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/CET1871009

Transport Route Optimization for Hazardous Chemicals Based on Heuristic Genetic Algorithm

Haifeng Hu[a], Liguo Xing[b]*

[a] College of Information Technology, Pingdingshan University, Pingdingshan 467000, China
[b] College of Computer Science and Technology, Pingdingshan University, Pingdingshan 467000, China
pdsxlg@pdsu.edu.cn

Today, China has witnessed the rapid development in the economy, bringing with it an inevitable booming in the supply and demand for hazardous chemicals. In this context, the production and transportation of hazardous chemicals have also been greatly stimulated. However badly, as dangerous chemicals are flammable and explosive, there is a great safety hazard in the transportation process. Once an accident occurs, it will bring tremendous losses to people's lives and property. It is imperative that the routes with lower cost but at a higher safety level in the transportation process should be developed. This paper builds a transport route optimization model that deliberates overall cost and safety coefficient by analyzing the factors affecting the transportation of dangerous chemicals, which searches for optimal solution with heuristic genetic algorithm. This model is designed to offer a scientific and quantitative evaluation standard for optimizing transport scheduling routes. The findings reveal that economic benefits and safety factors are subjected to different transport routes, and even quite different in some routes. Unreasonable transport routes will cause economic losses to the firms and even cause accidents; before the transportation of dangerous chemicals, scientific models and algorithms can have access to an integrated transport route that allows for economic benefits and safety level. The study can provide the clues to practical exploration and application of transport routes for hazardous chemicals so as to achieve scientific schedule for firms.

1. Introduction

China's infrastructure construction has seen a sustainable and steady development in recent years. The traditional industries that are closely bound up with it also evolve in full swing. Against this backdrop, so does the market of hazardous chemicals, which are inseparable from the development of traditional industries such as energy resources, chemicals, and light industry. It is also predicted according to relevant studies that the transaction volume of hazardous chemicals will be doubled in the next five years. Due to the natures of hazardous chemicals, they have to be produced intensively and transported safely before marketing (Matías et al., 2007; Boulmakoul et al., 2016). The relatively intensive production mode and the leap-forward market development have imposed tremendous pressure on the logistics process for transporting dangerous chemicals. While in the transportation process, traffic accidents caused by improper operation accounted for 42% of the total (Saat et al., 2014), which not only threatens people's lives and property, but also has greatly ruined the environment. In the past, when the demand and supply in the market are sluggish, most of hazardous chemicals need to be transported by manpower, which not only consumes time, but also caused the safety risk during transportation due to incomplete information (Cao et al., 2017). By far, the supply and demand in the market of dangerous chemicals hike up, it is imperative for us to seek scientific schedule methods and reasonable transport routes using scientific algorithms and information technologies to transport dangerous chemicals in a safe and efficient way, thus ensuring the safety of transportation and maximizing the profits (Song & Wang, 2016; Nie and Zhang, 2018).
As a branch of the logistics industry, how to optimize the transport route for hazardous goods, it is in fact a special type of vehicle scheduling problem (Kanoh & Hara, K, 2010; Chatras et al., 2016). In addition to the features the transportation of hazardous goods has as ordinary logistics, what's the most important is the risk of items consigned. In the transport route optimization process, we have to guarantee a certain economic

Please cite this article as: Hu H., Xing L., 2018, Transport route optimization for hazardous chemicals based on heuristic genetic algorithm, Chemical Engineering Transactions, 71, 49-54 DOI:10.3303/CET1871009

benefit and the transport safety in parallel (BoHuang et al., 2004; Asl et al., 2013). In order to find such a route where economic cost and transportation risk are all relatively low, the road conditions, weather and other factors that affect transportation safety are introduced into the route optimization model in an attempt to do a comprehensive evaluation with cost and risk coefficient weights. (Zhang et al., 2016).
Given the above, in the face of the transportation of hazardous goods, how to contemplate the risk factors and how to minimize the transportation cost and maximize the transportation safety are subjects that deserve to be studied hereof. This indeed has an important practical effect (Thapa et al., 2004; Fang et al., 2005). This paper analyzes the factors that affect the transportation of dangerous chemicals, based on which to build a route optimization model that ponders over transportation costs and transportation safety, and well solve the NP-hard problem using the genetic algorithm, thereby maximizing comprehensive evaluation on the economic benefit and the safety level of transportation route for hazardous chemicals.

2. Optimization model of dangerous chemical transportation route based on genetic algorithm

2.1 Overview of transportation path optimization model

The transport route optimization model needs to consider both route safety and cost, as shown in Fig. 1.

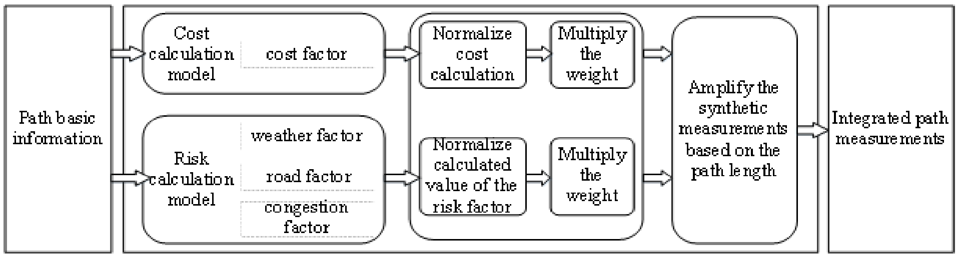

Figure 1: Model architecture

As shown in the figure, the model includes two parts: cost and risk coefficient calculations. First, the two parts are respectively calculated, and then normalized. In the end, the comprehensive value of the routes is available according to the addition of the weights to measure how well the route is.

2.2 Factors that affect the transport of hazardous chemicals

There are factors such as cost, weather, road conditions and road congestion, as shown in Fig. 2.

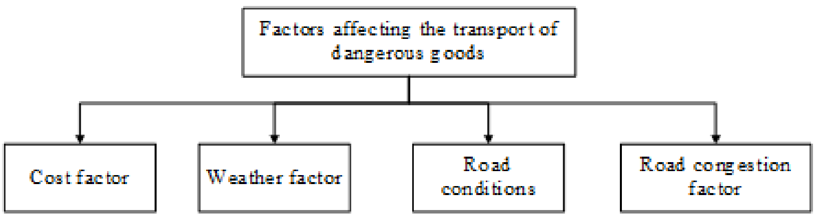

Figure 2: Model architecture

2.3 Establishment of optimization model for transport route of hazardous chemicals

2.3.1 Costing model

Table 1: Fuel costs at different road grades and under road conditions

Road grade	Road conditions	¥/(t.km)
The highway	Plains, mounds	0.43
Primary and secondary highway	Plains, mounds	0.56
The highway	Mountains, heavy hills	0.60
Primary and secondary highway	Mountains, heavy hills	0.73

In the transportation scheduling process, the costs invoked by route selection mainly include three items, transportation, fuel and labor costs. Among them, the transportation cost is set to RMB 0.16 (t.km), the fuel cost is shown in Table 1, and the labor cost needs to be set as the parameter relevant to the travel time according to the practical situation. Vehicle speed per hour needs to be considered combining the economic benefits of the company, so that the preset time penalty factor is RMB 2.8 / h.t.

Define the set of nodes in each route Road1n as K=(1,2,3,...,n), and each segment as Rxy, $y=x+1$, $x,y \in K$. See Table 2 for details of parameters.

Table 2: Parameters for costing model

Parameter	Meaning	Unit
RL_{xy}	Length of path RL_{xy}	km
RC_{xy}	The unit cost of the road and bridge of path RL_{xy}	¥/km.t
ROC_{xy}	The unit cost of fuel for path RL_{xy}	¥/km.t
RP	Human cost of the route.	¥
T_{xy}	Time taken by the driving RL_{xy}	h
TO	Time required for each route of non-driving rest	h
TA	Total time of the route	h
RS_{xy}	Speed of RL_{xy}	km/h
H	Shipping weight	t
ROC_{all}	Total fuel	¥
RC_{all}	The total toll fee	¥
C_{1ni}	Total cost of route I	¥
TP	Time penalty	¥
β	Time penalty parameter	¥/t.h

$$T_{xy} = RL_{xy} / RS_{xy} \tag{1}$$

$$Th \geq \frac{1}{3} h \tag{2}$$

$$TA = \sum_{x=1}^{n-1} T_{xy} + \frac{\sum_{x=1}^{n-1} T_{xy}}{4} Th \tag{3}$$

$$RC_{all} = \sum_{x=1}^{n-1} (RC_{xy} RL_{xy} H) \tag{4}$$

$$ROC_{all} = \sum_{x=1}^{n-1} (ROC_{xy} RL_{xy} H) \tag{5}$$

$$RP = TA / 5 \, 100 \tag{6}$$

$$TP = H \beta TA \tag{7}$$

$$C_{1ni} = ROC_{all} + RC_{all} + RP + TP \tag{8}$$

Where, formula (1) calculates the time consumption of the road segment xy; formula (2) indicates that the rest time (non-driving) must reach more than 20 minutes each time; formula (3) calculates the sum of the total driving and rest time; formula (4) calculates the total road and bridge expense; formula (5) indicates calculates the total fuel cost is calculated; and formula (6) calculates the human cost required to be paid additionally when the transportation time exceeds 8 h (the route is too long); formula (7) calculates the penalty value of the route relative to time; formula (8) gives the sum of all the costs of a single route.

The whole road network $G(K, E, L, N, P)$ includes multiple routes, where, K, E, L, N, P represent a set of nodes, a set of supply sides, a set of demand sides, a set of segments, and a set of segment weights, respectively. Using the least economic cost or the best benefit, the model needs to solve the route with the least cost from each demand side to each supply side, namely:

$$f(x) = \min C_{xpm} \quad (9)$$

Where, $x \in L$, $p \in E$, m is the number of the different route.

2.3.2 Risk coefficient calculation model

We conduct an analysis with the terrain risk parameters as a case. First, assume that the normal road transport safety risk factor is 1. Based on this, the risk factors for traffic safety under different situations are listed in Table 3.

Table 3: Terrain hazard parameters for traffic safety

Hazard parameter	Degree	Value
Rainfall	Light rain, moderate rain, heavy rain	1.36
Rainfall	Moderate rain, heavy rain	1.8
Rainfall	Moderate to heavy rain, heavy rain	2.1
Road conditions	Moisture, a little bit of water	1.4
Road conditions	A lot of water	1.6
Road conditions	Ice water mixture, ice, lots of snow	2.1
Road conditions	General snow, a little ice	1.6
Snow	Heavy snow	2.3
Snow	Light snow (high temperature)	1.7
Snow	Light snow (low temperature)	1.5
Snow	Medium snow (high temperature)	2
Fog	Heavy fog	1.8
congestion	Moderate (saturation 0.555-0.7)	2.1
congestion	Severe (saturation>0.7)	1.6
Terrain	Hills and the mountains	1.2
Snow	Medium snow (low temperature)	1.7
Snow	Sleet	2.1
Fog	Light fog (100-200 visibility)	2
Fog	Other fog	1.4

Each node is defined similarly to that the cost calculation. The hazard parameters are shown in Table 4.

Table 4: Risk parameters

Hazard parameter	Hazard parameter value
WD_{xy1}	Rainfall risk of route R_{xy}
WD_{xy2}	Snow risk of route R_{xy}
WD_{xy3}	Flog risk of route R_{xy}
RF_{xy1}	Hazard parameters of water accumulation of route R_{xy}
RF_{xy2}	Ice hazard parameters of route R_{xy}
RB_{xy}	Congestion hazard parameters of route R_{xy}
RCD_{xy}	Terrain hazard parameters of route R_{xy}
RL_{xy}	Length of route R_{xy}
W_{rain}	Parameter set of rainfall risk
W_{snow}	Parameter set of snow risk
W_{water}	Parameter set of accumulated water risk
W_{ice}	Parameter set of ice risk
WD_{xy}	Weather hazard parameters of route R_{xy}
ω	Penalty parameters for hazardous time
RB_{xy}	Dangerous parameters of road condition
D_{xy}	Total risk parameter
TDP	Amount of penalty for dangerous time

$$\exists WD_{xy1} \in W_{rain} \wedge RF_{xy1} \in W_{water} \rightarrow \min(WD_{xy1}, RF_{xy1}) = 1 \quad (10)$$

$$\exists WD_{xy2} \in W_{snow} \wedge RF_{xy2} \in W_{ice} \rightarrow \min(WD_{xy2}, RF_{xy2}) = 1 \tag{11}$$

$$WD_{xy} = \prod_{m=1}^{3} WD_{xym} \tag{12}$$

$$RF_{xy} = \prod_{m=1}^{2} RF_{xym} \tag{13}$$

$$D_{xy} = WD_{xy} RF_{xy} RB_{xy} RCD_{xy} \tag{14}$$

$$TDP = \varpi TA \tag{15}$$

$$D_{road} = \sum_{x=1}^{n-1} D_{xy} RL_{xy} + TDP \tag{16}$$

As Formula (10) indicates, when the rainfall appears with road waterlogging, the lesser risk factor is set to 1; formula (11) indicates that when snowfall and road icing occur concurrently, the lesser risk parameter is set to 1; Formulas (12), (13), and (14) represent the parameters of weather, road condition risks, and total hazard for each road segment; formula (15) represents the time hazard penalty parameter for the whole road segment; formula (16) is used to measure the risk of the full road.

3. Study case for transport route optimization

3.1 Establishment of transport network

This paper takes the road map in XX Province as an example, and its road network is shown in Fig. 3.

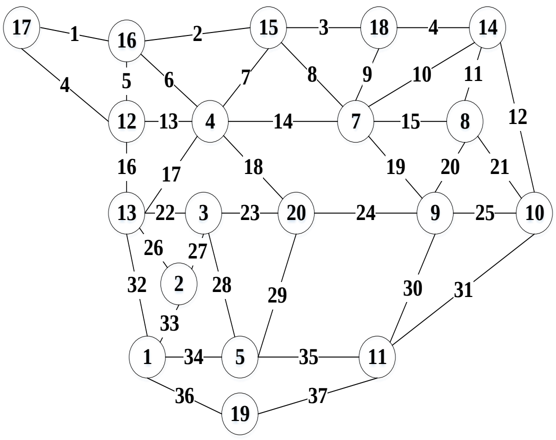

Figure 3: Architecture of transport network

3.2 Integration between genetic algorithm and route optimization model

The transport route optimization model in this paper is to make an evaluation with the given cost and risk of the comprehensive route. As a heuristic algorithm, the genetic algorithm has been widely used to solve various types of transportation problems. Based on the transport route optimization model, this paper solves the transport route optimization problem of large-scale road network by virtue of genetic algorithm.

3.3 Data simulation and analysis

Combined with the road network shown in Fig. 3, with the genetic algorithm shown in Fig. 4, the number of populations is set to 100, the genetic algebra is 300, the crossover probability is 0.85, and the mutation probability is 0.2, simulate and analyze the transport route. The experimental results show that after 100 iterations, 95% of the populations reach the optimal solution in about 50 generations, and about 5% achieve it in the 80th generation.

4. Conclusion

During transportation of dangerous chemicals, in order to find a transport route with the maximum cost efficiency and safety benefit, this paper implements the optimization of transport routes based on the genetic algorithm. Here are some conclusions:

(1) The cost and risk factor of the transport route should be comprehensively considered in the model since they will have a concurrent impact on the optimization of the transport route, thus providing the clues to the route selection.

(2) Heuristic genetic algorithm can adapt to the optimization of transport route under large-scale road network conditions, reduce the computation complexity, save the calculation time, and have access to a satisfactory transportation program.

(3) A good transport dispatching system should build on scientific route optimization model and find the solution with efficient calculation method. Only in this way can we ensure the safe transportation of dangerous chemicals and maximize the economic benefits of company.

Acknowledgement

The work was supported by Key Scientific and Technological Project of Henan Province [grant number: 172102210118].

Reference

Asl N. M., Kim J. H., Wen C. L., Liu Z., Lu P., Kim Y., 2013, A new chemical route for the synthesis of β′-lixv2o5 for use as a high performance cathode. Electrochimica Acta, 105, 403-411, DOI: 10.1016/j.electacta.2013.04.131

Boulmakoul A., Karim L., Lbath A., 2016, T-warehousing for hazardous materials transportation, Ingenierie des Systemes d'Information, 21(1), 39-59, DOI: 10.3166/ISI.21.1.39-59

Cao H., Li T., Li S., Fan T., 2017, An integrated emergency response model for toxic gas release accidents based on cellular automata. Annals of Operations Research, 255(1-2), 1-22, DOI: 10.1007/s10479-016-2125-4

Chatras C., Giard V., Sali M., 2016, Impact of mass customization on bill of materials structure and master production schedule, Journal Europeen des Systemes Automatises, 49(1), 55-91, DOI: 10.3166/JESA.49.55-91

Fang X. S., Ye C. H., Zhang L. D., Zhang J. X., Zhao J. W., Yan P., 2005, Direct observation of the growth process of mgo nanoflowers by a simple chemical route. Small, 1(4), 422-428, DOI: 10.1002/smll.200400087

Huang B., Longcheu R., Yong S. L., 2004, Gis and genetic algorithms for hazmat route planning with security considerations. International Journal of Geographical Information Systems, 18(8), 769-787, DOI: 10.1061/(ASCE)CO.1943-7862.0000216

Kanoh H., Hara K., 2010, Hybrid genetic algorithm for dynamic multi-objective route planning with predicted traffic in a real-world road network. Genetic and Evolutionary Computation Conference, GECCO 2008, Proceedings, Atlanta, Ga, Usa, 657-664, DOI: 10.1145/1389095.1389226

Matías J. M., Taboada J., Ordóñez C., Nieto P. G., 2007, Machine learning techniques applied to the determination of road suitability for the transportation of dangerous substances. Journal of Hazardous Materials, 147(1-2), 60, DOI: 10.1016/j.jhazmat.2006.12.042

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

Saat M. R., Werth C. J., Schaeffer D., Yoon H., Barkan C. P. L., 2014, Environmental risk analysis of hazardous material rail transportation. Journal of Hazardous Materials, 264(2), 560-569, DOI: 10.1016/j.jhazmat.2013.10.051

Song Y., Wang R. Y., 2016, Route optimization of the road transportation of dangerous goods based on bi-level programming. Journal of Highway & Transportation Research & Development, 10(2), 92-97, DOI: 10.1061/jhtrcq.0000508

Thapa D., Palkar V. R., Kurup M. B., Malik S. K., 2004, Properties of magnetite nanoparticles synthesized through a novel chemical route. Materials Letters, 58(21), 2692-2694, DOI: 10.1016/j.matlet.2004.03.045

Zhang Q., Sando D., Nagarajan V., 2016, Chemical route derived bismuth ferrite thin films and nanomaterials. Journal of Materials Chemistry C, 4(19), 4092-4124, DOI: 10.1039/c6tc00243a