Research on Risk Assessment of Dangerous Goods Vehicles Through Road Tunnels

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Abstract: This article studies the safety issues of dangerous goods vehicles through road tunnels, and considers four factors including the weather environment, tunnel characteristics, traffic characteristics, and emergency rescue conditions. Based on hierarchical analysis process, a risk assessment model of dangerous goods vehicles through road tunnels is proposed to evaluate the risk of 7 tunnels on the expressway from Beijing to Chengde in China, and propose targeted measures and suggestions based on the evaluation results.

Keywords: Risk assessment, dangerous goods vehicles, road tunnels, hierarchical analysis process

1. INTRODUCTION

As the output value of Chinese chemical industry increases year by year, the road transportation demand for dangerous goods is also increasing. In accordance with the requirements of the "Highway Safety Protection Regulations", vehicles carrying dangerous items such as flammable, explosive, toxic shall be in accordance with relevant national regulations and avoid crossing special bridges or tunnels. In actual situations, some competent departments ban all dangerous goods vehicles from crossing road tunnels, and the transportation risks of other open air roads have greatly increased. Therefore, it is necessary to study the risk assessment methods of dangerous goods vehicles through road tunnels, and build a hierarchical management and control system for dangerous goods vehicles through road tunnels.

Compared with the open air section, the space of the road tunnel is more closed. Once dangerous goods leak, fire or explode in a tunnel, it will be more difficult for personnel to escape and evacuate, and the consequences of the accident will be more serious. In 2014, two methanol transport vehicles exploded after colliding in a tunnel in Shanxi Province, China. The accident killed 40 people, injured 12 others, and burned 42 vehicles. Aiming at the safety risk of dangerous goods vehicles through road tunnels, an evaluation model is usually constructed considering tunnel length, traffic flow, and accident rate[1][2]. Some scholars use OECD/PIARC QRA Model to evaluate the risk of dangerous goods vehicles through tunnels[3-5], and on the basis of the evaluation results, the route of dangerous goods vehicles can be optimized[6].

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2. RISK FACTOR ANALYSIS

2.1 Weather environment

The weather environment in road tunnel sections has a certain impact on the traffic safety of dangerous goods vehicles. Hot weather can cause tire fires and brake failure on dangerous goods vehicles. In addition, severe rain and snow weather may also cause dangerous goods vehicles to skid or even rollover at high speeds, affecting driving safety.

2.2 Tunnel characteristics

The characteristics of road tunnels are important factors affecting the safety of dangerous goods vehicles. When dangerous goods leakage, fire, or explode in a tunnel, the length of the tunnel will directly affect the accumulation rate of harmful gases in the tunnel, the evacuation efficiency of trapped personnel, and the difficulty of rescue by firefighting forces. At the same time, when the number of lanes inside the tunnel is large, vehicles are more dispersed and less likely to collide with each other. In addition, the turning radius of the tunnel itself and the slope of the tunnel will also affect the driving safety of the driver to varying degrees, thereby affecting the probability of a vehicle collision accident in the tunnel.

2.3 Traffic characteristics

The vehicle traffic characteristics of road tunnel sections are also important factors that affect the probability and severity of accidents involving dangerous goods vehicles in tunnels. Generally speaking, the higher the accident rate and the proportion of dangerous goods vehicles in the section where the tunnel is located, the greater the possibility of a dangerous goods vehicle accident. In addition, road sections with large traffic flow are more likely to cause congestion in tunnels, which may lead to more serious consequences when dangerous goods leak, fire, and explode**.**

2.4 Emergency rescue conditions

Due to the dangerous characteristics of dangerous goods such as corrosion, explosion, and toxicity, accident rescue has strong professionalism. Therefore, in the event of cargo leakage, fire and other emergencies, emergency rescue operations rely on professional rescue teams. The application of fire alarm facilities, emergency rescue equipment and the arrival speed of professional rescue forces are different in different road tunnels. These factors will affect the emergency rescue efficiency of accidents involving dangerous goods vehicles in the tunnel.

3. RISK ASSESSMENT MODEL

3.1 Model building steps

The Analytical Hierarchy Process is a commonly used method to build a multi-indicator evaluation model. Many scholars apply this method to the risk assessment of dangerous goods transportation[7][8], or use this method to evaluate the safety risks of dangerous goods transportation enterprises[9]. The risk assessment of road tunnels for dangerous goods vehicles is divided into the following steps: First, build a model framework and determine the evaluation indicators at each level; Second, construct a comparison matrix based on the importance of each indicator at each level to the indicators at the previous level; Third, use a comparison matrix to calculate the weight of each indicator at each level, and conduct a consistency test to clarify whether the indicator weight is reasonable; Finally, according to the structural characteristics of the road tunnel and the traffic conditions of the tunnel, assign values to the lowest-level evaluation indicators and calculate risk value R, determine the risk level of dangerous goods vehicles through the current tunnel.

3.2 Model framework and indicators

The risk assessment model constructed in this article consists of three levels. The first level is the overall safety risk R of the tunnel, the second level is the four main indicators (A1~A4) that affect the first level, and the third level is the initial indicators (B1~B11), the specific indicator settings of the evaluation model are shown in Figure 1.

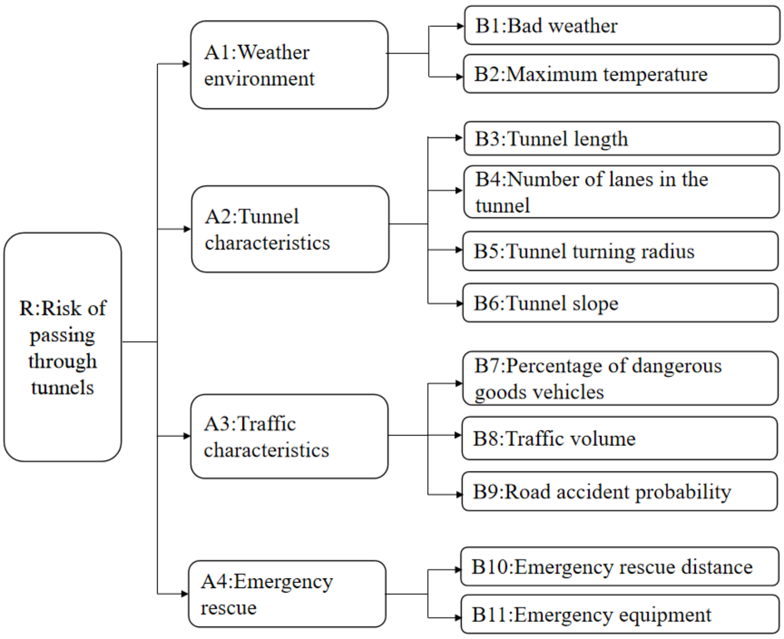

Figure 1. Evaluation model indicator settings.

3.3 Construct comparison matrices

Starting from the second level of the model, according to the relative importance of the indicators at each level to the indicator at the previous level, refer to Table 1. to construct a comparison matrix:

Table 1. Standards for constructing matrices.

Comparison result of i and j	Meaning
$a_{ij}=1$	For the upper level, indicator i and indicator j have the same importance

a_{ij}=3	For the upper level, indicator i is slightly more important than indicator j
a_{ij}=5	For the upper level, indicator i is more important than indicator j
a_{ij}=7	For the upper level, indicator i is much more important than indicator j
a_{ij}=9	For the upper level, indicator i is extremely important than indicator j
a_{ij}=2,4,6,8	Between the above
Reciprocal value	$a_{ji}=1/a_{ij}$

The comparison matrix of second-level indicators to indicator R is obtained, as shown in Table 2.

Table 2. Comparison matrix of R.

R	**A1**	**A2**	**A3**	**A4**
A1	1	1/6	1/7	1/4
A2	6	1	1/3	4
A3	7	3	1	5
A4	4	1/4	1/5	1

Using the same method, the comparison matrix of the third-level indicators B3~B6 to the second-level indicator A2 is obtained, as shown in Table 3.

Table 3. Comparison matrix of A2.

A2	**B3**	**B4**	**B5**	**B6**
B3	1	1/2	4	5
B4	2	1	5	6
B5	1/4	1/5	1	2
B6	1/5	1/6	1/2	1

3.4 Indicator weight calculation and consistency test

Use the comparison matrix to calculate the weight of each indicator at each level, and conduct a consistency test, the results are shown in Table 4.

Table 4. Weights and consistency test.

Indicator of upper level	**Indicators**	**Weights**	**Consistency test results**
R	A1	0.0507	CI=0.0815 CR=0.0915
	A2	0.2827	
	A3	0.5381	
	A4	0.1239	
A1	B1	0.3333	-
	B2	0.6667	
A2	B3	0.3240	CI=0.0203 CR=0.0228
	B4	0.5050	
	B5	0.1044	
	B6	0.0666	
A3	B7	0.2721	CI=0.0371 CR=0.0713
	B8	0.1199	

	B9	0.6080	
A4	B10	0.5000	-
	B11	0.5000	

3.5 Risk calculation

According to the actual situation, assign the third-level parameters B1~B11 according to Table 5.

Table 5. Indicator assignment standard.

Indicator	No risk	Low risk	Moderate risk	High risk
B1	Clear	Light rain or snow	Moderate rain or snow	Fog, heavy rain or snow
B2	The maximum temperature is less than 30℃	The maximum temperature is between 30℃ and 35℃	The maximum temperature is between 35℃ and 40℃	The maximum temperature is more than 40℃
B3	Tunnel length is less than 500m	Tunnel length is between 500m and 1000m	Tunnel length is between 1000m and 1500m	Tunnel length is more than 1500m
B4	Three lanes and emergency lane for each carriageway	Two lanes and emergency lane for each carriageway	Two lanes for each carriageway	One lane
B5	Straight tunnel	Tunnel turning radius is more than 1500m	Tunnel turning radius is between 1000m and 1500m	Tunnel turning radius is less than 1000m
B6	Plane road	Slope road, the gradient is less than 5%	Slope road, the gradient is more than 5%	Downhill road
B7	The proportion of dangerous goods vehicles is less than 1%	The proportion of dangerous goods vehicles is between 1% and 5%	The proportion of dangerous goods vehicles is between 5% and 10%	The proportion of dangerous goods vehicles is more than 10%
B8	Traffic flow is less than 500veh/h	Traffic flow is between 500veh/h to 1000veh/h	Traffic flow is between 1000veh/h to 1250veh/h	Traffic flow is more than 1250veh/h
B9	The accident rate is less than 50 accidents (100 million vehicle kilometers)$^{-1}$	The accident rate is between 50 accidents (100 million vehicle kilometers)$^{-1}$ to 100 accidents (100 million vehicle kilometers)$^{-1}$	The accident rate is between 100 accidents (100 million vehicle kilometers)$^{-1}$ to 150 accidents (100 million vehicle kilometers)$^{-1}$	The accident rate is more than 150 accidents (100 million vehicle kilometers)$^{-1}$
B10	The arrival time of the rescue team is less than 10min	The arrival time of the rescue team is between 10min to 20min	The arrival time of the rescue team is between 20min to 30min	The arrival time of the rescue team is more than 30min

B11	With emergency fire fighting equipment, ventilation equipment and video surveillance equipment	With emergency fire fighting equipment and ventilation equipment	With emergency fire fighting equipment	No emergency equipment
Value	5	10	15	20

Using indicator weights to calculate the second-level indicator risk A1~A4 and the overall service area parking risk R, determine the risk level of dangerous goods vehicles through road tunnels according to Table 6.

Table 6. Risk level determination standard.

Risk level	Risk value range	Degree of risk
I	RA≤10	No risk
II	10<RA≤12	Low risk
III	12<RA≤14	Moderate risk
IV	RA>14	High risk

4. INSTANCE TEST

Based on the statistical data and tunnel data of 7 tunnels (numbered T1~T7) on the expressway from Beijing to Chengde in China, the risk of dangerous goods vehicles passing through each tunnel is calculated, and the overall risk values and the second level risk values are shown in Table 7.

Table 7. Assessment results.

Number	Risk level	R	A1	A2	A3	A4
T1	II	10.74	5.00	13.81	9.24	12.50
T2	II	10.75	8.33	14.33	9.24	10.00
T3	I	9.76	5.00	10.38	9.24	12.50
T4	II	10.44	5.00	11.67	9.24	15.00
T5	III	12.53	5.00	15.43	12.28	10.00
T6	I	9.21	8.33	10.05	9.24	7.50
T7	I	9.45	5.00	10.38	9.24	10.00

Judging from the assessment results, 3 of the 7 tunnels have no risk, 3 tunnels have low risks, and 1 tunnel has a moderate risk. The main factor leading to the moderate risk of tunnel T5 is A2, that is, the structural characteristics of the tunnel itself lead to a high risk of dangerous goods vehicles passing through the tunnel. Specifically, it is due to the long length of tunnel T5.

5. SUGGESTIONS

5.1 About vehicle traffic managements

In terms of traffic control of dangerous goods vehicles, the competent department can classify tunnels according to the risk of dangerous goods vehicles passing through the tunnel. For road tunnels with low risks, dangerous goods vehicles can pass directly, while for tunnels with high risks, control measures such as limiting the traffic time of dangerous goods vehicles and restricting the types of goods loaded by dangerous goods vehicles can be taken. Under the premise that dangerous goods vehicles can pass through tunnels, ensure the safety of vehicles passing through road tunnels.

5.2 About the operation and management of tunnel

Road tunnel operating companies can use video recognition equipment at road entrances to monitor dangerous goods vehicles entering road tunnels. At the same time, highway tunnel operating companies can use the cargo information and satellite positioning information of dangerous goods vehicles to establish a monitoring and early warning system for vehicles in road tunnels. When a dangerous goods vehicle enters a tunnel or an accident occurs in the tunnel, other social vehicles in the tunnel section will be notified through electronic displays and other means.

5.3 About emergency rescue

Highway tunnel operating companies can configure targeted emergency response equipment in the tunnel based on the dangerous characteristics of the goods loaded by dangerous goods vehicles. When dangerous goods vehicles collide, leak, fire and other accidents occur in the tunnel, it can be quickly disposed of and the scope of the accident can be controlled. At the same time, road tunnel operating companies should formulate corresponding emergency plans for accidents such as leakage and burning of dangerous goods in the tunnel, and improve emergency rescue levels through regular rescue drills.

6. CONCLUSIONS

This article analyzes the factors that affect the safety of dangerous goods vehicles passing through road tunnels, builds a risk assessment model, selects 7 road tunnels from Beijing to Chengde in China for case analysis, and proposes corresponding safety management measures. In reality, the competent department can build a risk assessment model based on the actual local conditions and refer to the method in this article to obtain the safety risk level of road tunnels within their jurisdiction. At the same time, the competent department can formulate corresponding vehicle traffic control measures to reduce the overall risk of dangerous goods vehicle traffic. In addition, drivers of dangerous goods vehicles can also refer to the safety risk levels of various road tunnels in the transportation area to arrange more reasonable transportation routes, and pay more attention to driving vehicles to ensure safety when passing through road tunnels with higher risk levels.

Although the assessment model constructed in this article based on the analytic hierarchy process can conduct risk assessments for different road tunnels and obtain the risks of dangerous goods vehicles passing through tunnels, during the model construction process, the determination process of the weight of each indicator is more based on subjective judgment and personal experience. Once a comparison matrix is constructed based on the experience of different experts, the weights of each indicator obtained may be quite different. In addition, risk assessment models constructed based on the analytic hierarchy process focus more on the independent impact of each indicator, while ignoring the interrelationship between indicators, which may result in the actual contribution of some indicators not being fully reflected in the model.

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