Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 13 (11): 2077-2081, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.2077.2081

The Risk Assessment Research of Hazardous Chemicals Rail and Truck Transportation

Liu Liping, Yang Liangliang, Li Shuxia and Si Jiandong
East China University of Science and Technology, No. 130 Meilong Road Shanghai, 200237, China

Abstract: With the globalization of the world economy and the deepen integration, China's relations with the world is deeper and deeper and China has entered a rapid development stage. Because of the special nature of hazardous chemicals, once the accident happened will lead to the more destructive accidents than the general ones, so it needs special attention, especially during the processing of transportation. Based on this background, this study will consider the modes of railway and highway, to establish the risk assessment model which is a bi-objective programming model considering the risk and cost and solved by matlab. In the end can get the conclusion: combined transport mode can reduce costs and achieve the purpose of avoiding risk; similarity, we need to choose reasonable transportation time to achieve the purpose of accurate delivery.

Key words: Hazardous chemicals, risk assessment, combined transportation

INTRODUCTION

Hazardous chemicals are those flammable, explosive, toxic, corrosive, infectious and strong radioactive goods, such as gasoline, fuel oil, oil and chemicals, chlorine and so on. The direct use of these articles will be destructive for the survival environment and the human health but if we can take advantage of them which can be the most useful in our daily life and industry. Therefore, the issues related to hazardous chemicals become the focus on our researches, especially the transport process which is the most vulnerable to accidents. According to the statistics, 95% of hazardous chemicals are transported by highway and railway from producers to consumers in China.

With the globalization of the world economy and the deepen integration, China's relations with the world is deeper and deeper and China has entered a rapid development stage which led to the increase of hazardous chemicals demand. As the pillar industry of China's economy, industry developed particularly rapidly. Among them is the rapid development of chemical industry which promotes the demands of chemical transportation. But the accompanied is the increased of transportation risk. While in China, although the hazardous chemicals transportation accident probability is far less than the general ones but since the hazardous chemicals transportation and transportation quality cannot get a very good improvement, traffic accidents have occurred from time to time, so the research of hazardous chemicals transportation management, continuously improve the safety awareness and management level and to maintain the stable development of social economy, has a very important significance.

This study will research on the problems existed in the transportation of hazardous chemicals, analysis the characteristics of different transportation modes and select the railway and highway two modes. We will study the risk characteristics which will happen in the transportation and then establish the risk assessment model based on the railway and highway modes, so as to optimize the path, reduce transportation risk and provide a decision-making reference for government and enterprises.

LITERATURE REVIEW

Hazardous chemicals transportation risk assessments: In the risk assessment of hazardous chemicals transportation, since there are many risk factors affect the hazardous chemicals transportation, companied with the influence of randomness and uncertainty, quantitative risk assessment is more complex, as a result there's no unified method for risk assessment so far. Current and Ratick (1995) establish the evaluation method of hazardous chemicals highway transportation which balanced the risk, transport balance and cost; Zhang and Zhao (2007), from the aspects of accident rate and accident consequence simulation analyze the transport of hazardous chemicals risk.

Corresponding Author: Liu Liping, East China University of Science and Technology, No. 130 Meilong Road Shanghai, 200237, China

In order to make the risk evaluation is more accurate, more effective, domestic and foreign scholars have put forward several basic models to make quantitative research and many people then made some optimization models. For example, Abkowitz *et al.* (1992) proposed metric model to reflect the perceived risk; Erkut, (1995), on the basis of previous studies proposed "expected loss" to represent risk, think the risk is equal to the probability of the event multiply the event consequences; Sivakumar *et al.* (1995) proposed the conditional risk (after the accident risk value); Erkut and Ingolfsson (2000) puts forward the model of 3 big disaster to avoid the risk measurement since the characteristics of hazardous chemical transportation that is to say, low probability and high hazard, respectively with maximum exposure population, transport path on the minimum expected loss variance and the minimum expected effect to measure the risk of transportation; Erkut and Ingolfsson (2005) proposed three improved risk model, through the improvement of the accident rate makes the model more accurate.

The above researches, some are focus on evaluation to qualitative, some are quantitative while some are the accidents simulation. However, these risk assessment which were not fully considered the influence of various factors, the dynamic risk and transportation modes are less considered but the hazardous chemicals transportation risk is a dynamic process with the time changed, so many of which do not have a practical significance.

HAZARDOUS CHEMICALS TRANSPORTATION ROUTE RESEARCH

Risk assessment is aimed to select reasonable route, reduce the risk in maximum, so as to help enterprises decision-making provide reference, control the occurrence of disasters effectively. In previous literature, domestic and foreign scholars studied the path optimization and relationship of path optimization and the risk.

In the path selection, Chang *et al.* (2005) studied the problem of the route selecting in random condition, established the function based on the transportation time, the probability distribution of population coverage rate and accident rate and then gave a solution algorithm; Erkut and Gzara, (2008) for the government designated a bi-level programming model of hazardous goods transportation network and operators route selection; Verter and Kara (2008) established the hazardous goods route designed path model, in this model, the government shut down some roads so as to reduce the total risk of network to the minimum but they considered only total risk and ignored the distribution of risk in the network, as well as the transportation stakeholders; Bianco *et al.* (2009)adopted bi-level programming method considering the construction of road network transportation and translated it into single mixed integer programming problem; Kazantzi, *et al.*, (2011) thought of reducing the transportation costs and risk as the goal, to seek the best route meet the needs of the conditions.

The above research is to achieve the optimal transport path from the single mode but in the transport process, only one mode is obviously cannot meet the transportation requirements, different transportation modes combined is the tendency which can make use of their advantages, avoid their weaknesses, optimal transport path in order to reduce transportation costs as well as the risk.

PROBLEM DESCRIPTION AND MODEL

Problem description: This study presumes that in the same area, only the railway and highway two modes of transportation. From the origin to the destination, there are railway and highway two modes and a variety of transportation route choice, X_i, Y_i respectively, represents a truck or train in a path i and $R^H_i(t)$ and $R^R_i(t)$ represent the risk of choosing truck or railway. Since, the transportation is a dynamic process, so the risk is changing with the time and distance changed. This study considers the risk changing with time changed. And then set the different parameters in different time, as a result get a piecewise function to solve the time factor. C^H_i and C^R_i denote the fixed cost of highway transportation and railway transportation and C^H_i and C^H_i represent the time cost posed by the curfew, transportation delay and so on.

Model

Risk target: Based on the analysis of transportation risk, the risk can include four parts, namely the population risk, environment risk, property risk and combined transportation risk. Specifically, population risk will consider population density, population density, both sides population density and population point population; environmental risk will through the contaminated area; property risk is mainly measured by loss of property value, the damage of property loss, transportation equipment loss value and crop loss values; combined transportation risk is through evaluation factor and transfer station factor.

Through the above analysis, the target risk evaluation is as follows:

$$R = \min\left[\sum_i k_i X_i R_i^H(t) + \sum_i k_i Y_i R_i^R(t)\right]$$

Among:

$$R_i(t) = \alpha_1 R_{ip}(t) + \alpha_2 R_{ie}(t) + \alpha_3 R_{im}(t) + \alpha_4 R_{ic}(t)$$

$$R_{ip} = \sum_i \rho_i(t) * A_i * P_i(t) * L_i$$

$$R_{ie} = \sum_i (A_i^1 + A_i^2 + A_i^3 + A_i^4) * P_i(t) * L_i$$

$$R_{im} = \sum_i (Cap_i^1 + Cap_i^2 + Cap_i^3 + Cap_i^4) * P_i(t) * L_i$$

$$R_{ic} = \sum_i FM * X_i + FM * Y_i + TR * T_i$$

k_i	=	Area risk coefficient
X_i, Y_i	=	Decision variable (truck or train)
$R^H_i(t)$, $R^R_i(t)$	=	Risk values of truck or train
$R_{ip}(t)$	=	The population risk
$R_{ig}(t)$	=	The environmental risk
$R_{im}(t)$	=	The property risk
R_{ic}	=	Combined transportation risk
α	=	Adjustment coefficient
ρ	=	Population density
A	=	The area
L	=	The length
Cap	=	Equipment, goods, economic profit and economic compensation loss value
FM	=	Transportation factor
TR	=	Transfer factor

Cost target: Similar with the risk target, costs include two aspects, namely the transportation cost and the transfer cost.

Firstly, the transportation cost refers to, the fixed cost in highway or railway, transportation equipment, personnel, the procession cost; in addition, the transportation cost should also include the delay occurred in the transport process, the waiting cost, the transportation interruption cost etc..

Transfer cost is that transfer station operation cost, daily expenses etc. Therefore, the cost function is as follows:

$$\begin{aligned} C = \min\{&\sum_i X_i[C_i^H + C_i^H(t)] + \sum_i Y_i[C_i^R + C_i^R(t)] \\ &+ \max[0, (T - T_2) * M] \\ &+ \max[0, (T_1 - T) * S]\} + \sum_i C_i^{inter} \end{aligned}$$

Among:

$$C_i = C_0 + l_i \times \overline{C_i}$$

C^h_i, C^R_i	=	Fixed cost of truck or train
$C^H_i(t)$, $C^R_i(t)$,	=	Time cost caused by curfew, delay
C_0	=	Fixed cost of equipment, personnel *et al*
$\overline{C_i}$	=	The process average cost
$[T_1, T_2]$	=	Delivery time requirements
M	=	The default cost
S	=	The storage cost goods
C_i^{inter}	=	The operation cost of transfer station

Hazardous chemicals rail-truck transportation risk model:

$$\min R = \min\left[\sum_i k_i X_i R_i^H(t) + \sum_i k_i Y_i R_i^R(t)\right]$$

$$\begin{aligned} \min C = \min\{&\sum_i X_i[C_i^H + C_i^H(t)] + \\ &\sum_i Y_i[C_i^R + C_i^R(t)] + \max[0, (T - T_2) * M] \\ &+ \max[0, (T_1 - T) * S]\} + \sum_i C_i^{inter} \text{ s.t.} \end{aligned}$$

$$X_i = \begin{cases} 1 & \text{highway} \\ 0 & \text{others} \end{cases} \tag{1}$$

$$Y_i = \begin{cases} 1 & \text{railway} \\ 0 & \text{others} \end{cases} \tag{2}$$

$$\sum_i X_{ik} - \sum_i X_{ki} = \begin{cases} 1 & \text{origin} \\ -1 & \text{destination} \\ 0 & \text{others} \end{cases} \tag{3}$$

$$\sum_i Y_{ik} - \sum_i Y_{ki} = \begin{cases} 1 & \text{origin} \\ -1 & \text{destination} \\ 0 & \text{others} \end{cases} \tag{4}$$

$$\sum_i X_{ik} + \lambda_i \sum_i Y_{ik} - \sum_i X_{ki} - \lambda_i \sum_i Y_{ki} = 0 \tag{5}$$

$$1 - \lambda_i\left(\sum_i Y_{ik} - \sum_i Y_{ki}\right) = 0 \tag{6}$$

$$T_i = \left|\sum_i X_{ik} - \sum_i X_{ki}\right| \tag{7}$$

$$\sum_i T_i \times n \le \lambda_i \times CAP_i \tag{8}$$

$$5 \le t \le 24 \tag{9}$$

$$0 \le T_i \le 1 \tag{10}$$

$$\lambda_i = \{0, 1\} \tag{11}$$

Constraint (1-2) Respectively represent two kinds of transportation mode choice decision variables, (3) Said the flow conservation of road transportation, (4) Said the flow conservation of railway transportation, (5-6) Said the transfer station of the flow conservation, (7) Represents the transfer station of decision variables, (8) Represents the capacity limit of alternative transit station and (9) Stated that the expressway actual limit.

EXAMPLE ANALYSIS

Now we will transfer liquefied petroleum gas from point O to point I, known as the fixed cost is 10000, unit price is 17, the unit profit is 30, good weather, wind around level 5, fixed express road is 1, the transportation cost is 3. The specific route is as shown below:

The parameter is as follow

$M = 0.3 \quad S = 0.2 \quad [11, 12]$

A: 0.1 B: 0.3 C: 0.3
D: 0.2 E: 0.2 F: 0.4

O – A

$A^1 = 30000 \quad A^2 = 0 \quad A^3 = 0 \quad A^4 = 78000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 1 \quad C_0 = 0.5 \quad \overline{C}^H = 1.3 \quad t^H = 1$

$C^R = 0.7 \quad \overline{C}^H = 0.9 \quad t^R = 2$

O – A

$A^1 = 30000 \quad A^2 = 0 \quad A^3 = 0 \quad A^4 = 78000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 1 \quad C_0 = 0.5 \quad \overline{C}^H = 1.3 \quad t^H = 1$

$C^R = 0.7 \quad \overline{C}^H = 0.9 \quad t^R = 2$

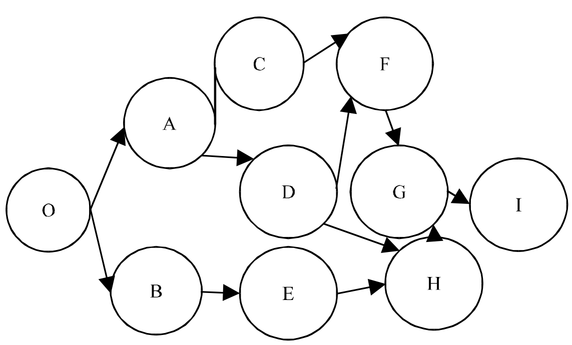

Fig. 1: Specific route for the transfer of liquefied petroleum

O – B

$A^1 = 50000 \quad A^2 = 2700 \quad A^3 = 0 \quad A^4 = 83000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 1.2 \quad C_0 = 0.5 \quad \overline{C}^H = 1.7 \quad t^H = 1$

A – C

$A^1 = 23000 \quad A^2 = 0 \quad A^3 = 0 \quad A^4 = 55000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 1.9 \quad C_0 = 0.5 \quad \overline{C}^H = 2.1 \quad t^H = 0.6$

$C^R = 0.9 \quad \overline{C}^H = 1 \quad t^R = 2.3$

A – D

$A^1 = 21000 \quad A^2 = 1700 \quad A^3 = 0 \quad A^4 = 41000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 1.2 \quad C_0 = 0.5 \quad \overline{C}^H = 1.6 \quad t^H = 1$

$C^R = 0.8 \quad \overline{C}^H = 0.9 \quad t^R = 2.1$

B – E

$A^1 = 0 \quad A^2 = 0 \quad A^3 = 0 \quad A^4 = 23000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 2.9 \quad C_0 = 0.5 \quad \overline{C}^H = 3.1 \quad t^H = 0.8$

$C^R = 1.2 \quad \overline{C}^H = 1.4 \quad t^R = 3.3$

D – F

$A^1 = 20000 \quad A^2 = 3500 \quad A^3 = 0 \quad A^4 = 50000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 1.3 \quad C_0 = 0.5 \quad \overline{C}^H = 1.7 \quad t^H = 1.2$

C – F

$A^1 = 15000 \quad A^2 = 1200 \quad A^3 = 0 \quad A^4 = 37000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 0.7 \quad C_0 = 0.5 \quad \overline{C}^H = 0.7 \quad t^H = 1$

$C^R = 0.5 \quad \overline{C}^H = 0.6 \quad t^R = 1$

F – G

$A^1 = 0 \quad A^2 = 0 \quad A^3 = 8800 \quad A^4 = 21000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 0.8 \quad C_0 = 0.5 \quad \overline{C}^H = 1 \quad t^H = 1.5$

E – H

$A^1 = 54000 \quad A^2 = 3100 \quad A^3 = 0 \quad A^4 = 92000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 1.3 \quad C_0 = 0.5 \quad \overline{C}^H = 1.7 \quad t^H = 1$

$C^R = 1 \quad \overline{C}^H = 1 \quad t^R = 1.8$

H – G

$A^1 = 0 \quad A^2 = 0 \quad A^3 = 0 \quad A^4 = 32000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 2.7 \quad C_0 = 0.5 \quad \overline{C}^H = 3 \quad t^H = 0.7$

$C^R = 1.2 \quad \overline{C}^H = 1.5 \quad t^R = 3$

$G-I$

$A^1 = 19000 \quad A^2 = 0 \quad A^3 = 0 \quad A^4 = 29000$

$Cap^1 = 390 \quad Cap^2 = 12 \quad Cap^3 = 3 \quad Cap^4 = 8$

$C^H = 1.3 \quad C_0 = 0.5 \quad \overline{C}^H = 1.7 \quad t^H = 1.1$

$C^R = 0.8 \quad \overline{C}^H = 0.9 \quad t^R = 2.3$

Transfer station factor:

A:2.1 B:3.6 C:2.7 D:5.5 E:1.3 F:7.9 G:0.3 H:6.1

Mode of transport factor:

Truck: 7.2 Rail: 0.9

According to the above parameters and with the help of MATLAB, we get the optimal route is that OB (Truck)-BE (Rail)-EH (Truck)-HG (Truck)-GI (Truck).

CONCLUSION

In the process of the hazardous chemicals transportation, enterprises would like to choose different modes to achieve the goal of reducing the cost and risk. Therefore, this study considered the railway and highway two modes and set up a model to achieve this goal and get the reasonable route in the end.

Through the above example analysis, we can obtain: 1.the different modes can greatly reduce transportation cost, at the same time, evade the risk to a certain degree. 2 the transportation mode selection should refer to the actually condition, only choose the lowest cost and risk is not the optimal choice. 3 in the logistics process, it inevitably involves the delivery problem, time-choosing would effectively reduce the transportation time, ensure accurate delivery. But in the actual transportation, time is affected by many factors and difficult to control.

Because the transportation is a time depended problem, coupled with the complexity of transportation network, is bound to lead to dynamic risk and variable cost because of the time-varying conditions. Therefore, research on time variability will be the focus.

ACKNOWLEDGMENT

This research was supported by the Humanities and Social Science Youth Fund from Ministry of Education for the project of “Research on dynamic risk assessment for transportation of dangerous chemicals” (No. 12JYC630120) and the National Nature Science Foundation of China (NSFC) for the project of Dynamic Environmental Risk Assessment and its Evolution Forecast of Hazardous Chemicals Accident” (No. 71001039). And this work was also supported by Fundament Research Funds for the Central Universities.

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