CHEMICAL ENGINEERING TRANSACTIONS
VOL. 71, 2018

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

Guest Editors: Xiantang Zhang, Songrong Qian, Jianmin Xu

ISBN 978-88-95608-68-6; **ISSN** 2283-9216

DOI: 10.3303/CET1871196

Risk and Cost Assessment of Dangerous Chemicals Transportation Based on Improved Particle Swarm Optimization

Junhui Song[a]*, Hua Xie[b], Chenglian Li[a]

[a] Xinyang Normal University, College of Computer and Information Technology, Xinyang, 464000, China
[b] Xinyang Vocational and Technical College, president's Office, Xinyang, 464000, China
85141727@qq.com

There is great safety risk in the transportation process of dangerous chemicals. In the commercial transportation of dangerous chemicals, it is of great significance to design reasonable transportation path of dangerous chemicals and to minimize the transportation cost of dangerous chemicals under the condition of ensuring transportation safety. This study deals with the transportation scheduling of dangerous chemicals, and constructs a risk and cost assessment model for dangerous chemicals transportation scheduling which aims at minimizing transportation risk and transportation cost. TR model is used to measure the risk in dangerous chemicals transportation scheduling process, a constraint variable considering the distribution order and a symbolic function for improving the solving speed of model are introduced to simplify the existing model. The improved particle swarm optimization (IPSO) is used to solve the proposed model. Based on the simulation experiment, IPSO is compared with the traditional particle swarm optimization (TPSO). The experimental result shows that IPSO has more excellent global search efficiency, obtains a better non-dominant solution, and reduces the transportation risk and transportation cost in the actual transportation after calculation. When the hybridization probability p = 0.6, IPSO proposed in this study has the best effective frontier.

1. Introduction

Along with the rapid development of society, more and more industrial enterprises use dangerous chemicals that are inflammable, explosive, corrosive and infectious (Topuz et al., 2011). Improper management of dangerous chemicals during transportation and storage can cause great damage to personnel property and the surrounding environment (Kara et al., 2003; Zhao, 2007; Liu et al., 2011; NijoleBatarliene, 2008). It is of great significance to design a reasonable transportation path for dangerous chemicals so as to minimize the transportation cost of dangerous chemicals while ensuring transportation safety (Han et al., 2014; Jiang and Ying, 2014).

The transportation modes of dangerous chemicals include railway transportation, road transportation and railway-road hybrid transportation. Railway transportation requires the establishment of large-scale storage and transfer centers for dangerous chemicals near railway stations, which greatly increases the overall transportation cost (Caliendo and De, 2017). Therefore, road transportation is the main means of transportation of dangerous chemicals at present (Liping et al., 2013). Transportation of dangerous chemicals can be considered as vehicle routing problem (VRP), and many researchers have studied the logistics transportation of dangerous chemicals. For example, Pradhanangad et al. consider the influence of the maximum load of the vehicle and the number of people along the road on the choice of vehicle path (Pradhananga, Taniguchi and Yamada, 2010; Pradhananga et al, 2014); Tarantilis, et al., uses the LBTA algorithm to find the optimal distribution path of dangerous chemicals (Tarantilis and Kiranoudis, 2001); Zografos et al. has studied the transportation of dangerous goods based on the hard time window method (Zografos and Androutsopoulos, 2008); Erkut et al. study the distribution path optimization of dangerous chemicals under the three optimization objective conditions of transportation cost, transportation expected

Please cite this article as: Song J., Xie H., Li C., 2018, Risk and cost assessment of dangerous chemicals transportation based on improved particle swarm optimization, Chemical Engineering Transactions, 71, 1171-1176 DOI:10.3303/CET1871196

effect and transportation affecting population (Erkut and Ingolfsson, 2000). Kang introduces the concept of "VaR" into the safety assessment of dangerous chemicals transportation (Kang, Batta and Kwon, 2014). Most of the above researches consider the influence of various potential risks on the transportation of dangerous chemicals, but few consider the optimal distribution of dangerous chemicals under the dual constraints of transportation cost and transportation risk.
Based on the deficiency of the above research, the risk and cost assessment model of dangerous chemicals transportation scheduling is constructed in this study, which aims at minimizing transportation risk and transportation cost. TR model is used to measure the risk in dangerous chemicals transportation scheduling process, a constraint variable considering the distribution order and a symbolic function for improving the solution speed of the model are introduced at the same time. The IPSO is used to solve the proposed model. The conclusions can provide theoretical reference for risk and cost assessment of transportation and scheduling of dangerous chemicals.

2. Risk and Cost Assessment Model for Transportation Scheduling of Dangerous Chemicals

TR model is used to measure the risk in the transportation and scheduling process of dangerous chemicals. A single transportation vehicle is arranged to distribute the goods to each demand point sequentially after starting from the storage bin, and finally returns to the storage bin. The quantity of dangerous chemicals in the distribution vehicle is dynamically changing, so the more goods are unloaded by the transportation vehicle, the smaller the risk of occurrence of the accident is. Then the transportation risk r_{ij} can be expressed as

$$r_{ij} = p_{ij} \cdot \rho_{ij} \cdot \frac{w_{ij}}{\text{cap}} \tag{1}$$

The total demand for dangerous chemicals distributed by vehicle v is:

$$\sum_m \text{sign}\left(r_m^v\right) \cdot d_m \tag{2}$$

Make

$$sg_m^{vk} = \frac{\text{sign}\left(\left(r_m^v + 1\right) - k\right) \cdot \left[\text{sign}\left(\left(\left(r_m^v + 1\right) - k\right) r_m^v\right) + \text{sign}\left(r_m^v\right)\right]}{2} \tag{3}$$

If the m_{th} demand point happens to be on the distribution path of the vehicle v and the number of distribution order of m is greater than k, then Formula 3 is equal to 1, otherwise Formula 3 is 0, and the carrying weight of the dangerous chemicals when the vehicle v is on the k_{th} distribution path may be expressed as:

$$\sum_m sg_m^{vk} \cdot d_m \tag{4}$$

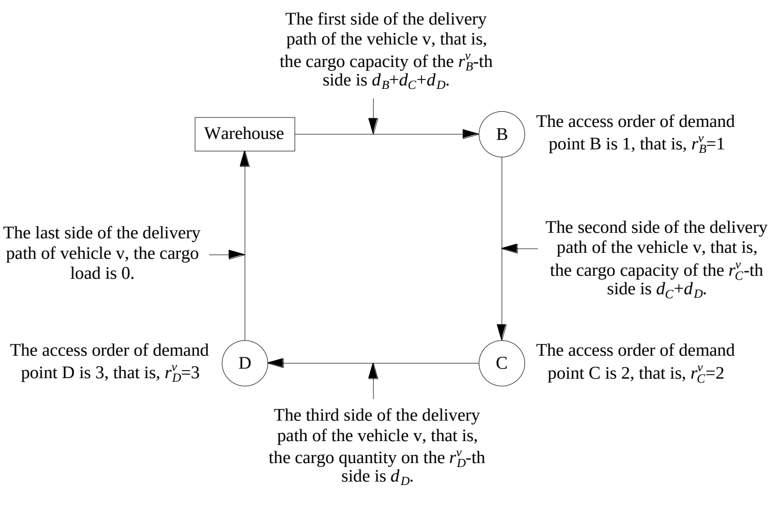


Figure 1: Schematic diagram of vehicle distribution order of dangerous chemicals

Taking the three distribution points as an example, the distribution order after the distribution vehicle starts from the warehouse is explained as shown in Figure 1.

$$sn_{ij}^{v} = \mathrm{sign}\left(r_i^v\right) \cdot \mathrm{sign}\left(r_j^v\right) \cdot \mathrm{sign}\left(\left|\left(\mathrm{sign}\left(\left|r_j^v - r_i^v\right| - 1\right) - 1\right)\right|\right) \cdot \frac{\left(r_j^v - r_i^v\right) + 1}{2} \quad (5)$$

Where, the sign function is used to determine whether each edge is in the distribution path of the vehicle, [(r_j^v-r_i^v)+1]/2 is used to determine whether the distribution order is correct. According to Figure 1, Formula 2-Formula 5, we can finally determine the vehicle's load on any distribution path edge (i, j) as:

$$w_{ij} = \sum_v \sum_m sg_m^{vr_j^v} \cdot sn_{ij}^v \cdot d_m \quad (6)$$

The transportation risk of the distribution vehicle from the warehouse on any path may be expressed as

$$r_{ij} = p_{ij} \cdot \rho_{ij} \cdot \frac{w_{ij}}{\mathrm{cap}} = \sum_v \sum_m sg_m^{vr_j^v} \cdot sn_{ij}^v \cdot p_{ij} \cdot \rho_{ij} \cdot \frac{d_m}{\mathrm{cap}} \quad (7)$$

The risk of the distribution vehicle starting from the warehouse to the first distribution point is not included in Formula 7, and the distribution risk on this path can be expressed as

$$R_1^v = \sum_m \mathrm{sign}\left(r_m^v\right) \cdot \mathrm{sign}\left(\left|\mathrm{sign}\left(r_m^v - 1\right) - 1\right|\right) \cdot \rho_{0m} \cdot p_{0m} \cdot \frac{d_m}{\mathrm{cap}} \quad (8)$$

The distribution cost of the corresponding distribution path may be expressed as

$$C_1^v = \sum_m \mathrm{sign}\left(r_m^v\right) \cdot \mathrm{sign}\left(\left|\mathrm{sign}\left(r_m^v - 1\right) - 1\right|\right) \cdot c_{0m} \quad (9)$$

When the distribution vehicle returns to the warehouse from the last distribution point, there is no dangerous chemicals on the vehicle, so the risk of the distance is zero, and the distribution cost of the distance is

$$C_{last}^v = \sum_m \mathrm{sign}\left(r_m^v\right) \cdot \mathrm{sign}\left(\left|\mathrm{sign}\left(\frac{\left(-1 + \sqrt{1 + 8\sum_m r_m^v}\right)}{2} - r_m^v\right) - 1\right|\right) \cdot c_{0m} \quad (10)$$

According to Formulas 1-10, a risk and cost assessment model for dangerous chemicals transportation scheduling can be established as:

$$\min Z_1 = \sum_{(i,j)\in A} \sum_v \sum_m \frac{sg_m^{vr_j^v} \cdot sn_{ij}^v \cdot \rho_{ij} \cdot p_{ij} \cdot d_m}{\mathrm{cap}} + \sum_v R_1^v \quad (11)$$

$$\min Z_2 = \sum_v \left(\sum_{(i,j)\in A} sn_{ij}^v \cdot c_{ij} + C_1^v + C_{last}^v \right) \quad (12)$$

$$\sum_m \mathrm{sign}\left(r_m^v\right) \cdot d_m \le \mathrm{cap} \quad v = 1, 2, \ldots, V \quad (13)$$

$$\sum_v \mathrm{sign}\left(r_m^v\right) = 1 \quad m = 1, 2, \ldots, M \quad (14)$$

Formula 11 and Formula 12 are the optimization objective functions, representing the minimized transportation risk and transportation cost respectively. Formula 13 and Formula 14 are constraint conditions of objective functions. Formula 13 indicates that the amount of distributed goods is not greater than the vehicle load, and Formula 14 indicates that each distribution point can only be distributed by one vehicle

3. IPSO

The IPSO is used to solve the two-objective optimization problem of dangerous chemicals transportation proposed in this study. If there are n distribution points in the distribution path, each distribution point is randomly initialized and two sets of scores are obtained. The first group determines the distribution vehicle corresponding to the distribution point, and the second group determines the distribution order of the

distribution vehicle. The initial solution of the problem is obtained by statistics of the components of all distribution points.
If that initial solution population is X = (X1, X2,., Xn), the population is updated by Formula 15 and Formula 16

$$V_{id}^{k+1} = w^k V_{id}^k + c_1 r_1 \left(P_{id}^k - X_{id}^k \right) + c_2 r_2 \left(P_{gd}^k - X_{id}^k \right) \tag{15}$$

$$X_{id}^{k+1} = X_{id}^k + V_{id}^{k+1} \tag{16}$$

Formula 15 indicates that the iteration speed of the population is updated, and Formula 16 indicates that the position of the population is updated.
The two-objective optimization problem of dangerous chemicals transportation is dealt with by non-dominant solution and population hybridization, and the initial population is divided into two sub-populations, namely child1 and child2, respectively.

$$\text{child}_1 = p \times \text{parent}_1 + (1-p) \times \text{parent}_2 \tag{17}$$

$$\text{child}_2 = p \times \text{parent}_2 + (1-p) \times \text{parent}_1 \tag{18}$$

The solution flow of the IPSO designed in this study is shown in Figure 2

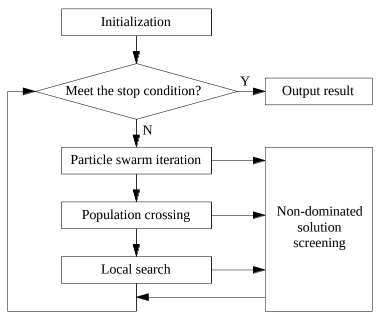


Figure 2: Solution flow of IPSO

4. Simulation Experiment and Result Analysis

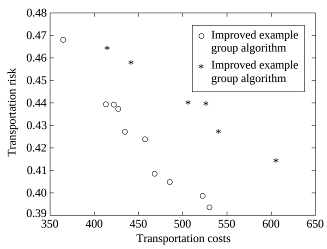
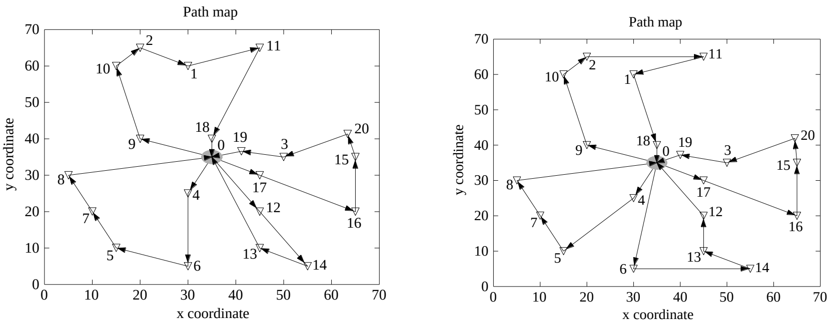


Figure 3: Non-dominant solution distribution of different algorithms

Furthermore, the validity of the risk and cost assessment model and solution algorithm for dangerous chemicals transportation scheduling proposed in this study is verified. Taking one warehouse and 20 distribution points as an example, the initial population size is 100, and the maximum number of iterations is 1,000. The distribution of the non-dominant solutions obtained by using IPSO and TPSO is shown in Figure 3.
By use of IPSO, the optimal distribution path of the vehicle is obtained based on the lowest cost and the lowest transportation risk, as shown in Figure 4. It can be seen from the figure that a better non-dominant solution can be obtained by using IPSO and the transportation risk and transportation cost can be reduced at the same time. The calculated effective frontier gives the optimal one-to-one strategy of transportation cost and transportation risk so that researchers can make efficiently and quickly make transportation plan and emergency measures.

Calculated by IPSO, the cost optimal solution is (360.22, 0.4713), the risk optimal solution is (295.74, 0.3957) and the number of non-dominant solutions is 10. The optimal cost solution is (420.86, 0.4883), the optimal risk solution is (62.06, 0.4209), and the number of non-dominant solutions is 6 after removing the population hybridization module. The cost optimal solution is (48.29, 0.4921), the risk optimal solution is (65.83, 0.4345), and the number of non-dominant solutions is 8 when the population hybridization module is retained. The results show that when the population hybrid module or the local search module is removed, the optimal solution is worse than that of the IPSO, which shows that the two modules can improve the search efficiency of IPSO. The population hybrid module can effectively enhance the diversity of the progeny population, and the local search module can improve the quality of the optimal solution.



(a) The lowest cost *(b) The lowest risk*

Figure 4: Optimal distribution path of vehicle under different optimization objective conditions

Figure 5 shows the non-dominant solutions obtained by IPSO under different hybridization probability p conditions. According to the theoretical calculation, when p<0.3 or p>0.8, the calculated non-dominant solutions are all poor, but when 0.4<p<0.8, the corresponding relationship between transportation cost and transportation risk is relatively good. It can be seen from the figure that IPSO in this study has the best effective frontier when p = 0.6.

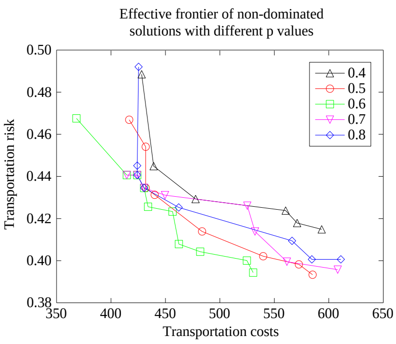


Figure 5: Non-dominant solutions under different hybridization probability conditions

5. Conclusions

This study explores the transportation scheduling of dangerous chemicals, and constructs a risk and cost assessment model for dangerous chemicals transportation scheduling, which aims at minimizing transportation risk and transportation cost. TR model is used to measure the risk in dangerous chemicals transportation scheduling process, a constraint variable considering the distribution order and a symbolic function for improving the solution speed of the model are introduced to simplify the existing model. The IPSO is used to solve the proposed model. Based on the simulation experiment, IPSO is compared with TPSO. The experimental result shows that IPSO has more excellent global search efficiency. After calculation, a better non-dominant solution can be obtained, and the transportation risk and transportation cost in the actual transportation of the vehicle can be reduced. When the hybridization probability p=0.6, IPSO has the best effective frontier. The conclusions can provide theoretical reference for risk and cost assessment of dangerous chemicals transportation scheduling (Nie and Zhang, 2018).

Acknowledgments

Key R&D and Promotion Projects in Henan Province (Science and Technology Tackling): Distributed System Task Scheduling Optimization Research and Development for Resource Sharing and Load Balance (NO. 192102210452); Henan Teacher Education Curriculum Reform Project: Network Training Model for Primary and Secondary School Teachers under the Background of Large Data (NO. 2018-JSJYYB-029).

References

Caliendo C., De Guglielmo M.L., 2017, Quantitative risk analysis on the transport of dangerous goods through a bi-directional road tunnel. Risk Analysis, 37(1), 116-129. DOI:10.1111/risa.12594

Erkut E., Ingolfsson A., 2000, Catastrophe Avoidance Models for Hazardous Materials Route Planning, 34 (2), 165-179. DOI: 10.1287/trsc.34.2.165.12303

Han X.G., Fan T.J., Li S.X., 2014, Route optimization for hazardous chemicals transportation. Advanced Materials Research, 869-870, 260-265. DOI: 10.4028/www.scientific.net/amr.869-870.260

Jiang M.W., Ying M., 2014, Study on route selection for hazardous chemicals transportation ☆. Procedia Engineering, 71(71), 130-138. DOI: 10.1016/j.proeng.2014.04.019

Kang Y., Batta R., Kwon C., 2014, Value-at-risk model for hazardous material transportation. Annals of Operations Research, 222(1), 361-387. DOI: 10.1007/s10479-012-1285-0

Kara B.Y., Erkut, E., Verter, V., 2003, Accurate calculation of hazardous materials transport risks. Operations Research Letters, 31(4), 285-292. DOI:10.1016/s0167-6377(02)00238-9

Klemeš J.J., Varbanov P., Lam H.L., 2009, Water Footprint, water recycling and Food Industry Supply Chain, Chapter In: K Waldron (Ed.), Waste management and co-product recovery in food processing, Vol 2, Woodhead Publishing Limited, Cambridge, UK, 134-168.

Liping L., Liangliang Y., Shuxia L., Jiandong S., 2013, The risk assessment research of hazardous chemicals rail and truck transportation. Journal of Applied Sciences, 13(11), 2077-2081. DOI: 10.3923/jas.2013.2077.2081

Liu L.P., Liu S.H., Li S.X., 2011, Transportation risk assessment of hazardous chemicals based on risk rank. Advanced Materials Research, 320, 180-184. DOI: 10.4028/www.scientific.net/amr.320.180

Nie Y., Zhang W., 2018, Research on optimization design of hazardous chemicals logistics safety management system based on big data, Chemical Engineering Transactions, 66, 1477-1482 DOI:10.3303/CET1866247

NijoleBatarliene., 2008, Risk analysis and assessment for transportation of dangerous freight. Transport, 23(2), 98-103. DOI:10.3846/1648-4142.2008.23.98-103

Pradhananga R., Taniguchi E., Yamada T., 2010, Ant colony system-based routing and scheduling for hazardous material transportation. Procedia - Social and Behavioral Sciences, 2(3), 6097-6108. DOI: 10.1016/j.sbspro.2010.04.022

Pradhananga R., Taniguchi E., Yamada T., Qureshi A.G., 2014, Bi-objective decision support system for routing and scheduling of hazardous materials. Socio-Economic Planning Sciences, 48(2), 135-148. DOI: 10.1016/j.seps.2014.02.003

Raissi K., 1994, Total site integration, PhD Thesis, University of Manchester Institute of Science and Technology, Manchester, UK.

Tarantilis C., Kiranoudis C.T., 2001, Using the vehicle routing problem for the transportation of hazardous materials. Operational Research, 1(1), 67-78. DOI: 10.1007/bf02936400

Topuz E., Talinli I., Aydin E., 2011, Integration of environmental and human health risk assessment for industries using hazardous materials: a quantitative multi criteria approach for environmental decision makers. Environment International, 37(2), 393-403. DOI: 10.1016/j.envint.2010.10.013

US DoE, 2016, Steam Turbines, US Department of Energy <energy.gov/sites/prod/files/2016/09/f33/CHP-Steam%20Turbine.pdf> accessed 24.07.2017.

Zhao LJ., 2007, Risk analysis of dangerous chemicals transportation. Systems Engineering - Theory & Practice, 27(12), 117-122. DOI:10.1016/s1874-8651(08)60077-0

Zografos K.G., Androutsopoulos K.N., 2008, A decision support system for integrated hazardous materials routing and emergency response decisions. Transportation Research Part C Emerging Technologies, 16(6), 684-703. DOI: 10.1016/j.trc.2008.01.004