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Analysis of Hazardous Chemicals Transportation Accidents and Transportation Management

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The causes of hazardous chemicals transportation accidents include direct and indirect causes, among which the lack of management is an important one. Through structural equation modelling, this paper constructs a hypothetic relationship between management factors and direct influencing factors to hazardous chemicals transportation accidents, and conducts an empirical analysis. It is found that hazardous chemicals transportation enterprises should be responsible for the management on personnel, vehicle facilities and transportation process, that the transportation authority should be responsible for the management on road transportation of hazardous chemicals and that other regulatory authorities should be responsible for the management on hazardous chemicals transportation vehicles and facilities and emergency rescue.

1. Introduction

Hazardous chemicals are materials or substances that will endanger the health and safety of people, environment and property, as well as those included in the lists of hazardous chemicals (specified by the State or organizations) or classified as hazardous chemicals in accordance with the laws and regulations. According to the two national classification standards - Classification and Labels of Hazardous Chemical Substances Commonly Used (GB13690-92) and Classification and Coding of Dangerous Goods (GB6944-86), hazardous chemicals are divided into 8 categories by their hazardousness: explosives; flammable solids, spontaneously combustible articles and wet flammable articles; radioactive materials; compressed gases and liquefied gases; oxidizing agents and organic peroxides; flammable liquids; toxic and infectious products; and corrosive products. With the rapid development of the petroleum, petrochemical, coal, chemical and other industries in China, the variety and quantity of hazardous chemicals are increasing, and their demands are also increasing. According to statistics, there are 3823 types of hazardous chemicals produced and used in China, of which 335 are highly toxic. According to the data released by the State Administration of work safety, in China, the daily transportation volume of hazardous chemicals exceeds 1 million tons, and the total annual volume exceeds 4 billion tons; the total output of hazardous chemicals has reached 14 million tons; and so far there have been 310,000 entities engaged in this industry, including 25014 in production, 11071 in warehousing, 136735 in operation, 9796 in transportation, 135310 users and 709 in waste disposal. Most of the hazardous chemicals involve the problem of off-site transportation. Because hazardous chemicals are flammable, explosive and highly corrosive, transportation of these materials can be very dangerous. If a hazardous chemical transportation accident occurs, it will cause great losses of properties and social influence. According to relevant data, about 40% of the accidents involving the explosion of hazardous chemicals on the road occurred in the course of transportation (Yang et al., 2010). Road transportation is the main mode of transportation for hazardous chemicals, but it is professionally demanding, highly risky, procedurally complicated and managerially challenging. The leakage, combustion and explosion caused by various accidents not only cause direct casualties and property losses, but also lead to secondary pollution to the surrounding atmosphere, water and soil environment, and cause unexpected environmental events. Therefore, the transportation of hazardous chemicals is closely related to the safety of people's lives, properties and ecological environment.

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2. Characteristics of hazardous chemicals transportation

The transportation of hazardous chemicals is a special kind of transportation, in which unconventional goods are carried on special vehicles by specialized agencies or professional technicians. The operation enterprises must be strictly examined by relevant national functional departments, and obtain appropriate qualifications, and their facilities and equipment must undergo strict inspection and obtain relevant certificates. Such transportation of hazardous chemicals have typical characteristics.

2.1 Strict admittance system

According to relevant provisions in the Regulations on Safety Management of Hazardous Chemicals, an enterprise must meet the following conditions to obtain the qualification for road transportation of dangerous goods: (1) having 10 and more special transport vehicles; (2) having 5 or more years of experience in transportation and operation and mature management experience; (3) having professional technicians and management personnel with appropriate qualifications; (4) sound safety operation procedures, clear post responsibility system, vehicle and equipment maintenance rules and mature staff safety education system in place; (5) obtaining the license for road transport of dangerous goods according to relevant laws and regulations, and completing registration in the administrative department of industry and commerce. All entities who intend to apply for commercial road transportation of dangerous goods, and those that have obtained the qualifications for commercial road transportation but need to add more items into their lists of dangerous goods permitted for road transportation must submit written applications to their local county road transport administration authorities in accordance with the regulations. The Road Transport License and the Road Transport Operation Permit can only be used exclusively for road transportation of dangerous goods.

2.2 Strict classification of goods

The requirements for transport of hazardous chemicals are very strict, including meticulous cargo classification and strict packaging and identification of goods. Any entity engaged in such transport should classify chemicals and carry out the packaging and labeling of all kinds of goods strictly in accordance with the United Nations Regulations on the Transport of Hazardous Goods (the internationally accepted classification standard for dangerous goods), Classification and Labels of Hazardous Chemical Substances Commonly Used and Classification and Coding of Dangerous Goods.

2.3 Special vehicles and personnel

In accordance with the requirements of the Administrative Regulations on the Road Transportation of Dangerous Goods, hazardous chemicals must be transported by specially designed vehicles. The technical performance of the vehicles must reach Level 1 industry standard and the requirements of the relevant national standards. In addition, high-level communication equipment must be provided, warning signs obvious and fire protection facilities complete. Employees (including drivers, loading/unloading and escort, etc.) must pass the professional examinations held by the municipal management authority, and obtain the qualification certificates before getting onboard.

3. Literature review

People, vehicle and environment are the main factors to the potential danger in the road transport of dangerous goods. Judging from the actual management experience, the management factors are the fundamental cause of the hazardous chemicals transportation accidents. The management factors refer to the negligence of the enterprise in safety and the supervision loopholes of the management departments in all aspects of the dangerous goods transportation. There are great potential hazards during the transportation of hazardous chemicals, so the transportation process must be subject to safety supervision. Effective management is the first line of defense against accidents. If there is any loophole in management, accidents resulting from human factors will not be effectively prevented. In terms of accident analysis, Bu et al. (2014) used fault tree analysis to identify risk sources. Bagheria et al. (2012) constructed a risk source identification model based on the consequences of transport accidents. Pelenyte-Vysniauskiene et al. (2011) assessed the risks by using the compound distribution of the risk levels. Qiu et al. (2015) put forward a quantitative analysis method for hazardous chemicals transportation accidents using the valuation-based theory and trust function.
Thierheimer et al. (2010) assessed the risks during the whole transportation process of hazardous chemicals, and pointed out the factors such as human, vehicle, environment and so on. Kirytopoulos et al. (2014) focused on the organizational and human factors in road transportation of hazardous chemicals. Kazantzi et al. (2011) assessed and analyzed the probabilities of the causes of hazardous chemical transportation accidents and also the different risk factors to the transportation network of hazardous chemicals, and explained the impacts of the risk events with different probabilities on transportation costs. Schubert et al. (2012) used the Bayesian

method to analyze and calculate the probability of traffic accidents and carried out risk assessment.
After establishing an accident network modeling prediction method, Baksh (2015) used the Bayesian network method to calculate the posterior probability of adverse events. Khakzad et al. (2015) used precursors and approximate reasoning as precursory data to predict the probability of major accidents.
In the aspect of cause analysis and probability analysis of hazardous chemicals transportation accidents, many enterprises started from safety management, and studied the factors like human, material, environment and so on. However, they did not pay much attention to the management factors and failed to study the comprehensive relationships between management and human, material and environmental factors. This paper attempts to construct a risk assessment system and model for the road transport of hazardous chemicals to analyze the hierarchical relationships between human, material, environment and management factors and find out the key factors and then puts forward the corresponding risk prevention measures.

4. Analysis of the causes of hazardous chemicals transportation accidents

4.1 Causality between direct causes of and management factors to hazardous chemicals transportation accidents and

In the analysis of the relationships between risk factors and management factors, Dong et al. (2013) put forward the safety risk factors to the road transport of hazardous chemicals, and emphasized the importance of safety management. Ma et al. (2014) studied the relationships between uncertain factors and the safety of hazardous chemicals road transportation, and carried out safety management evaluation under uncertain conditions. Xi et al. (2014), through the dynamic simulation of the hazardous chemical transportation management system, analyzed the causal relationships of five major risk factors, and put forward that the management factors play an important role in reducing the risks. Liu et al. (2008) studied the risks of water pollution accidents caused by spills of hazardous chemicals during road transportation. Verma et al. (2012) proposed a two-objective programming model, with one objective being to minimize the transportation cost, and the other to minimize the transportation risk. Zou et al. (2011) analyzed the current safety management on road transportation of hazardous chemicals.

4.2 Cause mechanism of hazardous chemical transportation accidents

Through the literature review, it is found that the causes of hazardous chemicals transportation accidents include vehicle collision, overloading, rear-end accidents and aging vehicle transportation facilities. The damages caused to the transportation vehicles and facilities during the accidents further lead to the spills of hazardous chemicals. If not handled and disposed of properly, hazardous chemicals will pollute the environment, infect human and livestock and what is more, combustible materials may be ignited or even explode. The occurrence of hazardous chemicals transportation accidents reflects negligence or loopholes in management.
Transportation vehicles and facilities, personnel management, market management, risk prevention, emergency management and related management systems are important throughout the whole transportation process of hazardous chemicals, and can bring many impacts on the safety of transportation. Transportation route planning, traffic network construction, transportation route approval, transport process management, transportation enterprise performance management and transportation environment protection are also the main factors affecting the safety of hazardous chemicals transportation. Vehicle collision, overloading, driving errors and equipment aging are the direct causes of hazardous chemical transportation accidents, while the negligence and loopholes in management are the indirect causes. Proper management can avoid the direct causes and reduce the accident probability.

5. Research hypotheses

For the hazardous chemicals transportation enterprises, the management of the hazardous chemicals transport employees is mainly reflected in their recruitment, training, performance assessment and daily management; the management of transport vehicles and facilities is reflected in the purchase, use and maintenance; emergency management is mainly reflected in the internal self-aid and emergency facility systems; the management of transportation process is mainly embodied in the aspects of transportation route planning, transportation network construction, transportation process development, and basic operation standard implementation. Based on this, the following hypotheses are proposed.
H1a: there is a positive correlation between the internal management and the employee management.
H1b: there is a positive correlation between the internal management and the vehicle facility management.
H1c: there is a positive correlation between the internal management and the emergency management.
H1d: there is a positive correlation between the internal management and the transportation process

management.

The supervision and management on transportation of hazardous chemicals by the transportation authority consists of “one level of approval and four levels of supervision”. It is responsible for the prior permission, supervision and post-event management of vehicles and containers and the examination of personnel qualifications and the establishment of enterprise safety management system and emergency rescue system. Based on this, the following hypotheses are proposed.

H2a: there is a positive correlation between the management by the transportation authority and the employee management.

H2b: there is a positive correlation between the management by the transportation authority and the vehicle facility management.

H2c: there is a positive correlation between the management by the transportation authority and the emergency management.

H2d: there is a positive correlation between the management by the transportation authority and the transportation process management.

Other regulatory authorities, including the public security, quality inspection, environmental protection, health, industry and commerce and tax authorities, are responsible for formulating relevant laws, regulations, rules and industrial standards for the management of hazardous chemicals transportation, standardizing the transportation process of hazardous chemicals, and giving guidance, supervision and management on the relevant aspects of transportation. Based on this, the following hypotheses are proposed.

H3a: there is a positive correlation between the management by other regulatory authorities and the employee management.

H3b: there is a positive correlation between the management by other regulatory authorities and the vehicle facility management.

H3c: there is a positive correlation between the management by other regulatory authorities and the emergency management.

H3d: there is a positive correlation between the management by other regulatory authorities and the transportation process management.

On the basis of the above research hypotheses, a risk management model for hazardous chemicals transportation is proposed.

6. Empirical analysis

6.1 Data sources

The structural equation model is an empirical analysis model, whose idea is to present the objective state of things in the form of causal hypothesis, and then use quantitative data to verify it. According to the research hypotheses, the author designed a 5-point Likert scale containing 28 items for online questionnaire survey. The questionnaires were issued and collected by a third-party network survey site, and finally 285 valid questionnaires were obtained. The number of questionnaires was more than 200, which is appropriate for the structural equation model analysis (Loehlin, 2004).

6.2 Fitting test

Table 1: Test result of fitness degree

Fitness index	Index value	Standard of adaptation	Fit degree analysis
Chi square value	p=0.204	p > 0.05	Reasonable matching
GFI	0.911	> 0.90	Reasonable matching
IFI	0.914	> 0.90	Reasonable matching
CFI	0.922	> 0.90	Reasonable matching
RMR	0.009	< 0.05	Reasonable matching

The hypotheses of the structural equation model were tested by SPSS21.0 and AMOS21.0 software. It was found that the Cronbach’s α of all the latent variables was more than 0.700, indicating that the scale is highly reliable; the KMO value was more than 0.700, and the Sig value of the statistics in the Bartlett spherical test was less than 0.01, indicating that there are significant correlations between the variables, and that factor analysis is suitable. The load of each measurement index is greater than 0.500 on the respective attributable factor, which shows that the scale has good convergence validity and discriminant validity. The combined reliability (CR) of each variable was greater than 0.700, and the average variance extracted (AVE) was greater

than 0.500. The internal consistency and validity of the scale were both good. According to the above reliability and validity analysis, the questionnaire has good reliability and validity, and can be used to further analyze the relationships between latent variables. In the analysis of the fitness degree between the measured data and the structural equation model, the absolute fitness statistics, including the chi square value, GFI, CFI and RMR, are all shown in Table 1, indicating that the overall fitness of the model is reasonable, that is, the structural equation model is fit with the actual survey data.

6.3 Hypothesis research

According to the survey data, the hypothesis test was carried out using the AMOS21.0 software, and the test results are shown in Table 2.

Table 2: Research hypothesis test results

Research hypothesis	Estimate	C.R.	P	Result
H1a	0.314	3.346	***	Accept
H1b	0.315	2.344	0.003	Accept
H1c	0.103	2.262	***	Reject
H1d	0.389	5.346	***	Accept
H2a	-0.126	1.312	0.721	Reject
H2b	0.827	-2.870	0.023	Reject
H2c	0.241	-6.870	0.129	Reject
H2d	0.227	3.564	***	Accept
H3a	0.027	4.352	***	Reject
H3b	0.282	2.498	0.005	Accept
H3c	0.386	2.382	***	Accept
H3d	0.161	1.554	***	Reject

Note: "***" means $P < 0.001$

Through analysis, the hypotheses H1a, H1b, H1d, H2d, H3b and H3c are accepted. According to the results, it is found that the internal management of an enterprise has a positive correlation with the management of employees, vehicle facilities and transportation process; that the transportation authority has a positive correlation with the transportation process management, and that other regulatory authorities have a positive correlation with the vehicle facilities and emergency management. There is no positive correlation between the enterprise internal management and the emergency rescue, nor is there any positive correlation between the transportation authority and the management of employees, vehicle facilities and emergency management, or between other regulatory authorities and the management of employees and the transportation process.

7. Conclusions

Based on the hypothetic causality between the causes of hazardous chemicals transportation accidents and the underlying management factors, this paper uses the structural equation model to classify the causes of accidents into human, vehicle and environment, and then attribute these causes to management loopholes and negligence. The research results indicate that management factors have significant indirect impacts on hazardous chemicals transportation accidents.

(1) Hazardous chemicals transportation enterprises should be responsible for the management on their personnel, vehicles, facilities and transportation processes. Any enterprise will have potential risks in hazardous chemicals transportation if any enterprise has negligence in the recruitment, training and daily management of its employees, or imposes poor supervision on the safety operation of transportation vehicles and facilities, or fails to do well in transportation route planning, transportation process development and transportation operation planning.

(2) The transport authority has the primary responsibilities for management on the road transportation of hazardous chemicals, especially in the approval of transportation routes, supervision on the safety of transportation networks and the supervision on the safety of transportation enterprises. Otherwise, it will indirectly lead to risks in the transportation of hazardous chemicals.

(3) Other regulatory authorities have major responsibilities for the vehicles and facilities management and emergency management. They should strengthen daily safety supervision on vehicles and facilities used for the production, storage, use, operation and transportation of hazardous chemicals. In order to prevent damages and avoid great losses, it is important that they should improve emergency management and establish an interconnected accident information communication and detection network.

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