Application and Analysis of Logistics Distribution Routing Based on Ant Colony Algorithm

Dewen Seng¹,², Qunxiao Wang¹,², Xujian Fang¹, Xuefeng Zhang¹

¹School of Computer Science and Technology, Hangzhou Dianzi University, Hangzhou, China;
²Key Laboratory of Complex Systems Modeling and Simulation, Ministry of Education, Hangzhou, China

Abstract

Intelligent Transportation System (ITS) is a means to realize the green transportation system's technical support. Vehicle routing optimization is the most important content in intelligent transportation, and plays a very important role in the logistics industry. This paper will optimize the routing problem of the vehicle by changing the distribution path of the logistics, improving the distribution efficiency of the logistics distribution, and combining the ant colony algorithm. Secondly, the basic theory and method of ant colony calculation are discussed. The feasibility of the improved ant colony algorithm in solving the problem of logistics distribution optimization is proved. The conception of solving the problems is put forward by using ant colony algorithm.

Key words: intelligent transportation system, logistics distribution, vehicle routing optimization, ant colony algorithm

1. INTRODUCTION

1.1 Background and Significance of Research

With the development of science and technology and social progress, the pace of national production and people's life has become faster and faster, all walks of life are increasingly the pursuit of higher efficiency, so the development of transportation is essential. As a major carrier of economic activities, transportation plays a very important role in various industries in different regions. Sustained economic development and improvement of living standards all need to be supported by efficient transportation. As the demand for transportation efficiency is increasing, the number of vehicles is increasing. Therefore, a series of problems such as road congestion, traffic congestion, environmental pollution and traffic accidents are becoming more and more prominent. An efficient logistics distribution path optimization problem needs to be solved urgently(Yang, 2014).

In the United States, suburbanization of population and economic activity makes people more dependent on private cars. Therefore, the road traffic flow increases ceaselessly, which aggravated the traffic crowded condition, and the traffic accident frequently occurs. Texas Transportation Research Institute do a survey base on the United States 39 major cities, estimated annual traffic congestion caused by the economic losses of about 41 billion US dollars, 12 largest cities each year the loss of more than 1 billion US dollars. It is predicted that by 2020, the economic losses caused by accidents will exceed 150 billion US dollars annually.In China, due to the rapid increase in the number of motor vehicles, traffic congestion problems in various cities have emerged. Traffic congestion is not only a waste of time, it is affecting the economic development. Thus, to solve the problem of traffic congestion has become an urgent need to solve the world's problems(Zhao et al., 2014).

At present, there are so many problems of the intelligent transportation need to solve urgently, we can put these types of problems as shown below in the figure 1:
The core of these problems is the path optimization problem. Vehicle routing optimization is the main content of ITS, which occupies a very important position in the logistics industry. With the rapid development of information technology, e-commerce under the logistics and distribution with high efficiency, versatility, high frequency characteristics, as people pay more and more attention to the logistics industry, it has developed into an important part of the current competitive field (Piancastelli et al., 2013).

Logistics distribution is an activity, which depends on user’s order requirements, distribution goods from the distribution centers and delivery the goods to the receivers timely (Hu and Wang, 2016). Logistics is directly related to the interests of consumers, affecting consumer satisfaction with the enterprise, which has an indirect impact to the competitiveness of the market. According to incomplete statistics, the annual expenditure of the US logistics industry accounts for about 10% of the GDP, Japan's logistics industry as a result of the development of economic benefits of economic growth accounted for about 1% of the total, while China's annual total logistics costs Accounting for about 20% of the total GDP (Zhuang and Tang, 2004).

1.2 Research Status of Vehicle Routing Problem

Vehicle Routing Problem (VRP) was first proposed by G. Danting and J. Ramser in 1959. Nowadays, the research on vehicle routing problem is very active. Since VRP was proposed in the 1960s, Savelsbergh (1985) proved that VRP is an NP-complete problem in 1985, which attracts more and more scholars to study it. In 2002, Toth and Vigo (2002) introduced the Capacitated Vehicle Routing Problem (CVRP) problem and its corresponding solving algorithm as well as its application in real life. Goldenet al., (2008) proposed a variety of models and algorithms for solving large-scale problems in 2008, and optimized it. Compared with foreign scholars on the VRP research, domestic scholars to its research started relatively late. Cai et al., (1998) etc, have solved full load vehicle routing problem by using simulated annealing algorithm and genetic algorithm. Li et al., (1999) etc, based on the nearest distance TSP heuristic and solved the simple VRP problem. Jiang et al., (1999) etc, using genetic algorithm to solve the no time window constraints under the vehicle routing problem, and obtained approximate solution at a faster speed.

After years of research, although the VRP has made some achievements, but with the expansion of the scale of the problem and the complexity is increased, at present, the study of large-scale vehicle routing problem is still not enough. Therefore, it is necessary to propose an easy-to-implement traditional algorithm, to solve the practical problems of large-scale logistics and distribution. Intelligent optimization algorithm is used to solve the problem of VRP, which makes the logistics distribution scientific and standardized, which is of great significance to logistics and transportation industry (Gao et al., 2016).

2. RESEARCH ON LOGISTICS DISTRIBUTION ROUTING PROBLEM

2.1 Research on Logistics Distribution Path

The problem of logistics distribution path optimization was first proposed in 1959, which has soon attracted great attention from the experts in the fields of operations research, applied mathematics, combinatorial mathematics,
graph theory and network analysis, logistics science, computer application and transport plan makers and managers. Which has become a frontier and research hotspot in operational research and combinatorial optimization (Chen et al., 2015).

Miller and Gillet (1974) proposed Sweep Method, the purpose is to solve the problem of vehicle scheduling. Barbarosoglu and Ozgur (1999) using a Tabu Search Method to Build a Train Order Decision Method DETABA for a Logistics Company in Turkey. Su & Chen (Su and Chen, 1999) successfully applied the self-organizing mapping network to solve the problem of vehicle distribution area and route planning.

With the introduction and continuous development of artificial intelligence technology, new methods such as simulated annealing algorithm and genetic algorithm, as well as new technologies such as artificial neural network and expert system, provide a new means to solve large-scale, multi-objective vehicle scheduling problem.

2.1 Description of Logistics Distribution Problem

General logistics distribution path problem is described as follows:

A logistics company has N customer points and M transport trucks, requiring each vehicle return to the distribution center with the shortest path after complete the distribution task. Based on the above description, the problem is generally has the following constraints:

1) The demand for each customer point is certain and known, and the sum of the total customer demand on each line does not exceed the vehicle load.

2) The distance from the customer point to the distribution center, and the distance between the customer points are known, and the one-time delivery does not exceed the longest distance traveled by the truck.

3) Customers uniform distributed in the distribution area, the demand for each customer point can only be served by a car, and each car can only serve a route.

4) The final purpose is to find an optimal distribution path, so that the minimum distance and total cost.

Figure 2 is an example of a simple logistics distribution route that includes a distribution center, five customer sites, and three distribution routes. Vehicles are starting from the logistics center, in order traverse the designated path of all customer points, complete the distribution, and finally return to the logistics center. As shown, distribution route 1 is responsible for the three customer points on the right, and distribution routes 2 and 3 are responsible for the top left and bottom left customer points, respectively.

Figure 2. A simple logistics distribution route

3. ANT COLONY ALGORITHM

3.1 Ant colony algorithm principle
Ant colony algorithm is a population-based simulation evolutionary algorithm, which has the characteristics of random search, global optimization, positive feedback and distributed, and has strong robustness (Chen, 2016). It was first used to solve the TSP problems (Costa et al., 2012), like other simulated evolutionary algorithms, the ant colony algorithm evolves through the population of feasible solutions and approaches, even reaches the optimal solution of the problem with the maximum probability. The process consists of two basic stages: the adaptation phase and the cooperation phase.

Ants are basically nothing visual, but the ant colony can easily find the shortest distance between the thing and the nest. It was found that the ants can secrete a biological information medium such as pheromone on their crawling path during the foraging process (Colorni et al., 1991). Ants can sense the existence and intensity of pheromones in the process of movement, and guide their movement direction, so that ants are more likely to move to the path of high pheromone intensity. The path search principle and mechanism of the ant colony are shown as Figure 3:

**Figure 3. Symmetric double bridge experiment**

**Figure 4. Non-double-bridge experiment**

Figure a is a double bridge, in the initial stage after a brief shock, ants tend to the same path, in the experiment, the vast majority of ants chose the A path.

In this non-double-bridge experiment, the ants began to be divided into upper and lower paths due to obstructions. The path above is longer than the path below. We assume that all ants run at the same speed, then the number of ants passing through the underlying path per unit time is, in terms of probability, much larger than the number of ants passing from above. Because the pheromone is generated during the movement of the ants, we assume that the pheromone produced by each ant is constant, then the pheromone concentration of the lower path is obviously larger than that of the upper path. With the increase of time, this difference is increasing, and the ants are transmitted through the pheromone information, so more and more ants because the pheromone concentration, will choose from the lower path through, until the vast majority of the last of the ants are from the lower road through.

**Figure 5. Ant colony algorithm experiment**
In addition, in the experiment shown in Fig 5, according to the above principle analysis, because the path from the food to the nest, over C point is shorter than over D point, so after a period of time, more ants will choose over C point path.

Ant colony algorithm can be used to solve various combinatorial optimization problems, especially for multi-point non-deterministic search in the solution space of discrete optimization problems. And ant colony algorithm prototype is a model to find the shortest path, so he has a natural advantage in the path optimization problem. At present, the ant colony algorithm has been successfully applied to the TSP problem, to solve the ATM network routing problem and telephone network routing problem (Li et al., 2000).

3.2 Ant colony algorithm model

As the ant colony algorithm was first proposed with the TSP problem model, therefore, we take the TSP problem of n cities as an example to illustrate the ant colony system model.

First define the following symbols:

\( m \): The total number of ants in the ant colony

\( d_{ij} \): Distance from city \( i \) to city \( j \)

\( \tau_{ij}(t) \): The amount of information remaining at time \( t \). When \( t = 0 \), the amount of information on each path is equal, and let \( \tau_{ij}(0) = C \) (\( C = \text{Const} \))

Ants determine the direction of the transfer based on the amount of information on each path. The probability of ants moving from city to city is:

\[
P_{ij}(t) = \frac{\tau_{ij}(t)^\alpha \cdot [\eta_{ij}]^\beta}{\sum_{k \in \text{allowed}_k} \tau_{ik}(t)^\alpha \cdot [\eta_{ik}]^\beta}, \quad \text{otherwise}, \quad P_{ij}(t) = 0.
\]

Because we use the artificial ants, artificial ants have a certain memory function, and the real ant colony system is different. In order to prevent ants from repeatedly visiting a city, each ant has its corresponding list \( \text{Tabu}(k) \) when visiting the city, and records the set of customer points it has visited, and it updates with the searching path of ants at any time. \( \text{allowed}_k = \{0, 1, \ldots, n-1\} \). \( \text{Tabu} \) represents the set of cities that the ant \( k \) is allowed to access next. In order to prevent the residual pheromone too much and cover the role of heuristic information, so each ant walks one step or a loop traversal after the end of the path, the residual pheromones on the path will be updated. This update mimics the characteristics of human memory, as new pheromones are deposited into the brain, the old pheromones stored in the brain are gradually faded with the passage of time or even forgotten (Ye and Zheng, 2004). The update rules are as follows:

\[
\tau_{ij}(t+n) = \rho \cdot \tau_{ij}(t) + \Delta \tau_{ij}(1)
\]

\[
\Delta \tau_{ij} = \sum_{m=1}^{M} \Delta \tau_{ij}^k
\]

Where \( \tau_{ij}(t+n) \) is the pheromone remaining after elapsed time \( t \), \( \rho \) is the pheromone volatilization rate, and \( \Delta \tau_{ij} \) is the pheromone increment from city \( i \) to city \( j \), and this increment is the sum of all pheromone \( (i, j) \) of the ant’s pheromone.
According to the pheromone update strategy, there are three different ant colony algorithm models: ant-quantity model, ant-density model, ant-cycle model.

1) ant-quantity model

If the variable \((i, j)\) is on the path of the ant \(k\), \(\Delta \tau^k_{ij}(t, t + n) = \frac{Q}{d_{ij}}\), otherwise, \(\Delta \tau^k_{ij}(t, t + n) = 0\). Where \(Q\) is a constant, indicating that the increment of the pheromone is related to the distance \((i, j)\).

2) ant-density model

If the variable \((i, j)\) is on the path of the ant \(k\), \(\Delta \tau^k_{ij}(t, t + n) = Q\), otherwise, \(\Delta \tau^k_{ij}(t, t + n) = 0\). Where \(Q\) is a constant, indicating that the increment of the pheromone is independent of the distance \((i, j)\).

3) ant-cycle model

If the variable \((i, j)\) is on the path of the ant \(k\), \(\Delta \tau^k_{ij}(t, t + n) = \frac{Q^3}{L}\), otherwise, \(\Delta \tau^k_{ij}(t, t + n) = 0\). Where \(Q\) is a constant, \(L\) represents the loop length of the \(k\)th ant, indicating that the increment of pheromone is related to the \(Q\) and the length \(L\) of circular route.

The ant-quantity model, the ant-density model uses local information, that is, the pheromone on the path will be updated after ants to complete one step (from one city to another city). The ant-cycle model uses the overall information, that the pheromone on all paths will be updated until the ant completes a loop or completing a path (after completing all city visits). Therefore, the ant-cycle model is usually used as the basic model of the ant colony algorithm solving the TSP problem, and the result is better.

In summary, the parameters of ant colony algorithm: the selection method and selection principle of the pheromone volatile coefficient \(\rho\), the information heuristic factor \(\alpha\), the excepted heuristic factor \(\beta\), the pheromone intensity \(Q\) and the selection method and the ant number \(m\) will directly affect Global Convergence and Solution Efficiency of Ant Colony Algorithm. The value of \(\alpha\) indicates the degree to which the pheromone left on each node is valued. The greater the value \(\alpha\), the more likely it is that the ant will select the previously traversed path. The size of \(\beta\) indicates the extent to which heuristic factors are valued, and the greater the \(\beta\), the greater the likelihood that ants will choose their nearest city. \(P\) represents the degree of information retention. So we have to make the appropriate choice of the above parameters.

4. ANTI COLONY ALGORITHM FOR LOGISTICS DISTRIBUTION PATH OPTIMIZATION

4.1 Ant colony algorithm is used to deal with the feasibility of logistics distribution path optimization

Ant colony algorithm prototype itself is a shortest path to find the model, so it has a natural advantage in path optimization, there are many ant colony algorithm in TSP problem in the successful use of the example. There are common points between the logistics distribution path optimization problem and the TSP problem: traversal all client points to find the shortest path. But there are some differences: the logistics distribution path optimization problems have more complex constraints and optimization goals.

Ant colony algorithm is a kind of positive feedback algorithm. It is not difficult to see that the ants can find the shortest path directly, which directly depends on the accumulation of information hormone in the shortest path, and the accumulation of information hormone is a positive feedback process. For the ant colony algorithm, there are exactly the same information hormones in the environment at the initial time, giving the system a slight perturbation, so that the trajectory concentration of each edge is not the same, the ant solution has advantages. The feedback method adopted by the algorithm is to leave more information hormones in the better solution path, and more information hormones attract more ants. This positive feedback process makes the initial difference be enlarged constantly, at the same time guide the whole system to the optimal solution direction evolution.
Therefore, the positive feedback is an important feature of the ant algorithm, which makes the algorithm evolution process can be carried out.

Through the second chapter of the logistics distribution problem description and the third chapter of the ant colony algorithm basic analysis, we can conclude that the use of ant colony algorithm, is better able to deal with the logistics distribution path optimization problem.

4.2 Ant colony algorithm used to deal with the general flow of distribution path

The general flow chart based on the classical ant colony algorithm to deal with the logistics distribution path is as Fig 6:

![Figure 6. Classical ant colony algorithm flow chart](image)

1) The ant colony and the path initialization, m ants are placed in the logistics distribution center, the pheromone on all paths is 0.
2) The number of cycles plus 1, ant k to access the customer point.
3) Calculate the corresponding path access probability, the ant k according to the calculated p to determine the next visit to a customer point.
4) Add the visited customer points to the Tabu list and update the Tabu list.
5) Compare whether all ants have traversed all customer points, and if they have visited all the customers, update the pheromone on the path, otherwise, send another ant to traverse.
6) If there is an ant to find the final customer point, then calculate the current ant path and, and update the current shortest path has been found.
7) If the maximum number of cycles is reached, the Tabu is cleared. Otherwise, the shortest path length is output.

4.3 The Ant Colony Algorithm Based on the Concept of Logistics Distribution Path

Ant colony algorithm is a kind of positive feedback algorithm. It is not difficult to see that the ants can find the shortest path directly, which directly depends on the accumulation of information hormone in the shortest path, and the accumulation of information hormone is a positive feedback process. Therefore, we will solve the problem of logistics allocation according to ant colony algorithm:

1) Modify its algorithm factor, get the optimal solution

Ant colony algorithm cannot guarantee that the shortest path can be obtained. But by modifying the algorithm factor, we can get the optimal approximate solution. It can also be processed several times, and the minimum value which is the optimal solution, is obtained from a set of optimal approximate solutions.
2) Establish multiple constraints

In reality, the problem of logistics distribution path optimization is larger and more complex. The establishment of practical and feasible constraints, in order to closer to the reality of the logistics distribution path, so as to solve the problem.

5. CONCLUSIONS

In today's world, with the rapid development of information technology, logistics and distribution has become another major factor affecting economic development in the context of electricity providers. Traditional manual route selection is entirely dependent on the experience and wisdom of workers, not only cost a lot of time and experience, and as business continues to expand, more and more complex distribution routes, the traditional manual distribution routes too difficult to meet the business needs of the enterprise. So with the computer arrangement of logistics and distribution routes are bound to get. Ant colony algorithm is mainly used to solve the path optimization problem of complex business. As a typical combinatorial optimization problem, the logistics distribution routing problem is a NP-complete problem. Combining the ant colony algorithm with the logistics distribution, the calculated line arrangement not only has the characteristics of fast speed and high efficiency, but also can effectively reduce the production cost of the enterprise. In this paper, the classical ant colony algorithm is combined with the logistic distribution path, and it is easy to fall into the local optimal solution. In the ant colony algorithm, the ant colony movement always tends to the strongest pheromone path. The ant colony algorithm itself has some shortcomings, it needs further research and improvement, the final results of the practice also need to be further verified.

ACKNOWLEDGMENTS

This work is supported by the National Natural Science Foundation of China (No. 61473108), the Public Projects of Zhejiang Province (No. 2013C33082), Zhejiang Provincial Natural Science Foundation (No. LY15F020038 and No. LQ13F020005) and the research foundation of the Education Department of Zhejiang Province (No. Y201430884).

REFERENCES


