CHEMICAL ENGINEERING TRANSACTIONS

VOL. 62, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Fei Song, Haibo Wang, Fang He

ISBN 978-88-95608- 60-0; **ISSN** 2283-9216

DOI: 10.3303/CET1762230

Research on Hazardous Chemical Road Transportation Route Optimization Based on the New Ant Colony Algorithm

Duan Zheng

Xi'an International University, Xi'an 710077, China

zhengduan@xaiu.edu.cn

With the acceleration of industrialization in China, the output and transportation volume of hazardous chemical have increased dramatically. On the one hand, chemical has injected new vitality into the social and economic development. On the other hand, the safety of hazardous chemical has also been highlighted. According to statistics, hazardous chemical accidents in transportation links accounted for 35% of hazardous chemical accidents. Hazardous chemical transportation accident belongs to the low probability and serious consequence event. Once hazardous chemical accident occurs, it will cause great losses to people's lives, property and ecological environment. The hazardous chemical road transportation security question becomes the question which the people pay close attention to. In order to reduce hazardous chemical transportation accidents, we study the hazardous chemical transportation route optimization. In this paper, we propose an improved ant colony algorithm. The improved ant colony algorithm not only considers the transportation time and transportation risk, but also improves its algorithm settings. The improved algorithm is more suitable for optimizing the path of hazardous chemical. The experiments in this paper also verify the effectiveness and reliability of the improved algorithm.

1. Introduction

Road transportation of hazardous chemical is an important link in the circulation of hazardous chemical. For China, hazardous chemical plays an important role in the national economy. Usually, hazardous chemical includes explosive materials, poisonous gas, Inflammable, corrosive chemical and radioactive material and so on. There are more than 30 thousand kinds of hazardous chemicals and they are increasing constantly.

In the process of hazardous chemical road transport, the container carrying flammable, explosive and toxic materials may be broken due to equipment defects, collision and other reasons. If a large number of flammable, explosive, toxic chemicals leak, this will cause fire, explosion, poisoning and other major accidents. The biggest difference between the hazardous chemical road transportation and other materials road transportation is that leakage accidents will exit the huge potential risk during hazardous chemical road transportation. The possibility or probability of hazardous chemical transportation accidents is very small. But this kind of accident is extremely hazardous and destructive. The leaked chemicals will cause injury or death to animals, plants and humans and will cause great harm to the environment and human health

On the basis of GIS technology, some scholars have proposed using GIS information platform to calculate the spatial distribution of transportation risk of hazardous chemical in plane (Bubbico et al., 2004). Some scholars think that the influence scope of road transportation risk is the two dimension structure in the plane. It points out that personal risk is related to the vertical distance of the accident place (Erkut and Ingolfsson, 2003; Erkut and Ingolfsson, 2005). In addition, scholars have established a transportation network of hazardous chemical on the basis of population density and distribution, and obtained optimal routes by using integer programming (Erkut and Osman, 2007). Vehicle distribution plan and route selection have important influence on hazardous chemical road transportation. Heuristic algorithm can solve the problem of the double target vehicle delivery (Konstantinos et al., 2004). Transportation time is an important parameter for model establishment. When the model is built, the departure time and arrival time of the transportation vehicle should be considered. The delivery cost and transportation risk depend on time (Konstantinos et al., 2010).

Please cite this article as: Duan Zheng, 2017, Research on hazardous chemical road transportation route optimization based on the new ant colony algorithm, Chemical Engineering Transactions, 62, 1375-1380 DOI:10.3303/CET1762230

Ant colony optimization (ACO) is a swarm intelligence optimization method based on the biological behavior of the ant colony foraging along the shortest path (Ye et al., 2017). The emergence of the algorithm is that scholars are inspired by the self-organization behavior of social animals (such as ants, bees, birds, etc.). Biologists have studied carefully and found that ants communicate indirectly with a substance called pheromones to find the shortest path (Mahato et al., 2017). Inspired by this, Italian scholars Maniezzo and Colorni proposed a simulated evolutionary algorithm based on population by simulating ant colony foraging behavior (Sitarz et al., 2016). The algorithm has attracted great attention of scholars. In the past more than 10 years, it has been widely used in the field of combinatorial optimization, network routing, function optimization, data mining and robot path planning. All achieved good results (Skinderowicz, 2016; Chen and An, 2016).
In this paper, in order to study the route optimization problem of hazardous chemical, we propose an improved ant colony algorithm. The algorithm considers the risk of road transportation and improves the transfer probability and pheromone update equation. The first part of this article is the introduction. The research background of transportation and hazardous chemical road transportation are introduced. The second part introduces the ant colony algorithm combined with the TSP problem. The third part puts forward the improved ant colony algorithm. The fourth part is experiment and the fifth part is conclusion.

2. Accident characteristics of hazardous chemical road transportation

In the process of the hazardous chemical road transportation, various factors may lead to the accidents due to the adverse changes of hazardous chemical, driver, vehicle, roads and climate and environment. Accidents are usually caused by one factor or the interaction of some factors in the above mentioned factors.
The causes of hazardous chemical road transportation can be divided into hazardous chemical accidents caused by road traffic accidents and the one caused by non-road traffic accidents. The non-road traffic accidents are divided into hazardous chemical accidents caused by vehicle and equipment, by environmental factors, by management failure and by failure of personnel.
The general road traffic accident has characteristics of sudden, uncertainty and sociality. Besides, the hazardous chemical road transportation accident has the following characteristics.
Unpredictable. Hazardous chemical transport vehicle is a hazardous source of flow. The time and place of the accident are uncertain. Different types of hazardous chemical also lead to unpredictable consequences of accidents. The nature of hazardous chemical has a great impact on accidents
Serious loss. Because of the dangerous nature of hazardous chemical, hazardous chemical road transportation accidents cause more heavy casualties and property losses than ordinary goods transportation
Rescue difficulty. Hazardous chemical transportation is affected by the surrounding environment and other factors. The time and place of the accident are uncertain and the types of accidents are also different.

3. Ant colony algorithm

Generally speaking, the ant colony algorithm is described in the background of travelling salesman problem (TSP). The travelling salesman problem can be stated as follows. A travelling salesman goes through *n* cities and returns to the original starting point. Every city must be allowed only once. The goal of TSP is to find the shortest route between all the cities. The distance between the city *r* and the city *s* is d_{rs}. When $d_{rs}\neq d_{sr}$, it is the symmetric travelling salesman problem. When $d_{rs}\neq d_{sr}$, it is the asymmetric travelling salesman problem.
Ant system is earliest proposed by Dorigo and it is the most basic ant colony algorithm. The algorithm can be described as follows. *m* ants are placed on a fully connected graph with *n* nodes at random. $\tau_{ij}(t)$ is the pheromone quantity on the line *ij* at the time *t*. $\eta_{ij}(t)$ is the heuristic information and we set $\eta_{ij}(t)=1/d_{ij}$. At the initial time, the information on each path is equal and $\tau_{ij}(0)=C$, *C* as constant. In the course of movement, ant k(k=1, 2,…, m) determines the direction of transfer according to the pheromone quantity and the heuristic information. $p_{ij}^{k}(t)$ is the probability that the ant *k* will be shifted from position *i* to position *j* at the time *t*.

$$p_{ij}^{k}(t)=\begin{cases}\dfrac{[\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}(t)]^{\beta}}{\sum\limits_{s\notin tabu_k}[\tau_{is}(t)]^{\alpha}\cdot[\eta_{is}(t)]^{\beta}}, if & j\notin tabu_k \\ 0, & otherwise\end{cases} \quad (1)$$

$tabu_k$ records the cities that have been traversed. α is the important parameter of τ and β is the of relative importance parameter of η.
After time *n*, the ant completes a tour. The pheromone quantity on each path should be adjusted according to the following

$$\tau_{ij}(t+n) = (1-\rho)\tau_{ij}(t) + \Delta\tau_{ij}(t+n) \tag{2}$$

$$\Delta\tau_{ij}(t+n) = \sum_{k=1}^{m} \Delta\tau_{ij}^{k}(t+n) \tag{3}$$

ρ⊂(0, 1) is the volatilization coefficient of pheromone. $\Delta\tau_{ij}^{k}$ is the pheromone quantity that the ant *k* left on the path (*i*, *j*) at this cycle. $\Delta\tau_{ij}$ is the pheromone quantity that all the ants left on the path (*i*, *j*) at this cycle. $\Delta\tau_{ij}^{k}$ is

$$\Delta\tau_{ij}^{k}(t+n) = \begin{cases} \dfrac{Q}{L_k}, ant\ k\ on\ path\ (i,\ j) \\ 0, otherwise \end{cases} \tag{4}$$

Q is a constant. L_k is the path length of the ant *k* traversal.

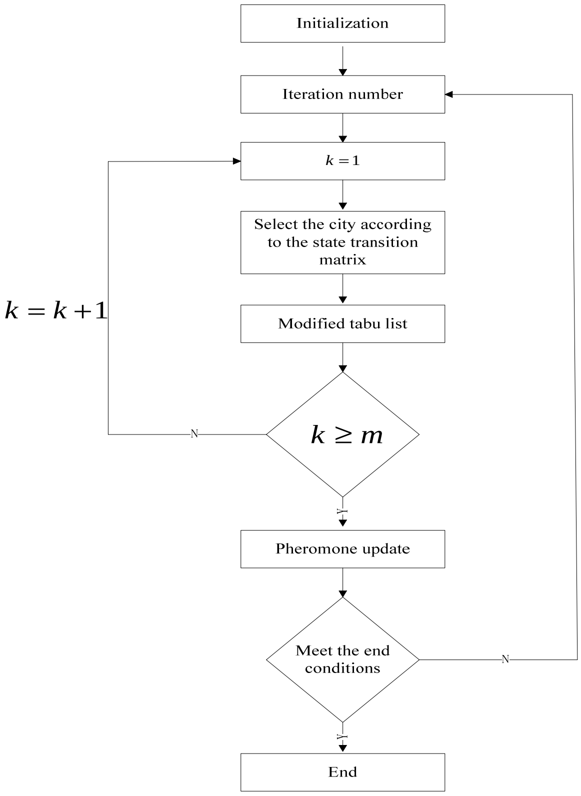

Figure 1: Structure of Ant colony algorithm

4. Improved ant colony algorithm

Many factors should be taken into consideration in the hazardous chemical transportation. The purpose of route optimization is to reduce the transportation path and transportation time of hazardous chemical. At the same time, the transport of hazardous chemical is a moving unsafe point. Therefore, we should also take into account the risk of hazardous chemical route transportation.

G(*N*, *A*) is a transport network. *N* is the set of nodes in the network. The node may be the intersection of roads, important facilities, location or population centre. 0 is the starting point. We assume that a hazardous chemical transport vehicle needs to transport certain hazardous chemical from the starting point 0 to the end *n+1*. Vehicle must be served before the time *T*. Given the allowable service window [S_i, $\bar{S}_i$] for each node. The vehicle can only pass node *i* within this time period. w_i indicates the waiting time of the vehicle at the node *i* and the vehicle may need to wait to meet the service window limit to reduce transport time and risk. t_{ij} is the actual time for the vehicle to pass through the arc (*i*, *j*).

r_{ij} is the actual risk of the arc (*i*, *j*). a_i is the arrival time to node *i*.

$$\min \sum_i \sum_j x_{ij} r_{ij} \tag{5}$$

$$\min \sum_i \sum_j x_{ij} t_{ij} + M \Delta t \tag{6}$$

s.t.

$$x_{ij} = \begin{cases} 0 \\ 1 \end{cases} \tag{7}$$

$$\sum_j x_{0j} = 1 \tag{8}$$

$$\sum_j x_{jn+1} = 1 \tag{9}$$

$$\sum_j x_{ij} = \sum_j x_{ji} \tag{10}$$

$$a_i + t_{ij} - a_j \le (1 - x_{ij}) M \tag{11}$$

$$d_i + t_{ij} - d_j \le (1 - x_{ij}) M \tag{12}$$

$$x_{ij} \cdot (d_i + t_{ij} - a_j) = 0 \tag{13}$$

$$d_i = w_i + a_j \tag{14}$$

$$S_i \sum_j x_{ij} \le d_i \le S_i \sum_j x_{ij} \tag{15}$$

$$\Delta t = \begin{cases} 0 \\ a_{n+1} - T \end{cases} \tag{16}$$

Formula 5 to 6 are the objective functions of the model, which means the minimum risk of transportation and the shortest transportation time. Formula 7-9 mean that if a path is selected, we use 1, otherwise 0. Formula 11-16 are time bound,

In daily transportation, we can find that the transportation time and the transportation risk of hazardous chemical are all relevant. During peak hours, the same section has long transit times. During the low peak period, the transportation time is shorter.

We set the transit time of *ij* path is the sum of the theoretical transit time and the difference time.

$$t_{ij} = t'_{ij} + ET(d_{ij}) \tag{17}$$

t'_{ij} is the theoretical transit time and $ET(d_{ij})$ is the difference time.

Similarly, we set the transit risk of *ij* path is the sum of the theoretical transit risk and the difference risk.

$$r_{ij} = r'_{ij} + ER(d_{ij}) \tag{18}$$

r'_{ij} is the theoretical transit time and $ER(d_{ij})$ is the difference time.

We will divide one day into four time periods. From 0 to 5 is low peak, 5 to 9 is normal period, 9 to 17 is peak period and 17 to 24 is low peak. At the same time, the difference time and difference risk follow an exponential distribution. For difference time, it is the $10/((t'_{ij})\cdot e^{((-10/t'_{ij})x)})$ at the low peak and normal period, and it is $5/((t'_{ij})\cdot e^{((-10/t'_{ij})x)})$ at the peak. For difference time risk, it is $5/((r'_{ij})\cdot e^{((-5/r'_{ij})x)})$ at low peak, $10/((r'_{ij})\cdot e^{((-10/r'_{ij})x)})$ at normal period and $5/((r'_{ij})\cdot e^{((-5/r'_{ij})x)})$ at peak.

p_{ij}^k is the transfer probability of ant

$$p_{ij}^k = \frac{[\tau_{ij}]^\alpha [\eta_{ij}]^\beta [\mu_{ij}]^\gamma [\omega_{ij}]^\theta}{\sum_l [\tau_{il}]^\alpha [\eta_{il}]^\beta [\mu_{il}]^\gamma [\omega_{il}]^\theta} \tag{19}$$

l is all possible value.

$$\eta_{ij} = \frac{1}{d_{ij}} \tag{20}$$

d_{ij} is the distance between two adjacent nodes. μ_j is the information intensity of node j

$$\mu_j = \frac{1}{|\alpha_j|^2} \tag{21}$$

$\gamma(\gamma>0)$ is the intensity heuristic factor which represents the relative importance of nodes. ω_j is the wait time. $\theta(\theta>0)$ is the relative importance of waiting time.
The pheromone renewal equation is

$$\tau_{ij}^{new} = \rho \cdot \tau_{ij}^{old} + \sum_k \Delta\tau_{ij}^k \tag{22}$$

ρ is the persistence of pheromone ($0\leq\rho<1$). When the pheromone is updated, Q is constant. More ants though arc edge (i, j), more local update. So the algorithm is easy to fall into local optimal solution. At the same time, Q will also affect the search efficiency of the algorithm. When Q is too small, the algorithm is easy to converge to the local minimum. When Q is too big, the convergence speed of the algorithm will be slowed down.
In this paper, Q is improved to the dynamic adjustment value to prevent the excessive gap of pheromone quantity between edges. So the algorithm can prevent the algorithm from falling into local optimum, and the convergence speed will be improved.

$$\Delta\tau_{ij}^k = \begin{cases} Q\cdot(|\alpha_i|^2), on\ the\ optimal\ \ path \\ 0, \qquad otherwise \end{cases} \tag{23}$$

5. Numerical experiment

In order to verify the applicability and effectiveness of the proposed algorithm to solve the problem of hazardous chemical road transportation routing, we conduct numerical experiments. First, we want to set the parameters of the algorithm. Because the formula of pheromone update is improved, we determine the value Q.
We can see that when Q=60, the total distance of the hazardous chemical transportation is shortest. So Q is 60. We restrict the transportation time of the nodes. We assume that node 3 can only pass between 9 to 18 and node 9 can only pass between 9 to 20 for the hazardous chemical transport vehicle. In addition, the vehicle departure time is not limited. The results are shown in the following table.
We find that the first transportation route for hazardous chemical has the longest transportation time, but the transportation risk is the least. The second route has the shortest transportation time, but the transportation risk is the biggest. The transportation time and transportation risk of the third day route are relatively moderate.

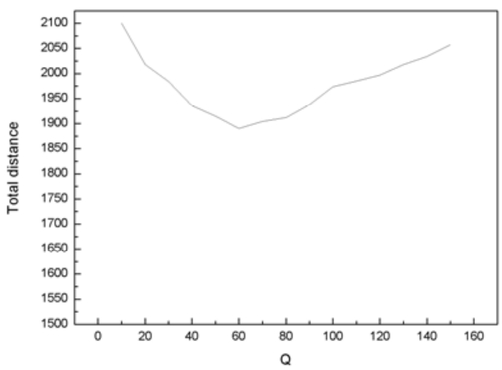

Figure 2: The relationship between Q and total distance

Table 1: The results of routes

Route	Node order	Transit time	Wait time	Transit risk
1	0-1-2-5-7-9-11	4.65h	3.75h	311.2
2	0-1-2-4-8-10-11	4.3h	0	487.6
3	0-1-2-5-8-9-11	4.35h	0	365.1

6. Conclusion

With the continuous development of China's economy, the level of road infrastructure and the number of hazardous chemical are increasing. The increase of highway mileage and the wide application of science and technology make the road transportation accidents of hazardous chemical develop in a new direction. Once the road transportation accident of hazardous chemical occurs, it will bring huge loss of life and property to many places. Because of the harmfulness of hazardous chemical road transportation accidents, the safety of hazardous chemical road transportation has become a common concern. Through the optimization of the path of hazardous chemical, the probability of hazardous chemical road transportation accidents can be effectively reduced. In this paper, we propose an improved ant colony algorithm to optimize the transportation path of hazardous chemical. The algorithm takes into account the time and risk characteristics of hazardous chemical road transportation, and proposes a new transfer probability and pheromone update equation. These improved measures ensure that the improved ant colony algorithm is more suitable for the hazardous chemical transportation route optimization. The reliability and effectiveness of this algorithm are verified by experiments in this paper.

References

Bubbico R., Di Cave S., Mazzarotta B., 2004, Risk analysis for road and rail transport of hazardous materials: a GIS approach, Journal of Loss Prevention in the process Industries, 17, 483- 48 8.

Chen Y.L., An A.J., 2016, Application of ant colony algorithm to geochemical anomaly detection, Journal of Geochemical Exploration, 164, 75-85.

Erkut E., Ingolfsson A., 2003, Catastrophe a voidance models for hazardous materials route planning, Transportation Science, 2000, 34(2), 165-179

Erkut E., Ingolfsson A., 2005, Transport risk models for hazardous materials: revisited, Operations Research Letters, 33(1), 81 -8 9

Erkut E., Osman A., 2007, Designing a road network for hazardous materials shipments, Computer & Operations Research, 34(5), 1389-1405.

Konstantinos N.A., Konstantinos G.Z., 2010, Solving the bicriterion routing and scheduling problem for hazardous materials distribution, Transportation Research Part C, 18, 713-726.

Konstantinos G.Z., Konstantinos N.A., 2004, A heuristic algorithm for solving hazardous materials distribution problems, European Journal of Operational Research, 152, 507-519.

Mahato D.P., Singh R.S., Tripathi A.K., Maurya A.K., 2017, On Scheduling Transactions in a Grid Processing System considering load through Ant Colony Optimization, Applied Soft Computing, In press, accepted manuscript, Available online 1.

Sitarz P., Powałka B., 2016, Modal parameters estimation using ant colony optimisation algorithm, Mechanical Systems and Signal Processing, 76–77, 531-554.

Skinderowicz R., 2016, The GPU-based parallel Ant Colony System, Journal of Parallel and Distributed Computing, 98, 48-60.

Ye K., Zhang C.S., Ning J.X., Liu X.J., 2017, Ant-colony algorithm with a strengthened negative-feedback mechanism for constraint-satisfaction problems, Information Sciences, 406–407, 29-41.