal solution by probability selection. At the same time, in practical problems, customer service time, reliability of split transportation, node flow control and other factors can be added. These problems can be further considered in future studies.
[15] Juman Z M S and Hoque M 2014 A heuristic solution technique to attain the minimal total cost bounds of transportationing a homogeneous product wit varying demands and supplies European journal of operational research pp 146-156.

[16] Kaur and Kumar 2012 A new approach for solving fuzzy transportation problems using generalized transportational fuzzy numbers Applied Soft Computing pp 1201-03

[17] Wang Y J 2014 Study on intermodal transportation mode and path optimization Beijing Jiaotong university: School of transportation

[18] Tong L, Nie L and Fu H L 2010 Study on the optimization model and method of multimodal transportation path Logistics technology p 57

[19] Liu Y Q and Xu S D 2010 Considering the feasibility of the route and the research on the route of the recycling vehicle in the warehousing mode Chinese journal of management science pp 98-107