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/CET1871046

Risk Evaluation of Hazardous Chemicals Transportation Based on Fuzzy Comprehensive Evaluation

Huihui Jia[a,*], Chunxiao Li[a], Zunwen Wang[b], Ruizhi Yin[c]

[a] School of Management and Economics, Hebei University of Architecture, zhangjiakou 075000, China
[b] Zhangjiakou Academy of Agricultural Sciences zhangjiakou 075000, China
[c] School of Management and Economics, Tianjin University, Tianjin 300072, China
jiahuihuigy@163.com

The purpose of this study is to provide safety pre-warning and guarantee for the transportation of hazardous chemicals in transport enterprises. To this end, this paper conducts a risk assessment study on hazardous chemicals transportation based on fuzzy comprehensive evaluation (FCE) method. Taking the waterway transportation of transport enterprises as the research object, the fuzzy analytic hierarchy process (AHP) was selected and used to establish secondary index evaluation system from five aspects: transportation equipment, hazardous chemicals, man, transportation environment and enterprise management. Also, the analytic hierarchy process (AHP) was applied to configure the index weights. Thus, a fuzzy comprehensive risk assessment model for hazardous chemicals was established. The example analysis results show that the fuzzy risk assessment model can quantitatively evaluate the risk level of hazardous chemicals transportation. The risk score of a transport enterprise in Zhoushan is 66.2, which belongs to the general safety level with potential transportation risks. This provides effective theoretical guidance for risk assessment and orientation reform of hazardous chemicals transportation enterprises.

1. Introduction

China’s production areas of chemical raw materials are mainly concentrated in old industrial bases of the northeast and northwest China. In order to improve the international competition of China’s chemical products, chemical enterprises have been developing to coastal cities. Currently, there have been more than 60 chemical industrial parks in China’s coastal areas (Delgado and Rosa, 2015). The transportation of chemical raw materials from inland to coastal chemical enterprises and the international transportation of chemical products have brought great opportunities and challenges to China’s chemical product transportation enterprises (Ng and Goetz, 2017). In view of the huge transportation volume and existing safety risks of chemical products such as flammability, explosiveness, toxicity and corrosiveness etc., the safety of chemical waterway transportation is of great significance to ensure the stable development of China’s chemical industry.

The research on the transportation of hazardous chemicals in China started late. There exist certain gaps in the industry standard and hardware facilities from the foreign countries. In 2015 alone, there were 212 waterborne traffic accidents in China, causing economic losses of more than 300 million yuan (Winder et al., 2005). In the context of the increasing concern about the safety of hazardous chemicals in waterway transportation, domestic scholars have carried out research at various levels. Some scholars formulated guidelines for the loading, transportation and unloading of dangerous chemicals. Other scholars developed an accident statistics database to facilitate risk prediction for the same type of transportation safety accidents; fault tree analysis method, neural network method, grey system method, and Genetic algorithms etc. have been successfully applied in transportation risk assessment (Boudnaya et al., 2016; Hu and Raymond, 2004; Poorzare and Abedidarabad, 2017). Based on this, this paper takes the waterway transportation of hazardous chemicals as the research object and conducts special research (Nie and Zhang, 2018).

For this, in this paper, taking one transportation enterprise of hazardous chemical in Zhoushan as the research object, the comprehensive evaluation method was used to establish the secondary index evaluation

Please cite this article as: Jia H., Li C., Wang Z., Yin R., 2018, Risk evaluation of hazardous chemicals transportation based on fuzzy comprehensive evaluation, Chemical Engineering Transactions, 71, 271-276 DOI:10.3303/CET1871046

system, including 5 first-level indicators and 12 second-level indicators. Combining the advantages of AHP and fuzzy theory, the Fuzzy-AHP method was applied to calculate the index weights. Thus, a fuzzy comprehensive evaluation model for hazardous chemicals in waterway transportation was constructed. It's also applied to the risk assessment in the example.

2. Waterway transportation risk of hazardous chemicals

2.1 Risk management of hazardous chemicals in waterway transportation

Risk management is a discipline that studies the law of risk generation and adopts relevant measures and methods to control risks. The risk of hazardous chemicals in waterway transportation is mainly to ensure the safety of hazardous chemicals in the transportation process through risk identification, analysis and evaluation, and to avoid accidents of hazardous chemicals during the whole period of waterway transportation (Jun and Ling, 2008). Figure 1 shows the pattern of risk management process.

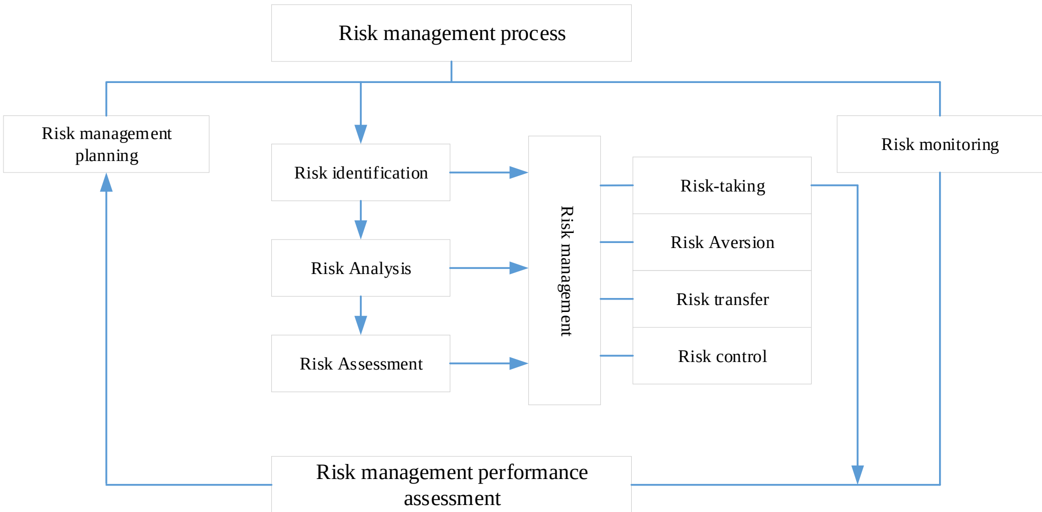

Figure 1: Pattern of risk management process

2.2 Risk analysis and risk assessment of hazardous chemicals in waterway transportation

2.2.1 Risk analysis

Risk analysis is to assess the risk based on the identification of risk factors and analyse the possibility of risk occurrence. Waterway transportation has developed rapidly in recent years, esp., in the first half of 2016 alone, the throughput of large-scale ports in the country reached 5.2 billion tons. The development of waterway transportation has promoted the large-scale hazardous chemicals and the development of chemical processing enterprises (Han-Gen, 2004).

With the increase of hazardous chemicals in waterway transportation, the frequency of hazardous chemicals transportation accidents has also grown. Such accidents as collisions, stranding, fire, explosion, and self-sinking etc. have caused huge loss of human safety and property (Luna et al., 2018).

2.2.2 Risk assessment

Risk assessment is based on risk management and analysis, using different quantitative and qualitative methods to evaluate the level of risk. Common assessment methods include: the Dow chemical index method, the six-stage method, and the Mond process etc. However, these methods have high subjectivity, complicated constraints and low accuracy. Therefore, one method with comprehensive evaluation effect is needed to evaluate the risk (Yang et al., 2018).

2.3 Risk identification of hazardous chemicals in waterway transportation

There are many factors influencing the transportation of hazardous chemicals. Table 1 mainly lists the safety factors that affect the waterway transportation of hazardous chemicals (Hanpattanakit, et al., 2018).

Table 1: The safety factors of hazardous chemicals waterway transportation

Safety factors	Description
Human factor	Management oversight capacity, Mastery of laws, regulations and standards, Operation of precision instruments and ships
Ship factor	Hardware of ship, Regular maintenance and maintenance of the ship
Environmental factor	Transport weather, transport channel
Cargo factor	Cargo packaging, cargo handling, Material inspection
Management factor	Enterprise security management, Risk management assessment

3. Risk Assessment of hazardous chemicals transportation based on fuzzy comprehensive evaluation method

3.1 Fuzzy comprehensive evaluation method

The concept of the fuzzy comprehensive evaluation (FCE) method is to quantitatively evaluate the object according to the fuzzy theory, firstly for the individual factor evaluation and then the comprehensive evaluation of all factors (Liu et al., 2018). It can be divided into the following five steps:
(1) Establishing the factor set;
The factor set is the combination of all the influencing factors, and it is denoted by U (Formula 1).

$$\mathrm{U} = \{u_1, u_2, \dots u_m\} \tag{1}$$

u_m indicates the influencing factors, and each influencing factor has different degrees of ambiguity.
(2) Establishing the weight set
The degree of influence on each factor is assigned with different weights, and important factors are reasonably selected. The set of weight index A is shown as:

$$\mathrm{A} = \{a_1, a_2 \dots a_m\} \tag{2}$$

(3) Establishing the evaluation sets
The evaluation set is a collection of evaluation structures given by the evaluator to the evaluation object (Ji, S. et al., 2000). The evaluation set V is given as:

$$\mathrm{V} = \{v_1, v_2 \dots v_m\} \tag{3}$$

(4) Single factor fuzzy evaluation
The single factor fuzzy evaluation is to evaluate each factor in the factor set, which can be expressed as:

$$R_i = \{r_{i1}, r_2, \dots r_{in}\} \tag{4}$$

(5) Fuzzy comprehensive evaluation
The fuzzy comprehensive evaluation is to multiply the weight by the single factor fuzzy evaluation matrix, and the fuzzy comprehensive evaluation is expressed as:

$$U = A \cdot R = (b_{ij}) \tag{5}$$

In formula 5, $b_{ij} = v_{k-1}^{n}(a_{ik} \wedge r_{ki})$, in which i=1,2,…m , j=1,2,…p , k=1,2,…,n, respectively indicating the number of columns in the weight set and the number of rows in the single factor evaluation set (Gong and Jin, 2009).
The traditional AHP is mainly based on the evaluator's understanding of problems and factors, paying more attention to the qualitative analysis and judgment, in which all the steps of judgment elements are processed by the brain and simplified into weight calculation. It is a method with a way of thinking that mimics the human brain (Guo et al., 2009). The Fuzzy-AHP just makes up for the shortcomings of the FCE method in qualitative analysis. Therefore, using the Fuzzy-AHP method to evaluate the risk of hazardous chemicals waterway transportation can avoid risks as much as possible and achieve better enterprise risk assessment management (Wei et al., 2010).

3.2 Fuzzy comprehensive risk assessment model

3.2.1 Risk assessment index system of waterway transportation

By comprehensively analysing the five factors of hazardous chemicals waterway transportation: man, ship, environment, cargo and management, the first and second level indicators were established, as shown in Table 2.

Table 2: The assessment index system

Target layer	Criteria layer (first layer index)	Index layer (second level index)
Risk assessment of dangerous chemicals in waterway transportation	Human factor U_1	Captain management ability U_{11}
		Crew average sea age U_{12}
		Crew qualifications U_{13}
		Crew operation level U_{14}
	Ship factor U_2	Ship type U_{21}
		Ship age U_{22}
		Ship facility equipment U_{23}
		Hull structural strength U_{24}
	Environmental factor U_3	Weather condition U_{31}
		Watershed geography U_{32}
		Water traffic environment U_{33}
	Cargo factor U_4	Hazard of the item U_{41}
		Item packaging quality U_{42}
		Dangerous goods stowage situation U_{43}
	Management factor U_5	Maritime supervision U_{51}
		Emergency plan completeness U_{52}
		Corporate organization rationality U_{53}

After establishing a complete index system, it is necessary to rate the safety level of hazardous chemicals in waterway transportation. According to the levels of “lower risk, low risk, general, high risk, higher risk”, the corresponding scores of V = 100, 80, 60, 40, 20 are rated.

3.2.2 Determining index weights based on AHP

Taking one certain chemical enterprise in Zhoushan as the research object for transportation risk, it conducts research on man, ship, waterway, cargo, and management, etc., and then scores the management ability of the enterprise through expert scoring (Gass, 2001).
The judgment matrix S was constructed, and the first-level index weights (Formula 6) were obtained according to the survey questionnaire of the enterprise.

$$S=\begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} \\ C_{21} & C_{22} & C_{23} & C_{24} & C_{25} \\ C_{31} & C_{32} & C_{33} & C_{34} & C_{35} \\ C_{41} & C_{42} & C_{43} & C_{44} & C_{45} \\ C_{51} & C_{52} & C_{53} & C_{54} & C_{55} \end{bmatrix}=\begin{bmatrix} 1 & 7/5 & 3/5 & 5/9 & 6/9 \\ 5/7 & 1 & 7/9 & 5/9 & 4/9 \\ 5/3 & 9/7 & 1 & 7/9 & 5/9 \\ 9/5 & 9/5 & 9/7 & 1 & 3/9 \\ 9/6 & 9/5 & 9/7 & 9/3 & 1 \end{bmatrix} \quad (6)$$

The maximum eigenvalue λ_{max}=4.0317 of the matrix was calculated, and the structure CR for the matrix consistency check was less than 0.1, so the weight coefficient is within a reasonable range. The weight coefficient of the first-level indicator was derived as A_1=(0.283, 0.205, 0.152, 0.216,0.144).
Similarly, the weight coefficient of the 2-level indicators for the transport of hazardous chemicals was calculated as: human factors (0.305, 0.267, 0.103, 0.325), ship factors (0.234, 0.121, 0.305, 0.34), environmental factors (0.303, 0.345, 0.352), cargo factor (0.402, 0.336, 0.262), and management factor (0.285, 0.482, 0.333).

3.2.3 Establishment of fuzzy comprehensive evaluation model

(1) Comprehensive evaluation of weighted fuzzy operators
The fuzzy weighted average operator was used to achieve the weight rationality of each factor. It’s calculated as:

$$b_i=\sum_{i=1}^{p}(a_i\cdot r_{ij})=min\{1,\sum_{i=1}^{p}a_i\cdot \gamma_{ij}\},\ \ j=1,2,\dots,m \quad (7)$$

where, b_i is the membership degree, a_i and γ_{ij} is the weight of the i-th evaluation index and the membership degree of the i-th evaluation index belonging to the j-th level, respectively.
(2) Multi-level fuzzy comprehensive evaluation result vector
According to the survey of membership degree for each first-level and second-level evaluation indicators, the fuzzy membership degree evaluation matrix R_i was obtained. Then, based on $B_1=A_i\cdot R_j$, the fuzzy comprehensive evaluation of each level was calculated. Below is the calculation process of human factors, ship factors, and environment factors and also the calculation results of cargo and management factors.

$$B_1 = (0.305,0.267,0.103,0.325) \cdot \begin{bmatrix} 0.0198 & 0.0763 & 0.3192 & 0.4040 & 0.1808 \\ 0.0226 & 0.1045 & 0.3390 & 0.3644 & 0.1695 \\ 0.0706 & 0.1667 & 0.2966 & 0.3051 & 0.1610 \\ 0.0503 & 0.2306 & 0.2154 & 0.2996 & 0.2031 \end{bmatrix} =$$

(0.0487,0.2311,0.3179,0.2861,0.1162);

$$B_2 = (0.234,0.121,0.305,0.34) \cdot \begin{bmatrix} 0.0198 & 0.0650 & 0.1864 & 0.4040 & 0.1808 \\ 0.0282 & 0.0904 & 0.1638 & 0.4944 & 0.2232 \\ 0.0254 & 0.1102 & 0.2260 & 0.4011 & 0.2373 \\ 0.0304 & 0.2206 & 0.2996 & 0.2996 & 0.1498 \end{bmatrix} =$$

(0.0319,0.1393,0.2743,0.3757,0.1788);

$$B_3 = (0.303,0.345,0.352) \cdot \begin{bmatrix} 0.1356 & 0.2401 & 0.2241 & 0.3142 & 0.0960 \\ 0.0204 & 0.1385 & 0.3623 & 0.3944 & 0.0847 \\ 0.0226 & 0.1045 & 0.3390 & 0.3644 & 0.1695 \end{bmatrix} =$$

(0. 0247,0.0913, 0.1956,0.4491,0.2393)

$$B_4 = (0.0250,0.1506,0.2818,0.3747,0.1679)$$

$$B_5 = (0.1393,0.2743,0.3757,0.1788,0.0319)$$

(3) Comprehensive risk rating

The first-level indicator $A_1 \cdot B_i$ was adopted to obtain the final evaluation result of membership degree B:

$$\mathrm{B} = (0.283,0.205,0.152,0.216,0.144) \cdot \begin{bmatrix} 0.0487 & 0.2311 & 0.3179 & 0.2861 & 0.1162 \\ 0.0319 & 0.1393 & 0.2743 & 0.3757 & 0.1788 \\ 0.0247 & 0.0913 & 0.1956 & 0.4491 & 0.2393 \\ 0.0364 & 0.1403 & 0.3179 & 0.2861 & 0.2193 \\ 0.0250 & 0.1506 & 0.2818 & 0.3747 & 0.1679 \end{bmatrix} =$$

(0. 1393, 0.2743, 0.3757,0.1788, 0.0319)

The transportation risk safety rating of the hazardous chemical transportation enterprise in Zhoushan is shown as:

$\mathrm{P} = \mathrm{BV}$=0. 1393×100 + 0.2743× 80 + 0.3757× 60+0.1788× 40+ 0.0319× 20=66.206 (8)

Therefore, the safety risk assessment results of this enterprise are at a general level according to the rating of the safe transportation risk scale. The weight coefficient calculation and data analysis show: the ship indicators and enterprise management indicators are in the higher risk range; the environmental indicator belongs to a safer risk range; the cargos and personnel indicators belong to the general risk range, which indicates that the main transportation risk of the enterprise exists in the management and ship factors. Thus, the targeted investment in management training and hardware design is required to reduce the risk of waterway transportation of hazardous chemicals. Also, the risk monitoring should be provided to minimize the occurrence probability of risks.

4. Conclusions

Risk assessment is a necessary condition for risk management and risk control. With the increasing demand for hazardous chemicals, it is of great significance to quantitatively and qualitatively evaluate the risk of hazardous chemicals transportation. Based on the fuzzy comprehensive evaluation method, this paper conducts risk analysis, risk assessment and risk identification for hazardous chemicals waterway transportation, and establishes a fuzzy comprehensive risk assessment model. Then, it applies this model d to evaluate the risk of hazardous chemicals transportation in one certain chemical transportation enterprise. The main findings are as follows:

(1) Innovative use of the Fuzzy-APH method combining the advantages of both can quantitatively and qualitatively evaluate the weight of risk factors, so that the accuracy of risk assessment can be improved.
(2) Based on the first-level and second-level index evaluation system, the evaluation model was established. The evaluation value of the chemical enterprise in Zhoushan was 66.206, indicating that the risk management of the enterprise is at a general level and the risk management level needs to be improved.

Acknowledgments

This work is supported by Science and Technology Project of Financial Assistance in Zhangjiakou in 2016 (1611074I): The Innovative research of Project Quality Management Model Based on Lean Thought.

References

Boudnaya J., Mkhida A., Sallak M., 2016, A reliability evaluation of the Moroccan level crossing system using fault tree modelling and importance measures, Journal Europeen des Systemes Automatises, 49(4-5), 487-502, DOI: 10.3166/JESA.49.487-502

Delgado L.A., and Rosa E.P., 2015, Energy intensity in road freight transport of heavy goods vehicles in Spain. Energy Policy, 85, 309-321. DOI: /10.1016/j.enpol.2015.06.018

Gass S.I., 2001, The analytic hierarchy process--an exposition. Operations Research, 49(4), 469-486.

Gong L., and Jin C., 2009, Fuzzy comprehensive evaluation for carrying capacity of regional water resources. Water Resources Management, 23(12), 2505-2513. DOI: /10.1007/s11269-008-9393-y

Guo L., Gao J., Yang J., and Kang J., 2009, Criticality evaluation of petrochemical equipment based on fuzzy comprehensive evaluation and a bp neural network. Journal of Loss Prevention in the Process Industries, 22(4), 469-476. DOI: /10.1016/j.jlp.2009.03.003

Han-Gen C., 2004, Disaster accident management of hazardous chemicals reacting with water. Fire Science & Technology.

Hanpattanakit P., Pimonsree L., Jamnongchob A., and Boonpoke A., 2018, Co2 emission and reduction of tourist transportation at kok mak island, thailand. Chemical Engineering Transactions, 63.

Hu C.Y., and Raymond D.J., 2004, Lessons learned from hazardous chemical incidents—louisiana hazardous substances emergency events surveillance (hsees) system. Journal of Hazardous Materials, 115(1), 33-38. DOI: /10.1016/j.jhazmat.2004.05.006

Ji S., Li X., Ma Y., and Cai H., 2000, Optimal tolerance allocation based on fuzzy comprehensive evaluation and genetic algorithm. International Journal of Advanced Manufacturing Technology, 16(7), 461-468. DOI: /10.1007/s001700070053

Jun W., and Ling C.Y., 2008, Risk assessment of hazardous chemical materials waterborne transportation based on fuzzy comprehensive assessment. Journal of Dalian Maritime University.

Liu J.G., Wang J.J., Zhou H., and Zhang Y.Q., 2018, Research on supervision problems of port hazardous chemicals base on security risk level. Systems Engineering-Theory & Practice.

Luna J.M., Pinto A.A.L., Pinto M.I.S., Brasileiro P.P.F., Rufino R.D., and Almeida, D. G., 2018, Production in bioreactor and application of biosurfactant in dissolved air flotation for the treatment of industrial effluents. Chemical Engineering Transactions, 64.

Ng C.A., and Goetz N.V., 2017, The global food system as a transport pathway for hazardous chemicals: the missing link between emissions and exposure. Environmental Health Perspectives, 125(1), 1-7. DOI: /10.1289/ehp168

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

Poorzare R., Abedidarabad S., 2017, Optimizing optical networks by using CWN algorithm, Review of Computer Engineering Studies, 4(3), 98-102, DOI: 10.18280/rces.040303

Wei B., Wang S.L., and Li L., 2010, Fuzzy comprehensive evaluation of district heating systems. Energy Policy, 38(10), 5947-5955. DOI: /10.1016/j.enpol.2010.05.048

Winder C., Azzi R., and Wagner D., 2005, The development of the globally harmonized system (ghs) of classification and labelling of hazardous chemicals. Journal of Hazardous Materials, 125(1), 29-44.

Yang Q., Chin K.S., Li Y.L., 2018, A quality function deployment-based framework for the risk management of hazardous material transportation process. Journal of Loss Prevention in the Process Industries, 52. DOI: 10.1016/j.jlp.2018.02.001.