Risk Evaluation of Hazardous Chemicals Transportation Based on Fuzzy Comprehensive Evaluation

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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.
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](image)

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

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

### 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).
   
   $$U = \{u_1, u_2, \ldots, u_m\}$$ (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:
   
   $$A = \{a_1, a_2, \ldots, a_m\}$$ (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:
   
   $$V = \{v_1, v_2, \ldots, v_m\}$$ (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:
   
   $$R_i = \{r_{i1}, r_{i2}, \ldots, r_{in}\}$$ (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:
   
   $$U = A \cdot R = (b_{ij})$$ (5)

In formula 5, $b_{ij} = v_k^n \left( a_{ik} \land r_{ki} \right)$, in which $i=1,2,\ldots,m$, $j=1,2,\ldots,p$, and $k=1,2,\ldots,n$, 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

<table>
<thead>
<tr>
<th>Target layer</th>
<th>Criteria layer (first layer index)</th>
<th>Index layer (second level index)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human factor $U_1$</td>
<td>Captain management ability $U_{11}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crew average sea age $U_{12}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crew qualifications $U_{13}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crew operation level $U_{14}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ship type $U_{21}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ship age $U_{22}$</td>
<td></td>
</tr>
<tr>
<td>Ship factor $U_2$</td>
<td>Ship facility equipment $U_{23}$</td>
<td></td>
</tr>
<tr>
<td>Environmental factor $U_3$</td>
<td>Hull structural strength $U_{31}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weather condition $U_{32}$</td>
<td></td>
</tr>
<tr>
<td>Cargo factor $U_4$</td>
<td>Watershed geography $U_{41}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weather traffic environment $U_{42}$</td>
<td></td>
</tr>
<tr>
<td>Management factor $U_5$</td>
<td>Hazard of the item $U_{43}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Item packaging quality $U_{44}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dangerous goods stowage situation $U_{45}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maritime supervision $U_{51}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Emergency plan completeness $U_{52}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corporate organization rationality $U_{53}$</td>
<td></td>
</tr>
</tbody>
</table>

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.

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

The maximum eigenvalue $\lambda_{max} = 4.0317$ 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:

$$
b_{ij} = \sum_{i=1}^{p} \alpha_i \cdot r_{ij} = \min \left\{ 1, \sum_{i=1}^{p} a_i \cdot y_{ij} \right\}, \quad j = 1, 2, \ldots, m
$$

where, $b_{ij}$ is the membership degree, $a_i$ and $y_{ij}$ 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 $B_1 = A_1 \cdot R_1$, 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.
(0.0319, 0.1393, 0.2743, 0.3757, 0.1788);

\[ B_3 = (0.0250, 0.1506, 0.2818, 0.3747, 0.1679) \]

\[ B_5 = (0.1393, 0.2743, 0.3757, 0.1788, 0.0319) \]

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

\[ P = B \times V = 0.1393 \times 100 + 0.2743 \times 80 + 0.3757 \times 60 + 0.1788 \times 40 + 0.0319 \times 20 = 66.206 \]

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 to evaluate the risk of hazardous chemicals transportation in a 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

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