Research Article

Risk Field Model Construction and Risk Classification of Hazardous Chemical Transportation

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To reduce the risk of hazardous chemical road transportation, domestic and foreign scholars have analyzed transportation risks from theoretical points of view and built risk assessment models. Based on 483 cases of hazardous chemical road transportation accidents from 2015 to 2019, this paper analyzes the causes of accidents from the perspective of traffic regulations and constructs a risk field model of hazardous chemical transportation. Through the simulation of an accident by TruckSim, a risk classification is completed according to the risk field model of hazardous chemical transportation. The results show that the model can be used to evaluate the risk of hazardous chemical transportation in complex environments and provide criteria for the safe control of hazardous chemical transportation vehicles.

1. Introduction

Hazardous chemicals can be flammable, explosive, toxic, harmful, or radioactive, any of which can endanger human health and pollute the natural environment [1]. After an accident involving a hazardous chemical transport vehicle, the leakage of hazardous chemicals can easily cause considerable economic losses, pollute the surrounding environment, and even endanger people’s lives. For example, in May 2017, a tank car transporting sodium chlorate in a high-speed tunnel in Hebei Province had a combustion and explosion accident, causing a very bad impact; in June 2020, an explosion accident occurred in a LPG tanker in Zhejiang, causing a large number of casualties among surrounding residents and a bad social impact.

How to ensure the safety of hazardous chemicals during transportation, reduce casualties and property losses, and put forward effective suggestions to avoid the recurrence of such accidents is the main problem at this stage. Scholars have evaluated driving risk by building driving risk models and have achieved notable results. Wang and Shi [2] analyzed the trend of traffic accident risk change under the superposition of multiple factors and constructed a traffic accident risk measurement model. Dong et al. [3] constructed an evaluation index system based on the interpretative structural modeling (ISM) model of hazardous chemical road transportation risk and then judged the influence degree of each risk element on hazardous chemical transportation. Hu et al. [4] constructed an accident risk assessment model based on a driver’s characteristics by analyzing their driving behavior, which provides a basis for active vehicle safety control research. Peng et al. [5] proposed a local path planning algorithm based on discrete optimization, which uses cost function to evaluate the safety and smoothness of discretely generated candidate paths, and then obtains the local optimal path through the weighted calculation of each cost function.

It is noted that most of the existing traffic risk assessment models mentioned above focused on whether an accident occurs, and the classification of risk level is not clear. However, the risk of hazardous chemical transportation is constantly changing, not a simple “0” or “1” problem [6]. To
judge the transportation risk of hazardous chemicals, it is necessary to classify the risk field model.

Therefore, in this paper, we will use the statistics of the accident case database of the China Chemical Safety Association, analyze these cases, and summarize the risk factors. On the basis of the existing risk assessment model, this paper integrates the hazardous, overspeed, overload, rainy days, and fatigue driving factors of hazardous chemicals and constructs the risk field model of hazardous chemical transportation.

2. The Risk Field Model

According to the "Road Traffic Safety Law of the People’s Republic of China" and "Regulations on the Application and Use of Motor Vehicle Driver Licenses," this paper analyzes the risk factors existing in the transportation of dangerous chemicals, including speeding, overloading, fatigue driving, and rainy days. Overspeed can be divided into three levels: slight overspeed, moderate overspeed, and severe overspeed. Overload can be divided into slight overload and severe overload. Driving continuously for more than 4 hours is considered fatigue driving. The main effect of rainy days is the decrease of the road adhesion coefficient caused by rainfall.

The elements of the risk field model of hazardous chemical transportation mainly include the hazard of hazardous chemicals and the various risk factors. The harmfulness of hazardous chemicals was quantified by an analytic hierarchy process. On the basis of the existing research on driving risk assessment, the influence of various risk factors on accident risk is analyzed. Integrating the above factors, the risk field model of hazardous chemical transportation is constructed.

2.1. Hazard Analysis of Hazardous Chemicals. Analytic hierarchy process (AHP) is mainly applied to target problems with multiple consideration standards and solutions. There are adjacent or upper-lower level relationships among the alternative solutions. Standards and solutions: Design a hierarchical structure model, and finally get the weight of each element in the problem by designing a comparison matrix, quantitative analysis and calculation, and consistency check. In this paper, the analytic hierarchy process is used to quantitatively analyze the hazard of hazardous chemicals.

The hazard of hazardous chemicals is decomposed into decision-making schemes with different evaluation criteria according to the target layer, the criterion layer, and the index layer.

The target layer is to judge the hazard of hazardous chemicals, and in the hierarchical structure model, the target layer is located at the top layer. The criterion layer is the evaluation criterion for the hazard of hazardous chemicals, which is located in the middle layer in the model, and the index layer is the refinement of the items in the criterion layer, which is located at the bottom layer in the model, as shown in Table 1.

Referring to Li’s [7] research on the hazard characteristics of hazardous chemicals, a comparison matrix was

constructed by synthesizing experts’ judgments on the importance of each index at the criterion layer and index layer in the ladder hierarchy, as well as the relative importance scale. Use natural numbers from 1 to 5 to reflect the relative importance of the first indicator to the second indicator in turn. The larger the number, the higher the importance of the first indicator to the second indicator. The reciprocal of the number is used to represent the importance of the second indicator to the first indicator, and the comparison matrix \( A = (a_{ij})_{m \times n} \) has the following characteristics:

\[
    a_{ij} > 0, \quad a_{ii} = 1,
\]

\[
    a_{ij} = \frac{1}{a_{ji}}.
\]

The scale assignment method of each element in the judgment and comparison matrix is shown in Table 2.

Based on the above characteristics and construction steps, various comparison matrices about the hazard capacity of hazardous chemicals are obtained, including the comparison matrix of criterion layer, the comparison matrix of index layer B1, the comparison matrix of index layer B2, the comparison matrix of index layer B3, and the comparison matrix of index layer B4, as shown in Tables 3–7 respectively.

Calculate the influence of four factors in criterion layer B, including the health hazard B1 of dangerous goods, the flammability B2 of dangerous goods, the reactivity B3 of dangerous goods, and the special hazard B4 of dangerous goods on the hazard ability of dangerous chemicals.

1. Calculate the product of the elements in each row of the comparison matrix of the criterion layer B.

\[
\begin{pmatrix}
1 & 5 & 3 & 5 \\
1 & 1 & 1 & 1 \\
5 & 5 & 3 & 3 \\
1 & 3 & 5 & 1 \\
5 & 3 & 1 & 3 \\
1 & 3 & 1 & 1
\end{pmatrix}
\]

Then, \( m_i = \prod_{j=1}^{n} a_{ij} \). Therefore, we have

\[
m_1 = 75,
\]

\[
m_2 = \frac{1}{75},
\]

\[
m_3 = 5,
\]

\[
m_4 = \frac{1}{5}.
\]
Calculate the root of $n$ power, $n = 4$, and the result is the weight of each factor.

$$\bar{w}_i = (m_i)^{1/n}.$$  \hspace{1cm} (4)

Then, we have

$$\bar{w}_1 = 2.94,$$

$$\bar{w}_2 = 0.34,$$

$$\bar{w}_3 = 1.49,$$

$$\bar{w}_4 = 0.67.$$  \hspace{1cm} (5)

(3) Consistency check: normalize the vector $\mathbf{\bar{w}} = (\bar{w}_1, \bar{w}_2, \bar{w}_3, \bar{w}_4)^T$, and we obtain

$$\hat{\mathbf{w}} = (2.94, 0.34, 1.49, 0.67)^T.$$  \hspace{1cm} (6)

and

$$\hat{w}_i = \frac{w_i}{\sum_{j=1}^{n} w_j}.$$  \hspace{1cm} (7)

Then, we have

$$\hat{w}_1 = 0.54,$$

$$\hat{w}_2 = 0.062,$$

$$\hat{w}_3 = 0.27,$$

$$\hat{w}_4 = 0.123.$$  \hspace{1cm} (8)

Calculate the maximum eigenvalue $\lambda_{\text{max}}$ and the corresponding CI.
\[ \lambda_{\text{max}} = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{A \lambda}{\tilde{w}_i} \right)_i, \quad CI = \frac{\lambda_{\text{max}} - n}{n - 1}. \] (9)

Hence, we obtain \( \lambda_{\text{max}} = 4 \cdot 2, \quad CI = 0 \cdot 0.067. \)

Calculate the consistency standard and look up Table 8 to get the random consistency index RI value.

When the consistency ratio (CR) is less than 0.1, it is considered that the degree of inconsistency of the comparison matrix is within the allowable range. Substitute the above calculation results, and check the inconsistency degree of the comparison matrix in the test criterion layer B.

\[ CR = \frac{CI}{RI}, \] (10)

\[ CR = 0.074. \]

After inspection, CR = 0.074 is less than 0.1, which satisfies the consistency test. Based on the above calculations, the comparison matrix and weight of criterion layer B are shown in Table 9.

Calculate the index weight of each index layer, and the calculation method is the same as that of the criterion layer, as shown in Tables 10–13.

Based on the above calculations, the consistency ratio (CR) of the comparison matrix of each index layer is less than 0.1, indicating that the comparison matrix of each index layer is consistent, and the consistency ratio (CR) of the criterion layer is also less than 0.1, which satisfies the consistency. Therefore, the important relationship between the indicators proposed by experts is accurate. The criterion layer and index layer proposed in this paper conform to the standard of a reasonable judgment matrix. The product of the index weight of the criterion layer and the index weight of the corresponding index layer is the final index of each index layer. Weights are shown in Table 14.

According to the final weight of each hazardous chemical hazard evaluation index in the criterion layer, the hazardous chemical hazard calculation method is obtained, as shown in formula

\[ D_t = \left( \frac{B_1^2 + B_2^2 + B_3^2 + B_4^2}{B_1 + B_2 + B_3 + B_4} \right)^{\frac{1}{4}} \] (11)

2.2. Construction of a Risk Field Model for Hazardous Chemical Transportation. The severity of accidents caused by hazardous chemical transport vehicles is related to the hazard degree of hazardous chemical being transported. The greater the hazard degree, the more serious the consequences of accidents caused by hazardous chemical transport vehicles [8]. In this paper, the ratio \( M_i \) of overloaded and rated load hazardous chemical transport vehicles is used to reflect the impact of overload on hazardous chemical transport risk. To avoid the distortion of the overload risk description when the impact coefficient is less than 1, the influence coefficient description method in the Cui [9] traffic risk assessment study is used for reference, and MI is finally obtained, as shown in

\[ M_i = \left( \frac{m_i}{m} \right)^{k_i+1}. \] (12)

where \( m_i \) is the actual load of the hazardous chemical transport vehicle, \( m \) is the rated load, and \( k_i \) is the impact coefficient of overload on accident risk.

In the process of driving, the driver’s impact on the risk of hazardous chemical transportation is reflected in their use of hazardous chemical transportation vehicles, mainly including turning and speed control. According to traffic accident reports over the years, driver fatigue is one of the main factors leading to accidents. Referring to the
description of the speed factor in Wang et al. research [10, 11] on driving risk, this paper quantifies the influence of "human" on the risk of hazardous chemical road transportation accidents from fatigue driving, cornering, and speed, as shown in the following formula:

\[
\text{person} = \exp \left[ \frac{v}{v_{\text{safe}}} \right]^{D_i(k_{i+1})},
\]

where \( v \) is the real-time speed of the hazardous chemical transport vehicle and \( v_{\text{safe}} \) is the critical safe speed of turning.

\[
v_{\text{safe}} = \sqrt{\frac{g \times R \times B}{2h}},
\]

where \( R \) is the turning radius, \( h \) is the height from the center of mass to the horizontal road surface, and \( B \) is the track width of the left and right wheels. According to the 2014 edition of the highway engineering technical standard, generally, the radius of a highway curve will not be greater than 250 m. When the radius of the curve \( R \) is greater than or equal to 300 m or the hazardous chemical transport vehicle is running in a straight line, \( v_{\text{safe}} \) sets the safe speed of the hazardous chemical transport vehicle at 70 km/h, while \( k_3 \) is the overspeed influence coefficient.

\( D_i \) represents the impact of fatigue driving on the risk of hazardous chemical road transportation, as shown in the following formula:

\[
D_i = 1 + k_3,
\]

where \( k_3 \) is the fatigue driving influence coefficient.

Based on the road adhesion coefficient under different rainfall levels and referring to the research on the road adhesion coefficient on rainy days by Meng et al. [12], this paper uses the ratio of the standard road adhesion coefficient and road adhesion coefficient to characterize the influence of rainfall weather on driving safety and obtains the influence parameter \( n \) on rainy days, as shown in the following formula:

\[
N = \left( \frac{r_u}{r_i} \right)^{k_{i+1}},
\]

where \( r_u \) is the standard road adhesion coefficient, the standard road adhesion coefficient is \( r_u \) under dry conditions, \( r_i = 0.8 \). \( R_l \) is the road adhesion coefficient, and \( k_i \) is the influence coefficient of rainy days.

In addition, under the influence of other conditions, the possibility of rear end accidents will be increased when the vehicle separation distance is reduced, and the possibility of rear end accidents will be greatly reduced when the distance is in the safe range. According to the Wang and Liu [13] research on the braking distance and safety distance of vehicles, this paper reflects the influence of vehicle distance \( L \) on the transport risk of dangerous chemicals in the form of an inverse score. The safety distance is taken as 150 m. When the distance \( L \geq 150 \text{ m} \), 150 m is taken as the safety distance.

In summary, based on the results of [14] driving risk model, the risk field model of dangerous chemical transportation is constructed based on the influence of humans, vehicles, and roads, as shown in

\[
\text{Risk} = \frac{D_i M_i N}{I - \exp \left[ \frac{v}{v_{\text{safe}}} \right]^{D_i(k_{i+1})}}.
\]

According to the accident case database of China Chemical Safety Association, there were a total of 483 road transport accidents of hazardous chemicals from 2015 to 2019 [15], as shown in Table 15.

According to the "Road Traffic Safety Law of the People’s Republic of China" and "Regulations on the Application and Use of Motor Vehicle Driving Licenses" [16], speeding can be divided into three levels: slight speeding, moderate speeding, and serious speeding. Overloading can be divided into two levels: slight overloading and severe overloading. Continuous driving for more than 4 hours is fatigue driving. The impact of rainy days is mainly manifested in the reduction of road adhesion coefficient caused by rainfall. This
paper summarizes the transportation risks from the perspective of traffic regulations. The factors that affect the safety of road transportation of hazardous chemicals include four risks, such as speeding, overloading, fatigue driving, and rainy weather.

Combined with the relevant provisions of the “Road Traffic Safety Law of the People’s Republic of China” and the “Regulations on the Application and Use of Motor Vehicle Driving Licenses,” according to the degree of speeding, speeding is divided into three levels: slight speeding, moderate speeding, and serious speeding. Slight speeding means that the driving speed does not exceed 20% of the specified speed, and 3 points will be deducted for this violation. Moderate speeding refers to driving 20%–60% of the specified speed, and 6 points will be deducted for this violation. Serious speeding means that the driving speed exceeds 60% of the specified speed, and 12 points will be deducted for this violation. Depending on the degree of overloading, overloading is divided into two levels: slight overloading and severe overloading. Slight overloading means that the dangerous chemical transport vehicle has been overloaded, but the overloaded amount has not reached 30% of the rated load, and 3 points will be deducted for this violation. Serious overloading means that the overload exceeds 30% of the rated load, and 6 points will be deducted for this violation. Fatigue driving refers to continuous driving for more than 4 hours. Among the accident cases collected, there are few accident cases in fog and snow conditions, and it is difficult to obtain the accurate impact of fog and snow on accidents. This paper mainly studies the impact of rain on the transportation risk of hazardous chemicals. According to statistics, there were 292 road transport accidents of hazardous chemicals caused by overspeed, 283 cases of road transport accidents of hazardous chemicals caused by overloading, 112 cases of road transport accidents of hazardous chemicals caused by fatigue driving, and road transport accidents of hazardous chemicals caused by slippery ground. 109 cases are shown in Table 16. Table 17 shows the number of accidents caused by various risk factors in the five-year period, such as slight speeding, moderate speeding, severe speeding, slight overloading, severe overloading, fatigue driving, and slippery ground.

The risk of road transportation of hazardous chemicals is uncertain, and with the change of risk factors during the transportation process, the transportation risk will be affected. However, this risk is measurable. According to the analysis of accident cases, it is found that the magnitude of transportation risk is closely related to the change of risk factors and shows regularity.

In statistics, regression analysis is a statistical method used to determine the interdependent quantitative relationship between two or more variables [17]. According to the number of variables involved, regression analysis can be divided into univariate regression analysis and multiple regression analysis. Regression analysis, as a predictive modeling technique, mainly studies the influence of independent variables on dependent variables and discovers causal relationships between variables. A phenomenon is often associated with multiple factors, and predicting or estimating the dependent variable through a combination of multiple independent variables is more realistic than using only one independent variable to predict or estimate. Multiple regression analysis satisfies the practical needs of this paper and is conducive to dealing with the relationship between risk factors and accidents in the transportation of hazardous chemicals. This paper adopts multiple regression analysis as the statistical analysis method of the research.

According to the accident case database statistics of the China Chemical Safety Association and the accident investigation report of the local traffic control department, this paper takes the number of hazardous chemical transportation accidents that occurred between 2015 and 2019 as the dependent variable, and uses speeding, overloading, fatigue driving, and rain effects as the dependent variable. The number of accidents caused by the other four risk factors is the independent variable. Based on the multiple regression analysis theory, the influence of the above four accident components on the transportation accidents of hazardous chemicals is determined, as shown in the formula.

\[
\text{Accident} = \beta_1 \cdot \text{Speed} + \beta_2 \cdot \text{Load} + \beta_3 \cdot \text{Time} + \beta_4 \cdot \text{Adhesion coefficient} + \omega,
\]

where Accident is the number of accidents caused by hazardous chemical transportation, Speed is the number of accidents caused by overspeed, Load is the number of accidents caused by overloading, Time is the number of accidents caused by fatigue driving, Adhesion coefficient is the number of accidents caused by rain, and \(\omega\) is the error term. \(\beta_1, \beta_2, \beta_3, \text{ and } \beta_4\) are the influence coefficients of each

### Table 15: Statistics of transportation accidents of dangerous chemicals in highway from 2015 to 2019.

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerical value</td>
<td>87</td>
<td>105</td>
<td>90</td>
<td>98</td>
<td>103</td>
</tr>
</tbody>
</table>

### Table 16: Statistics of various accident types of hazardous chemical transportation accidents in 2015–2019.

<table>
<thead>
<tr>
<th>Types of accident factors</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speeding</td>
<td>292</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overload</td>
<td>283</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatigue driving</td>
<td>112</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rain effect</td>
<td>109</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 17: Statistics of risk factors of hazardous chemical transportation accidents in 2015–2019.

<table>
<thead>
<tr>
<th>Types of accident factors</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slight overspeed</td>
<td>19</td>
<td>23</td>
<td>17</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td>Moderate speeding</td>
<td>17</td>
<td>25</td>
<td>18</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>Severe speeding</td>
<td>14</td>
<td>19</td>
<td>15</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>Slight overloading</td>
<td>15</td>
<td>26</td>
<td>16</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>Severely overloaded</td>
<td>31</td>
<td>42</td>
<td>36</td>
<td>38</td>
<td>41</td>
</tr>
<tr>
<td>Fatigue driving</td>
<td>14</td>
<td>27</td>
<td>17</td>
<td>26</td>
<td>28</td>
</tr>
<tr>
<td>Rain effect</td>
<td>19</td>
<td>29</td>
<td>15</td>
<td>21</td>
<td>25</td>
</tr>
</tbody>
</table>
3. Risk Classification of the Risk Field Model

Risk classification is carried out for the dangerous chemical transportation risk field, which provides the basis for the evaluation of the transportation status of dangerous chemicals. According to the restrictive description of factors such as speed, load, and continuous driving time according to the relevant regulations of traffic and transportation in China, the class I risk value is calculated according to the risk field model of dangerous chemical transportation. The accident of a dangerous chemical transport vehicle is simulated through the TruckSim software, and the accident values of various risk factors in the simulation experiment are obtained. The risk value of class II is calculated according to the risk field model of dangerous chemical transportation. The transport accidents of dangerous chemicals are mainly in the form of rollovers and jack knives, and the simulation experiments are mainly of these two types.

Through the simulations of hazardous chemical transportation vehicle accidents with TruckSim software, the accident value of each risk factor in the simulation model is obtained, and the level II risk value is calculated according to the hazardous chemical transportation risk field model. When the risk field value calculated by the risk field model of hazardous chemical transportation is less than the level I risk value, the road transportation of hazardous chemicals is in a safe state. When the risk field value is greater than the level I risk value and less than the level II risk value, the road transportation of hazardous chemicals is in a risk state. When the risk field value is greater than the level II risk value, the road transportation of hazardous chemicals is in a dangerous state.

3.1. Determination of Level I Risk Value. According to the relevant provisions of the road traffic safety law of the People’s Republic of China and the provisions on the application and use of motor vehicle driving licenses, overspeed can be divided into three levels: slight overspeed, moderate overspeed, and severe overspeed according to the degree of overspeed. The critical value of slight overspeed of dangerous chemical transport vehicles on the highway is 80 km/h as the limit value of overspeed. According to the different overloads, overload can be divided into two levels: slight overload and serious overload. Slight overload refers to the overload of dangerous chemical transport vehicles, but the overload amount does not exceed the rated load by more than 30%, and serious overload refers to an overload exceeding 30% of the rated load. Similarly, the overload ratio limit (the ratio of actual load to rated load) is 1.3. According to Article 80 of the regulations of the People’s Republic of China on traffic safety law, when the vehicle speed exceeds 80 km/h, it should be kept more than 100 meters from vehicles in the same lane, and so the limit value of vehicle distance is 100 m. According to the study of the influence of rainfall on the adhesion coefficient by Meng et al. [12], when the rainfall level is described as a medium rain, the impact on transportation safety is obvious. When the rainfall level is medium rain, the limit value of the rain effect is calculated. The road attachment coefficient is 0.7, and the limit value of rain impact is 1.35. According to relevant regulations, fatigue driving refers to a continuous driving period of more than 4 hours. It is assumed that fatigue driving behavior exists in the transportation process. Combined with the study of fatigue driving risk factors in Chapter 2, a fatigue driving influence coefficient of 1.2 is taken as the limit value of fatigue driving. The limit values of each risk factor are shown in Table 18.

Taking gasoline as a transportation medium, for example, the harm of gasoline is 1.36. The hazard of gasoline is shown in Table 20.

Referring to Table 19, when the transported material is gasoline, the values of various factors in the risk field model are as follows: the hazard DV of hazardous chemical transportation is 1.36, the ratio Mi of overload to rated load of hazardous chemical transportation vehicle is 1.3, the influence parameter n in rainy days is 1.35, the vehicle distance L is 100 m, the vehicle speed is 80 km/h, and the influence Di of fatigue driving on the risk of hazardous chemical highway transportation is 2.19. According to formula (16), the level I risk value of the hazardous chemical transportation risk field is 0.16.

3.2. Determination of Level II Risk Value

3.2.1. Rollover Accident Simulation Experiment. The accident model consists of a road model and a vehicle model. The ellipse runways are constructed with radii of 250 m, 150 m, and 125 m. The coefficient of adhesion is 0.4 on rainy days and 0.8 on nonrainy days. Taking the curve radius of 250 m as an example, the oval runway model is constructed.

The simulation of hazardous chemical transport vehicles mainly parametersize the sprung mass and load of hazardous chemical transport vehicles, which are composed of tractors and trailers. The model of the simulation experiment is a Ling Yu gly5320gyf liquid tank truck, and its main parameters are shown in Table 21.

The paper analyzes the rollover accidents of dangerous chemical road transportation in recent years, including the factors of overspeed, overload, and rainy days. Among them, the main reason for the accident is the excessive turning speed. Therefore, to explore the specific influence of speed on rollover accidents, the simulation model vehicle
accelerates uniformly in the oval runway at an initial speed of 60 km/h until roll (roll slip) occurs. Overload and rainy days have less influence on rollover accidents than overspeed. Only when the overload is too much and the rainfall is too heavy do these two factors have an obvious influence on rollover risk. Overloads are selected as 30% and overload 60%. The influence of rainy days on the road adhesion coefficient is 0.4 according to the analysis in the previous chapter.

The radii of the bends are 250 m, 150 m, and 125 m. Taking the radius of the bend as an example, the experimental scheme is shown in Table 22.

Taking Experiment 1 as an example, in the simulation model, the road adhesion coefficient is taken as 0.8, the initial speed is taken as 60 km/h, the uniform speed is 60 km/h in the first 2 seconds, and the uniform acceleration is from 60 km/h to 120 km/h from 2 to 12 seconds. According to the simulation results, when the vertical downward force of the simulation model car is 0 in 12.47 seconds, rollover occurs, and the vehicle speed is 101.95 km/h. The simulation model vehicle speed is shown in Figure 1.

In 0 to 2 seconds, the simulation model car runs normally on the straight section of the runway. After 2 seconds, the simulation model car enters the curve. Due to the lateral force, the load on one tire first increases and then tends to be stable, while the load of the other tire first decreases and then tends to be stable. When the vehicle speed reaches 98.75 km/h in 11.47 seconds, the loads on each wheel of the simulation model car rapidly decrease, as shown in Figure 2. Combined with the simulation model animation in TruckSim software, we can see that the simulation model car rolls over at this time.

3.2.2. Rear End Collision Simulation Experiment. Based on the analysis of the reports of rear end collision accidents in hazardous chemical transportation accidents over the years, the causes of accidents mainly include that the front and rear vehicles do not keep a safe distance, the speed is too fast, the influence of rainy days, driver fatigue driving, and transportation overload. In this paper, the response surface module of the design expert is used to design a rear end simulation experiment.

According to the safety management measures for the road transport of dangerous goods, the speed of dangerous goods transport vehicles on the expressway shall not exceed 80 km/h. In the rear end collision simulation experiment, the speed of the front vehicle is 80 km/h, and the minimum speed of the simulation model vehicle is 85 km/h. In China, the definition of serious overspeed is 60% of the safe speed, and the maximum speed of the simulation model vehicle is set at 125 km/h.

Similarly, the minimum load of the simulation model car is 30% of the rated load. According to the actual transportation situation, in the process of transportation, the driver of the transport car is seriously overloaded to make high profits. In this paper, the maximum load is set to 60% of the rated load.

According to the research on the road adhesion coefficient on rainy days by Meng et al. [12], the lowest value of the road adhesion coefficient is 0.4, and the highest value is 0.7.

Referring to Zhang et al.[18] analysis on the safe distance between two vehicles, when the speed is lower than 70 km/h, the distance between two vehicles and the front vehicle in the same lane can be appropriately shortened, but if the distance is too small, the possibility of accidents will be greatly increased. To fully reflect the impact of the passing car distance on the rear end collision risk, the minimum distance between the front and rear cars is 25 m. Referring to the setting of safety car distance in Chapter 3, the maximum distance is 150 m.

The braking reaction time is the driver’s reaction ability in the face of an impending rear end collision, that is, the time it takes for the driver to step on the brake pedal after he recognizes the danger. Generally, the braking reaction time is 0.5 s ~ 2.5 s, which is taken as 1.5 s in this paper. The hydraulic braking reaction time of hazardous chemical transport vehicles is usually approximately 0.2 s ~ 0.6 s, which is taken as 0.5 s in this paper. In conclusion, the braking response time is 2.0 s. When the driver is in a fatigue state, the reaction time is usually delayed by 1.5 ~ 2.5 s, and the minimum response time of fatigue driving is 0 s; that is, there is no fatigue driving behavior, and the maximum response time is 2.5 s. In conclusion, under the influence of fatigue driving, the minimum braking response time is 2 s, and the maximum is 4.5 s.
The specific ranges of each factor in the rear end collision simulation experiment are shown in Table 23. The user-defined design module in the response surface of the design expert sets the range of risk factors and generates the list of rear end simulation experiments, for a total of 185 cases. Taking the 76th group of experiments as an example, in the rear end simulation experiment, the front car is set as a tourist bus, the standard speed of the front car is set as 80 km/h, and the distance between the front and rear cars is 66.67 m. The speed of the simulation model is 105 km/h, the overload condition is 30%, the adhesion coefficient is 0.6, the fatigue driving influence time is 0 s, and the braking response time of the model vehicle is braking response time plus fatigue driving influence time, which is 2 s. By combining the results of the TruckSim animation simulation and the reaction data, it can be seen that when the simulation model car decelerates to 80 km/h, it is 46.76 m away from the front car, and there is no collision.

### 3.2.3. Calculation of Level II Risk Value

In the rollover accident simulation, taking the curve radius of 250 m as an example, the parameters of six simulation experiments during rollover (sideslip) are shown in Table 24.

Taking gasoline as the transportation medium, according to the risk field model of hazardous chemical transportation, when the radii of the curves are 250 m, 150 m, and 125 m, the minimum value of the field in 18 groups of simulation experiments is 1.42.

In the simulations of a rear end collision, 45 of 185 experiments have rear end collision, and some of the experimental results are shown in Table 25.

The first and second experiments are taken as examples. In the first simulation experiment, the distance between front and rear vehicles is set to 150 m. The speed of the front vehicle is 80 km/h. The speed of the model car is 125 km/h. The model car is set to overload 30%. The road adhesion coefficient is 0.6. The influence time of fatigue is 1.67 s. The effective time of braking is 3.67 s. Combined with the simulation animation of TruckSim, the results show that there is no rear end collision. When the model car decelerates to the same speed as the front car, the distance between the front car and the model car is 81.81 m. In the second simulation experiment, the distance between front and rear vehicles is set as 25 m. The speed of the front vehicle is 80 km/h. The speed of the rear vehicle is 111.67 km/h. The model car is set to overload 30%. The road adhesion coefficient is 0.7. The influence time of fatigue is 0 s. The effective time of braking is 2 s. Combined with the simulation animation of TruckSim, the results show that rear end collision occurs in 3.10 s, and the vehicle speed is 95.74 km/h.

Taking gasoline as the transportation medium as an example, according to the risk field model of hazardous chemical transportation obtained in Chapter 3, the minimum risk value of 45 groups of simulation experiments with rear end collisions is 1.06. The minimum risk value calculated by rollover simulation accidents is 1.42, and the smaller risk field value is the level II risk value. To sum up, the level II risk value is 1.06.

### Table 19: Limit value of each factor.

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>Limit value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of actual load to rated load</td>
<td>1.3</td>
</tr>
<tr>
<td>Speed (km/h)</td>
<td>80</td>
</tr>
<tr>
<td>Distance between cars (m)</td>
<td>100</td>
</tr>
<tr>
<td>Continuous driving time (h)</td>
<td>4</td>
</tr>
<tr>
<td>Road adhesion coefficient (moderate rain)</td>
<td>0.7</td>
</tr>
<tr>
<td>Influence of rainy days</td>
<td>1.35</td>
</tr>
</tbody>
</table>

### Table 20: Hazards of gasoline.

<table>
<thead>
<tr>
<th>Hazard assessment criteria</th>
<th>Level</th>
<th>Influence weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health hazards</td>
<td>Low</td>
<td>0.97</td>
</tr>
<tr>
<td>Flammability of dangerous goods</td>
<td>Middle</td>
<td>0.51</td>
</tr>
<tr>
<td>Reactivity of dangerous goods</td>
<td>Middle</td>
<td>1.92</td>
</tr>
<tr>
<td>Special risk of dangerous goods</td>
<td>No</td>
<td>0.23</td>
</tr>
</tbody>
</table>

### Table 21: Main technical parameters.

<table>
<thead>
<tr>
<th>Technical parameter</th>
<th>Numerical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mass (kg)</td>
<td>32000</td>
</tr>
<tr>
<td>Rated mass (kg)</td>
<td>20735</td>
</tr>
<tr>
<td>External dimension (mm)</td>
<td>1177025503550</td>
</tr>
<tr>
<td>Curb weight (kg)</td>
<td>11135</td>
</tr>
<tr>
<td>Approach/departure angle (°)</td>
<td>13/12</td>
</tr>
</tbody>
</table>

### Table 22: Simulation test scheme of a rollover with a radius of 250 m.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Overload (30%)</th>
<th>Overload (60%)</th>
<th>Influence of rainy days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>No</td>
<td>Existence</td>
</tr>
<tr>
<td>3</td>
<td>Existence</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>No</td>
<td>Existence</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>Existence</td>
<td>No</td>
<td>Existence</td>
</tr>
<tr>
<td>6</td>
<td>No</td>
<td>Existence</td>
<td>Existence</td>
</tr>
</tbody>
</table>

### Figure 1: Experiment 1, actual speed of model car.
4. Empirical Analysis of Accident Cases

To verify the reliability of the risk field model of hazardous chemicals, the rationality of the level I and level II risk values was determined. Based on the illegal notice records of Nantong Chemical Dangerous Goods Transportation Co., Ltd., and the accident cases of the China Chemical Safety Association, this paper conducts an empirical study.

The first level of value at risk case demonstration: According to the case records of Nantong Chemical Dangerous Goods Transportation Co., Ltd., 30 cases of road traffic safety violations recorded by Nantong Chemical Dangerous Goods Transportation Co., Ltd., were randomly selected to calculate the risk field value when the violations occurred and compared with the level I risk.

For example, on September 26, 2017, a dangerous chemical transport vehicle loaded with gasoline was fined 50 yuan, and three points were deducted when it was speeding 30% on the 121 provincial road section of the Huai’an-Anning-Xu line in Jiangsu Province. The driver had been driving continuously for more than four hours, which was fatigue driving. When speeding occurred, the risk field value of dangerous chemical transport was 0.48, which exceeded the level I risk value. Less than the level II risk value, the specific data are shown in Table 26.

![Figure 2: Experiment 1, wheel stress of model car. (a) Longitudinal force on each wheel. (b) Lateral force on each wheel. (c) Longitudinal supporting force of each wheel.](image-url)
When the distance between front and rear vehicles is more than 150m, the safe distance is 150m in the risk field model. Although there was no accident in the transportation process, there was a potential safety hazard, which was punished by the traffic police. Similarly, the remaining 29 cases are calculated, and some cases are shown in Table 27. When these cases violate the traffic regulations, the risk field value exceeds the level I risk value, and there is a potential safety hazard, but it does not exceed the level II risk value, and there is no accident.

Table 23: Factors of rear-end collision simulation experiment.

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Minimum value</th>
<th>Maximum value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (km/h)</td>
<td>85</td>
<td>125</td>
</tr>
<tr>
<td>Overload (%)</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>Road adhesion coefficient</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Distance between front and rear vehicles (m)</td>
<td>25</td>
<td>150</td>
</tr>
<tr>
<td>Influence time of fatigue driving (s)</td>
<td>0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

The approved load of the transport vehicle is 1.58 tons, and the actual gasoline load was 6.52 tons. The accident occurred on a sunny day. The specific accident data are shown in Table 28.

Table 24: Parameters of rollover when the radius of the curve is 250 m.

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>Overload 30%</th>
<th>Overload 60%</th>
<th>Road adhesion coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 1</td>
<td>102</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Experiment 2</td>
<td>75</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Experiment 3</td>
<td>95.8</td>
<td>Existence</td>
<td>No</td>
</tr>
<tr>
<td>Experiment 4</td>
<td>92.5</td>
<td>No</td>
<td>Existence</td>
</tr>
<tr>
<td>Experiment 5</td>
<td>71.7</td>
<td>Existence</td>
<td>No</td>
</tr>
<tr>
<td>Experiment 6</td>
<td>68.5</td>
<td>No</td>
<td>Existence</td>
</tr>
</tbody>
</table>

When the vehicle speed exceeds 100km/h, the distance between the front and rear vehicles should be maintained at more than 150meters. Therefore, when the distance between the front and rear vehicles is 150 meters, the truck should adopt braking deceleration. According to the accident report, the truck driver has had a number of illegal operations and does not stop to rest at night, which is classified as fatigue driving and 312% overload, which is classified as serious overload. In summary, when the distance between the front and rear vehicles is 150 meters, the risk field value of hazardous chemical transportation of the truck is 7.48, which is more than the level II risk value. Similarly, the remaining 49 hazardous chemical transportation accidents are calculated, and some cases are shown in Table 29. In 50 accident cases, the risk field value before the accident is greater than the level II risk value.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Speed</th>
<th>Overload</th>
<th>Adhesion coefficient</th>
<th>Braking time</th>
<th>If</th>
<th>Speed at impact (km/h)</th>
<th>After deceleration (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>125</td>
<td>30</td>
<td>0.6</td>
<td>3.67</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>111.67</td>
<td>30</td>
<td>0.7</td>
<td>2</td>
<td>Yes</td>
<td>95.74</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>125</td>
<td>40</td>
<td>0.5</td>
<td>2</td>
<td>Yes</td>
<td>124.83</td>
</tr>
<tr>
<td>4</td>
<td>150</td>
<td>111.67</td>
<td>60</td>
<td>0.4</td>
<td>4.5</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>111.67</td>
<td>60</td>
<td>0.5</td>
<td>2</td>
<td>Yes</td>
<td>102.74</td>
</tr>
<tr>
<td>6</td>
<td>150</td>
<td>98.33</td>
<td>30</td>
<td>0.4</td>
<td>2</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>87.5</td>
<td>85</td>
<td>60</td>
<td>0.7</td>
<td>2</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>56.25</td>
<td>95</td>
<td>37.5</td>
<td>0.47</td>
<td>2.63</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 26: Violation data of “9.26” hazardous chemical transportation.

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>Overload</th>
<th>Adhesion coefficient</th>
<th>Fatigue driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>96</td>
<td>No</td>
<td>0.8</td>
<td>Existence</td>
</tr>
</tbody>
</table>

When the distance between front and rear vehicles is more than 150 m, the safe distance is 150 m in the risk field model. Although there was no accident in the transportation process, there was a potential safety hazard, which was punished by the traffic police.

Similarly, the remaining 29 cases are calculated, and some cases are shown in Table 27. When these cases violate the traffic regulations, the risk field value exceeds the level I risk value, and there is a potential safety hazard, but it does not exceed the level II risk value, and there is no accident.

The case study of level II risk value: According to the accident case database of the China Chemical Safety Association, there were 483 dangerous chemical goods road transportation accidents between 2015 and 2019, most of which were jack knives and rollovers. Fifty cases were randomly selected from the 483 cases. According to the accident reports of each case, the risk field values of dangerous chemical transportation before the occurrence of the hazard were calculated and compared with the level II risk.

An example is the transportation accident of “7.19” major hazardous chemicals, at 2.57 p.m. On July 19, 2014, a liquid tank car with a full load of gasoline, license plate No. Xiang a3zt46, was driven from east to west. The truck driver did not stop, rest as required, and drove fatigued. The truck driver collided with a bus driving ahead of it at 115km/h in the Shaoyang section of the Shanghai Kunming Expressway, which led to the leakage and combustion of gasoline. Trucks and buses were burned, and 54 people were killed. The approved load of the transport vehicle is 1.58 tons, and the actual gasoline load was 6.52 tons. The accident occurred on a sunny day. The specific accident data are shown in Table 28.
5. Conclusion

The accident case database of the China Chemical Safety Association is analyzed from the perspective of traffic regulations. The basis includes the road traffic safety law of the People’s Republic of China, the implementation regulations of the road traffic safety law of the People’s Republic of China, and the regulations on the application and use of motor vehicle driving licenses. All risk factors include overspeed, overload, fatigue driving, and rainy day influence.

Hazardous chemicals are divided into decision-making schemes with different evaluation standards according to the target layer, criterion layer, and index level. The target layer is the judgment of the degree of hazard of a hazardous chemical, the criterion layer is the evaluation criteria for the hazardous chemical, and the index layer is the refinement of each item in the standard layer. The degree of hazard of a hazardous chemical is quantified by the analytic hierarchy process.

Based on the existing risk assessment model, the risk impacts of overspeed, overload, rain, and fatigue driving are analyzed. The risk field model of dangerous chemical transportation is constructed by combining the factors of hazard, overspeed, overload, rain, and fatigue driving. The risk field model of hazardous chemical transportation is verified.

According to traffic regulations and regulations, the limiting descriptions of speed, load, and continuous driving time are described. The risk field model of dangerous chemical transportation is used to calculate and determine the level I risk value. Through the simulation experiment of truck accidents, the accident value of risk factors in the simulation model is obtained by TruckSim. The level II risk value is calculated according to the risk field model of dangerous chemical transportation. Through a case study, it is found that the risk classification of the dangerous chemical transportation risk field is reasonable, which provides the judgment basis for active safety control.

When building the model, due to the lack of accident data and difficult statistics, we use expert experience method to select some data, which is lack of objectivity. Therefore, we will widely collect relevant data in the future to support it with objective facts. In addition, in this paper, we use analytic hierarchy process for research, and in future research, we will use other methods for research, such as the dynamic linear regression approach [19, 20].

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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