Evaluation Techniques for Traffic Safety of Operating Highway Tunnels

Hongbo WU
Research Institute of Highway, MOT, Beijing 100088, China

Abstract: With the consideration of frequent occurrence of traffic accidents on operating highway tunnels, the advancement of safety evaluation for highway tunnels in domestic and abroad are systematically summarized. Through the comprehensive analysis of infrastructure factors influencing on traffic safety of highway tunnels, safety checklists focusing on tunnel horizontal and vertical alignment, tunnel portal situation, pavement condition, ventilation and lighting facilities, traffic safety facilities are provided in qualitatively evaluating operating highway tunnels. Based on the concept of risk, risk assessment indices oriented in infrastructure factors, environmental factors and management factors for operation safety of expressway tunnels and standard highway tunnels are put forward. Quantitative evaluation methods based on indices architecture and the corresponding classification criteria for operation safety risk of tunnels are developed.

1 Preface

In recent years, with the development of national economy and the increasing demand of production and life, the highway transportation in China has developed rapidly, and the construction of highway tunnels has also made great achievements. By 2016, China had built 15,181 road tunnels with a total length of 14,039.7 kilometers, including 815 extra-long tunnels with 3,622.7 kilometers and 3,520 long tunnels with 6,045.5 kilometers. The tunnel belongs to the road section with abrupt change of road environment. The driver needs to deal with a large amount of information in the process of vehicle driving, which is easy to cause operational errors, resulting in the tunnel becoming a section with frequent traffic accidents. As an important means to prevent traffic accidents and reduce the severity of accidents, safety evaluation has been widely used in foreign countries. Therefore, combined with the relevant research results domestic and abroad, through the analysis of the factors affecting the safety of highway tunnel operation, the corresponding safety checklist is prepared, and the quantitative safety assessment methods based on risk assessment are proposed respectively for highway and standard highway tunnels, in order to provide technical support for the safety assessment of highway tunnels in service.

2 Analysis of research status domestic and abroad

In the world, tunnel safety has always been very concerned. In particular, European countries began to pay attention to the safety of tunnel operation after major fire accidents in Mont Blanc tunnel and Taun tunnel. According to the requirements of "Minimum requirements for tunnel safety in the trans European road network Directive 2004 / 54 / EC of the European Conference / Council of 29 April 2004", it is necessary to carry out safety assessment on the tunnel and set up a special organization Eurotest to check and evaluate the risk degree and safety of the existing road tunnel in Europe. Generally speaking, the technology of highway tunnel safety evaluation in European countries has developed earlier and more mature, and the evaluation method is mainly the combination of quantitative and qualitative. But there are also some shortcomings, such as the imperfect evaluation index system, the less consideration of the impact on human behavior and organizational structure, and the weak operability.

The research on the safety evaluation of highway tunnels started late in China. At present, the research mainly focuses on the safety evaluation index system and evaluation methods of tunnel operation or the advanced methods and technologies of the European Union, applying the concepts of risk potential and safety potential. The Specifications for Highway Safety Audit (JTG B05-2015), which was officially implemented in April 2016, only made general regulations on the safety evaluation contents of the existing highway tunnels from the aspects of highway geometry, sight distance, pavement anti-sliding ability, cross section, electromechanical facilities, safety facilities, etc. The existing research results and industry norms are relatively shallow to the special safety evaluation of highway tunnels in service, and lack of detailed evaluation index system and corresponding qualitative and quantitative...
evaluation methods, which is difficult to meet the safety evaluation requirements of a single tunnel.

3 Evaluation method based on safety checklist

According to the basic principles of safety engineering, combined with the relevant research results domestic and abroad and the summary and refinement of some typical road tunnel accidents, the safety checklist is a list of problems affecting the traffic safety of tunnels based on the field investigation and observation of some tunnels. When carrying out safety evaluation for highway tunnels in service, according to the safety checklist for issue list, through the review of design documents, field reconnaissance, field test or inquiries related personnel from the tunnel horizontal alignment, vertical alignment, pavement, ventilation, lighting, such as traffic safety facilities for inspection, found the potential risk factors and potential safety hazard.

| Table 1. Safety checklists for operating highway tunnel |
|-------------------------------------------------------|
| **Evaluation content** | **Evaluation means** | **Evaluation conclusion** |
| 1 horizontal alignment |  |  |
| Is horizontal curve set in the tunnel? If it has to be set, is the flat curve radius without superelevation adopted and meets the requirements of stopping sight distance? | Evaluation according to design documents |  |
| Is the exit direction of long and extra long tunnels connected with small radius horizontal curve? | Evaluation according to design documents |  |
| 2 vertical alignment |  |  |
| Does the longitudinal slope of the tunnel consider traffic safety, operation ventilation scale and drainage requirements? Is it not less than 0.3% and not more than 3%? | Evaluation according to design documents |  |
| Are there too many slope change points in the tunnel? | Evaluation according to design documents |  |
| 3 horizontal and vertical alignment of portal section |  |  |
| Is the horizontal and vertical alignment consistent within the range of 3S design speed stroke length inside and outside the tunnel portal? | Evaluation according to design documents |  |
| Is the tunnel entrance located near the slope change point of convex vertical curve? | Evaluation according to design documents |  |
| Is the tunnel portal located in the section with long and steep downhill and small radius curve? | Evaluation according to design documents |  |
| Is there a certain length of transition between the tunnel and the wiring outside the tunnel? | According to the design documents and site survey evaluation. |  |
| Are emergency parking strips provided in long and extra long tunnels? Does the width of the emergency stop belt meet the requirements of safe parking for large trucks? | According to the design documents and site survey evaluation. |  |
| 4 road surface |  |  |
| Does the tunnel pavement have good skid resistance? | According to the field test evaluation. |  |
| When cement concrete is used in the tunnel and asphalt pavement is used outside the tunnel, is there a certain length of transition section? | According to the site survey evaluation |  |
| Is the long and extra long tunnel equipped with color pavement within 50m of the entrance and exit? | According to site survey and evaluation. |  |
| Will the tunnel pavement return to moisture under adverse weather conditions? | According to site survey and evaluation. |  |
| 5 ventilation facilities |  |  |
| Does the tunnel ventilation design meet the requirements of current specifications? | Evaluation according to design documents. |  |
| Does the tunnel ventilation system have the ventilation control function under normal and fire conditions? | Evaluation according to design documents. |  |
| Is ventilation good? Is good visibility guaranteed in the tunnel? | According to site survey and evaluation. |  |
| Is the ventilation equipment capable of resisting high temperature? | Evaluation according to design documents. |  |
| Can the fan run in reverse? | According to field test evaluation. |  |
| 6 lighting facilities |  |  |


| Does the tunnel lighting design meet the requirements of current specifications? | Evaluation according to design documents. |
|---|---|
| Is the tunnel open normally? Is there emergency lighting? | According to site survey and evaluation. |
| Can power supply be ensured in case of partial failure? Is there a continuous power system UPS? | According to site survey and evaluation. |
| Is there an obvious “black and white hole” effect at the tunnel entrance? | According to site survey and evaluation. |
| Whether the lighting fixtures are clean? | According to site survey and evaluation. |

7 traffic safety facilities

| Are tunnel signs, speed limit signs and no overtaking signs set before the tunnel entrance? | According to site survey and evaluation. |
|---|---|
| When the tunnel is long, the traffic volume is large and located in the uphill road section, is lane indication sign set in front of the tunnel entrance? | According to site survey and evaluation. |
| When the radius of horizontal curve in the tunnel is small, is there a linear guide sign or active luminous contour sign? | According to the design documents and site survey evaluation. |
| Is the end wall of tunnel portal marked with facade mark? | According to site survey and evaluation. |
| Is a zebra crossing in the direction of oblique traffic built in the hard shoulder 50m in front of the tunnel entrance? | According to site survey and evaluation. |
| Is lane change forbidden at the boundary of carriageway 100m in front of the tunnel entrance and 50m behind the tunnel exit? | According to site survey and evaluation. |
| Is the subgrade guardrail gradually transited to the end of the tunnel portal access road? | According to site survey and evaluation. |
| In order to alleviate the "black hole" and "white hole" effects at the entrance and exit of the tunnel, are active light-emitting inducing facilities set up to realize the smooth transition of light and shade level inside and outside the tunnel? | According to site survey and evaluation. |

8 fire fighting and rescue facilities

| Is the number of fire extinguishers in accordance with fire regulations? | According to site survey and evaluation. |
|---|---|
| Is the fire extinguisher in an open and fixed position and easy to use? | According to site survey and evaluation. |
| Is the fire extinguisher dated? Is it regularly inspected and maintained? | According to site survey and evaluation. |
| Does the fire hose and emergency broadcast system work normally? | According to the field test evaluation. |
| Is the fire hydrant and fire pump adapter in good condition? | According to field test evaluation. |
| Is there a fire water reservoir? Is there any accumulation and garbage in the pool? | According to site survey and evaluation. |
| Is the emergency exit spacing reasonable? | Evaluate according to the design documents |
| Is the emergency exit sign set? Is it clearly visible? | According to site survey and evaluation. |
| Is the escape way provided with good smoke and fire protection function? | According to site survey and evaluation. |
| Is there emergency lighting in the escape way? | According to site survey and evaluation. |

9 monitoring facilities

| Is there a tunnel monitoring center? | According to site survey and evaluation. |
|---|---|
| Is the tunnel monitoring center manned 24 hours a day? | According to on-site inquiry and evaluation. |
| Is vehicle detector installed? Is the vehicle detector intact? | According to site survey and evaluation. |
Can real-time monitoring of the whole tunnel be realized? According to site survey and evaluation.
Does the camera and video monitoring control equipment work normally? Pass the field test evaluation.
Is variable information board installed? According to site survey and evaluation.
Is there a radio broadcast in the whole tunnel? According to site survey and evaluation.
Is there an emergency phone? Are emergency telephone signs complete? According to site survey and evaluation.

10 other facilities
Is the long and extra long tunnel provided with a connecting passage at a suitable position outside the tunnel entrance to facilitate vehicle turning around? According to site survey and evaluation.
For the road section with more heavy vehicles, does the cover strength of drainage side ditch and cable trench in the tunnel meet the requirements of vehicle driving? Through the evaluation of design documents.
When the tunnel exit is greatly affected by bad weather, such as heavy fog and snowfall, have targeted measures been taken? According to site survey and evaluation.

### 4 Evaluation method based on risk assessment

After many years of operation, some highway tunnels have some problems, such as the aging or defect of fire-fighting equipment, the failure of ventilation and lighting facilities to operate as required, the weak emergency rescue capacity, the inadequate management of dangerous goods transport vehicles, etc., which lead to a large potential safety hazard and traffic accidents. Therefore, in the process of tunnel operation, the concept of risk is introduced, the safety risk of tunnel operation is identified, and its qualitative and quantitative evaluation is carried out, which has attracted the attention of many researchers domestic and abroad, and qualitative and quantitative evaluation methods such as Delphi method, event tree method, checklist method, analytic hierarchy process, fuzzy comprehensive evaluation method are proposed.

### 4.1 Safety risk assessment of expressway tunnel operation

Because there are many risk factors that affect the safety of highway tunnel operation, some of them, such as driver and vehicle conditions, are difficult to quantify. In order to evaluate the safety risk of expressway tunnel operation accurately, it is necessary to extract the risk factors which are easy to quantitatively or qualitatively evaluate and have great influence on the safety risk of operation on the basis of safety risk identification, and then establish the corresponding risk assessment index system. Combined with the current situation of expressway tunnel operation safety in China and relevant research results domestic and abroad, the tunnel operation safety risk assessment index system as shown in Table 2. It is constructed from three aspects of facility factors, environmental factors and management factors.

#### Table 2. Risk assessment indices for operation safety of expressway tunnels

| Factors | Evaluation index | Classification | Basic score ($R_{ij}$) | Range of values | Weight coefficient ($\gamma_{ij}$) | Evaluation score ($T_{ij}$) |
|---------|------------------|----------------|------------------------|----------------|-------------------------------|------------------------|
| Tunnel length $T_{11}$ | | L > 3000m | 75-100 | $R_{11}$ | $\gamma_{11}$ | $T_{11}=\gamma_{11} \times R_{11}$ |
| | | 1000m < L ≤ 3000m | 50-74 | | | |
| | | 500m < L ≤ 1000m | 25-49 | | | |
| | | L ≤ 500m | 0-24 | | | |
| Facility factor $T_{1}$ | Horizontal and vertical alignment combination of tunnel $T_{12}$ | The combination of horizontal and vertical alignment is poor, and there is a serious potential safety hazard | 75-100 | $R_{12}$ | $\gamma_{12}$ | $T_{12}=\gamma_{12} \times R_{12}$ |
| | | The combination of horizontal and vertical alignment is unreasonable, and there is obvious potential safety hazard | 50-74 | | | |
| | | Poor combination of horizontal and vertical alignment has certain impact on driving safety | 25-49 | | | |
| | | Good combination of horizontal and vertical alignment | 0-24 | | | |
| | Skid | SFC < 0.3 | 75-100 | $R_{13}$ | $\gamma_{13}$ | $T_{13}=\gamma_{13} \times R_{13}$ |
| Environmental factors $T_2$ | Resistance of pavement $T_{13}$ | Safety facilities $T_{14}$ | Tunnel lighting $T_{15}$ | Emergency exit distance $T_{16}$ | Monitoring facilities $T_{17}$ | Annual average daily traffic volume of single tunnel $T_{31}$ | Heavy truck ratio $T_{32}$ | Climatic factors $T_{33}$ | Accident rate per million vehicle kilometers $T_{31}$ | Management factors $T_{33}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $0.3 \leq SFC < 0.4$ | $0.4 \leq SFC < 0.5$ | $SFC \geq 0.5$ | The tunnel section lacks corresponding safety protection, driving guidance and speed control facilities | The tunnel portal lacks necessary safety protection and speed control facilities | Lack of necessary driving guidance and prompt facilities in the tunnel | Perfect and reasonable traffic safety facilities in tunnel section | Good tunnel lighting | The tunnel lighting is not turned on | The tunnel lighting is poor, and there is obvious black and white hole effect at the tunnel entrance | The tunnel lighting is general, and there are some light and shade adaptation problems at the entrance of the tunnel |
| 50-74 | 25-49 | 0-24 | 75-100 | 50-74 | 25-49 | 0-24 | 0-24 | 75-100 | 50-74 | 25-49 |
| $D > 650m$ | $450m < D \leq 650m$ | $250m < D \leq 450m$ | $D < 250m$ | | | | | | | |
| 75-100 | 50-74 | 25-49 | 0-24 | 75-100 | 50-74 | 25-49 | 0-24 | 75-100 | 50-74 | 25-49 |
| $AADT > 30000$ | $10000 < AADT < 30000$ | $4000 \leq AADT \leq 10000$ | $AADT > 4000$ | $30\% < HGV < 50\%$ | $10\% < HGV < 30\%$ | $HGV \geq 50\%$ | $HGV \leq 10\%$ | Frequent bad weather | More bad weather | Less bad weather | Almost no bad weather |
| 75-100 | 50-74 | 25-49 | 0-24 | 75-100 | 50-74 | 25-49 | 0-24 | 75-100 | 50-74 | 25-49 | 0-24 |
| $CR > 0.50$ | $0.30 \leq CR < 0.50$ | $0.15 \leq CR < 0.30$ | $CR < 0.15$ | | | | | | | |
| 75-100 | 50-74 | 25-49 | 0-24 | 75-100 | 50-74 | 25-49 | 0-24 | 75-100 | 50-74 | 25-49 | 0-24 |
| $SL > 100km/h$ | $80km/h < SL \leq 100km/h$ | $60km/h < SL \leq 80km/h$ | $SL \leq 60km/h$ | | | | | | | |
| 75-100 | 50-74 | 25-49 | 0-24 | 75-100 | 50-74 | 25-49 | 0-24 | 75-100 | 50-74 | 25-49 | 0-24 |
| $ERT > 20min$ | $10 < ERT \leq 20min$ | $5 < ERT \leq 10min$ | $ERT \leq 5min$ | | | | | | | |
| 75-100 | 50-74 | 25-49 | 0-24 | 75-100 | 50-74 | 25-49 | 0-24 | 75-100 | 50-74 | 25-49 | 0-24 |
4.2. Operation safety risk assessment of standard highway tunnel

Since the overtaking tunnel or another tunnel can be used for traffic evacuation and escape in the event of an accident in the expressway tunnel, traffic organization and rescue escape will face greater problems in the event of an accident in the standard highway tunnel, therefore, it is necessary to evaluate the operation safety risk of the standard highway tunnel. Considering that compared with the expressway tunnel, the standard highway tunnel is poor in geometry, ventilation and safety management, on the basis of expressway tunnel operation safety risk evaluation index system, several evaluation indexes are added, and the evaluation index system of standard highway tunnel operation safety risk is proposed as shown in Table 3.

| Factors                     | Evaluation index | Classification                                                                 | Basic score (Rij) | Weight coefficient (γij) | Evaluation score (Tij) |
|-----------------------------|------------------|-------------------------------------------------------------------------------|------------------|--------------------------|------------------------|
| Tunnel length T11           |                  | L >3000m                                                                       | 75-100           | R11                      | T11=γ11×R11            |
|                             |                  | 1000m ≤ L ≤ 3000m                                                              | 50-74            | γ12                      | T12=γ12×R12            |
|                             |                  | 500m ≤ L ≤ 1000m                                                               | 25-49            | γ13                      | T13=γ13×R13            |
|                             |                  | L ≤ 500m                                                                       | 0-24             | γ14                      | T14=γ14×R14            |
| Tunnel portal alignment     |                  | The alignment inside and outside the tunnel portal is in very poor consistency | 75-100           |                          |                        |
| T12                         |                  | The alignment inside and outside the tunnel portal is in poor consistency       | 50-74            |                          |                        |
| Facility factor T1          |                  | The alignment inside and outside the tunnel portal is in general consistency    | 25-49            |                          |                        |
|                             |                  | The alignment inside and outside the tunnel portal is in good consistency       | 0-24             |                          |                        |
| Longitudinal slope of tunnel T13 |                  | 2.5% ≤ G ≤ 3%                                                                  | 75-100           |                          |                        |
|                             |                  | 2% ≤ G ≤ 2.5%                                                                  | 50-74            |                          |                        |
|                             |                  | 1.5% ≤ G ≤ 2%                                                                  | 25-49            |                          |                        |
|                             |                  | G ≤ 1.5%                                                                       | 0-24             |                          |                        |
| Tunnel pavement condition T14 |                  | Large area of obvious subsidence, uplift, pothole, damage, crack, overflow    | 75-100           |                          |                        |
|                             |                  | and other conditions on the tunnel pavement seriously affect the traffic safety and may lead to traffic accidents |                  |                          |                        |
|                             |                  | Large area of subsidence, uplift, pothole, damage, crack and serious ponding occur in the tunnel pavement, which affects the driving safety, and the low anti sliding coefficient causes vehicle slipping | 50-74            |                          |                        |
| Traffic sign                |                  | Most of them are dirty, falling off                                             | 75-100           | γ15                      | T15=γ15×R15            |
| Marking | T15 | Missing, which affects driving safety | 50-74 |
|---------|-----|--------------------------------------|-------|
|         |     | There are dirt, local falling off,    |       |
|         |     | loss, etc., which affect traffic      |       |
|         |     | safety                               |       |
|         |     | Dirty, incomplete, not obstructing   | 25-49 |
|         |     | traffic                              |       |
| Tunnel lighting | T16 | There is no lighting lamp in the    | 75-100|
|         |     | tunnel or the lighting lamp is not   |       |
|         |     | turned on                             |       |
|         |     | The tunnel lighting is poor, and     | 50-74 |
|         |     | there is obvious “black and white    |       |
|         |     | hole” effect at the tunnel entrance  |       |
|         |     | Tunnel lighting is general, and      | 25-49 |
|         |     | there are some light and shade       |       |
|         |     | adaptation problems at the entrance  |       |
|         |     | of the tunnel                         |       |
|         |     | Good tunnel lighting                  | 0-24  |
| Tunnel ventilation | T17 | There is no ventilation facilities in | 75-100|
|         |     | the tunnel or the ventilation         |       |
|         |     | facilities cannot be opened           |       |
|         |     | normally                              |       |
|         |     | There are few ventilation facilities  | 50-74 |
|         |     | in the tunnel or some ventilation     |       |
|         |     | facilities are damaged                |       |
|         |     | Some ventilation facilities in the    | 25-49 |
|         |     | tunnel are damaged                    |       |
|         |     | Ventilation facilities in the tunnel  | 0-24  |
|         |     | can be opened normally                |       |
| Evacuation and rescue facilities | T18 | There is no fire alarm and fire      | 75-100|
|         |     | rescue facilities in the tunnel or the|       |
|         |     | facilities cannot be used normally    |       |
|         |     | There are only a few fire alarm and   | 50-74 |
|         |     | fire rescue facilities in the tunnel  |       |
|         |     | or some facilities cannot be used     |       |
|         |     | normally                              |       |
|         |     | Some fire alarm and fire rescue      | 25-49 |
|         |     | facilities in the tunnel cannot be    |       |
|         |     | used normally                         |       |
|         |     | Necessary fire alarm and rescue      | 0-24  |
|         |     | facilities shall be set in the tunnel |       |
| Monitoring facilities | T19 | There is no monitoring facility in   | 75-100|
|         |     | the tunnel or the monitoring facility |       |
|         |     | cannot be used normally               |       |
|         |     | There are only a few monitoring      | 50-74 |
|         |     | facilities in the tunnel or some of   |       |
|         |     | them cannot be used normally          |       |
|         |     | Some monitoring facilities in the     | 25-49 |
|         |     | tunnel cannot be used normally        |       |
|         |     | The monitoring facilities in the      | 0-24  |
|         |     | tunnel are relatively complete        |       |
| Environmental factors | T2  | AADT > 15000. The situation of       | 75-100|
|         |     | mixed operation of locomotive and     |       |
|         |     | non locomotive is serious             |       |
|         |     | 6000 < AADT ≤ 15000. The situation   | 50-74 |
|         |     | of mixed operation of locomotive and  |       |
|         |     | non locomotive is relatively serious  |       |
|         |     | 2000 < AADT ≤ 6000. There are few    | 25-49 |
|         |     | cases of mixed operation of locomotive|       |
|         |     | and non locomotive                    |       |
|         |     | AADT ≤ 2000. The situation of mixed   | 0-24  |
|         |     | operation of locomotive and non       |       |
|         |     | locomotive is very seldom             |       |
|         |     | Heavy vehicle percentage              | 75-100|
|         |     | HGV > 50%                             |       |
|         |     | 30% < HGV ≤ 50%                      | 50-74 |
|         |     |                                     |       |
According to the risk assessment index system established in Table 2 and Table 3, the safety risk of tunnel operation is evaluated by the index system method. The safety risk of tunnel operation shall be determined according to formula (1) and (2).

\[ R = \sum T_j \]  \hspace{1cm} (1)

\[ T_j = \gamma_j \times R_j \]  \hspace{1cm} (2)

Where: \( T_j \) - the evaluation score of the evaluation index, \( i=1,2,3; \) \( j=1,2,...,n \), \( n \) is the number of the corresponding class of evaluation index; \( R_j \) - the basic score of the evaluation index. For the quantitative index, the value of the evaluation index can be obtained through design documents, field observation or field test, and the basic score can be calculated by linear interpolation method. For the qualitative index, it can be determined by the professional according to the engineering...
experience; $\gamma_y$ - weight coefficient of each evaluation index, generally, it is determined by the method of "determining the value of weight by ranking the importance of evaluation indicators", and the calculation formula (3) is as follows:

$$\gamma_y = \frac{2n - 2m + 1}{n^2} \quad (3)$$

Table 4. Classification criteria for operation safety risk of tunnel

| No | Evaluation indicators | Weight coefficient |
|----|-----------------------|--------------------|
| 1  | Tunnel length $T_{11}$ | 0.14               |
| 2  | Horizontal and vertical alignment combination of tunnel $T_{12}$ | 0.11               |
| 3  | Skid resistance of pavement $T_{13}$ | 0.06               |
| 4  | Safety facilities $T_{14}$ | 0.05               |
| 5  | Tunnel lighting $T_{15}$ | 0.08               |
| 6  | Emergency exit distance $T_{16}$ | 0.02               |
| 7  | Monitoring facilities $T_{17}$ | 0.03               |
| 8  | Annual average daily traffic volume of single tunnel $T_{21}$ | 0.13               |
| 9  | Heavy truck ratio $T_{22}$ | 0.09               |
| 10 | Climatic factors $T_{23}$ | 0.04               |
| 11 | Accident rate per million vehicle kilometers $T_{31}$ | 0.12               |
| 12 | Speed limit $T_{32}$ | 0.07               |
| 13 | Emergency response time $T_{33}$ | 0.01               |
| 14 | Dangerous goods vehicle management $T_{34}$ | 0.10               |

The weight coefficient of the risk assessment index of the operation safety of the standard highway tunnel can also be determined according to the similar process. After the calculated value, the safety risk level of tunnel operation is determined according to Table 5.

Table 5. Classification criteria for operation safety risk of tunnel

| Risk level                  | R       |
|-----------------------------|---------|
| Grade IV (very high risk)   | $R > 80$|
| Level III (high risk)       | $60 < R \leq 80$ |
| Level II (moderate risk)    | $40 < R \leq 60$ |
| Grade I (low risk)          | $R \leq 40$ |

5 Conclusion

With the rapid development of highway tunnel construction in China, the safety situation of highway tunnel operation is not optimistic, so it is very urgent to evaluate the safety of highway tunnel in service. Combined with the research status of safety evaluation of highway tunnels domestic and abroad, the safety checklist of highway tunnels is compiled by summarizing and analyzing the facility factors that affect the traffic safety of highway tunnels in China. Based on the concept of risk, the evaluation index system of tunnel operation safety risk is formed from three aspects: facility factor, environment factor and management factor. The evaluation index system of operation safety risk and the quantitative evaluation method of tunnel operation safety based on the index system method are proposed for the expressway and standard highway respectively, which is used to carry out the special safety evaluation of highway tunnel in service and provide technical support for the daily management and maintenance work and safety self inspection of the tunnel operation management unit.

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