Study on Static Risk Assessment Model of Expressway Operation Companies

Xiaofeng Zhang, Lianghai Lv and Yabo Xu
Beijing Key Laboratory of Control Technology for Toxic, Hazardous, Flammable and Explosive Sources of City, Beijing Municipal Institute of Labor Protection, Beijing 100054, China

Abstract. In order to achieve that the expressway operation companies may manage itself by different levels, and avoid accidents effectively, establishing a risk assessment model for static risk sources is necessary. First, according to the result of surveying, the risk source units of expressway operation enterprises was divided, and the risk sources of each unit were identified. The list of risk sources was established. At the same time, the types of accidents that may be caused by all risk sources were analyzed. Secondly, according to the principles of practical operability and effectiveness, and the relevant laws and regulations of the state on accident grading, criteria for evaluating the severity of accidents and consequences was set up. Finally, the risk matrix for risk level determination of the risk source of the expressway operation enterprise was set up.

Keywords: expressway; the risk source units; the list of risk sources; risk level; risk matrix.

In recent years, the mileage of the expressway in China has been increasing. By the end of 2016, the total mileage reached 124 thousand and 500 kilometers, and the total scale has been in the forefront of the world. Safe operation, and effectively reducing the serious impact of highway emergencies on life and property has increasingly aroused the attention of experts of the industry. In 2017, the “8.10” special accident in Qinling Mountains tunnel caused 36 deaths and 13 injuries. In 2012, the “7.21” heavy rain in Beijing caused the accumulation of water under the bridge named Nangangwa in Beijing, causing 127 cars to be flooded, and several deaths. These accidents result in serious adverse effects in society. Therefore, using the idea of risk management to identify the risk sources, carrying out quantitative or qualitative risk assessment, and Carrying out risk prevention and control are very necessary. Therefore, combined with the relevant research results at home and abroad, the paper identifies the risk source of the highway operation in the process, establishes a risk assessment model, to provide theoretical and technical support for highway operation units and related sectors to carry out risk management.

1. Research Status
In recent years, with the rapid development of the social economy, the mileage and traffic volume of the expressway have also increased rapidly, and the safety risk of the expressway operation is becoming more and more prominent. The risk of highway operation is generally expressed by the possibility and the severity of the consequences, which is shown in the following form.

\[ R = f(P, C) \] \hspace{1cm} (1)
R is the safety risk of highway operation. P is the possibility of accident. C is the loss caused by accident, including economic loss, casualty and environmental impact.

At present, many experts in China have carried out the research on the risk assessment of expressway operation. For example, based on the traffic flow characteristics of expressway network components, combined with the topological structure characteristics and functional attributes of expressway network, some professor of Beijing Jiaotong University set up the operational risk measurement set and calculation model of highway network, and put forward the operation risk analysis method of expressway network. (Zhang, Chenchen, 2016) Based on the analysis of the operation status of highway tunnel section and the influence of different time on tunnel operation safety, the Key Laboratory of the Ministry of education of road and traffic engineering of Tongji University has established a dynamic early warning system for highway tunnel section. (SU Donglan, 2016) Combined highway operation situation of our country, some Professor from safety and Environment Research Institute of Tongji University put forward the comprehensive evaluation method, which base on highway safety analysis, accident investigation and analysis, design compliance and safety assessment checklists for speed. (LI Zhihong, 2008) Tian Wei established a risk assessment index system for expressway maintenance operation. With the help of Near-Miss management theory, an improved highway safety management mode of special maintenance project was formed (Tian Wei, 2011).

In domestic research, the current domestic highway operation risk assessment research is mainly focused on applying various kinds of risk assessment model to the main body of the highway, tunnel, bridge operation, maintenance and other local or specific parts. The research of overall risk evaluation for all components of Expressway is missing. Aiming at the risk assessment of expressway operation companies is lack of comprehensiveness.

2. Risk Identification of Expressway Operation

2.1. Unit Division of Risk Source

Through the highway operation enterprise field visits to research, in general, highway operators involved in places including highways, bridges, tunnels, work area, road maintenance office premises, pumping stations, toll station area, service area (including gas station). In order to fully grasp the risk sources involved in the highway operation, the location of the risk source unit is divided, as shown in Figure 1.

![Figure 1. Division of static risk source unit of expressway operation enterprise.](image-url)
2.2. Risk Source List Establishment

According to the Classification standard for casualty accidents of enterprises (GB6441-86), the risk sources of each unit of highway operation enterprises are carding out, and the list of risk sources as Table 1 is established.

Table 1. List of static risk sources for expressway operation enterprises.

| Unit name | Name of risk source | Object strike | Vehicle injury | Mechanical injury | Lifting injury | Electric shock | Drowning | Scorching | Fire | Falling | Collapse | Boiler explosion | Container explosion | Other explosions | Poisoning and asphyxia | Other injuries |
|-----------|---------------------|--------------|----------------|-------------------|--------------|----------------|-----------|----------|------|---------|----------|-------------------|-------------------|-----------------|----------------------|-------------|
|           | A road with defects on the road |   |     |       |     |     |           |         |         |     |         |         |                  |                  |                 |                      |             |
|           | A defective section of a subsidiary facility (including a barrier, a fence, etc) |   |     |       |     |     |           |         |         |     |         |         |                  |                  |                 |                      |             |
|           | Well, the rain perforated strainer |   |     |       |     |     |           |         |         |     |         |         |                  |                  |                 |                      |             |
|           | Billboard            |   |     |       |     |     |           |         |         |     |         |         |                  |                  |                 |                      |             |
|           | The body of expressway section |   |     |       |     |     |           |         |         |     |         |         |                  |                  |                 |                      |             |
|           | Long and downhill section |   |     |       |     |     |           |         |         |     |         |         |                  |                  |                 |                      |             |
|           | Sharp steep slope    |   |     |       |     |     |           |         |         |     |         |         |                  |                  |                 |                      |             |
|           | Easy to water section (deep grooves, pavement below road slope elevation) |   |     |       |     |     |           |         |         |     |         |         |                  |                  |                 |                      |             |
|           | Prone to fall stones, debris flows, landslides and other sections |   |     |       |     |     |           |         |         |     |         |         |                  |                  |                 |                      |             |
|           | Bridge main body     |   |     |       |     |     |           |         |         |     |         |         |                  |                  |                 |                      |             |
|           | Space under the bridge (storage of inflammable and explosive materials, |   |     |       |     |     |           |         |         |     |         |         |                  |                  |                 |                      |             |
| Lighting, cables, vehicles, etc. | • | |
| Building structures | • | |
| Various kinds of pipeline (drainage) of bridge | • | |
| A bridge hanging board, sign, etc | • | |
| Power supply and distribution facilities | • | |
| Tunnel main body | • | • |
| Pilot area | • | • |
| Lifting equipment | • | |
| Road cleaning machinery and vehicles | • | |
| Temporary electrical wiring | • | • |
| Snow removing vehicle equipment | • | |
| Alternator | • | |
| Drainage equipment (drainage station, drainage unit, combined pump) | • | |
| Oxygen and acetylene cylinders | • | • |
| Scaffolding | • | • |
| The slope of the high work | • | |
| Mobile operating platform | • | |
| Mechanical vehicle | • | • |
| Equipment for maintenance | Work area | Limited space (septic tank, sewage pool, etc.) | Information Center | Archives Center | Kitchen | Dormitory | Cistern | Grill machine | Electricity | Pumping stations | Diesel storage facility | A well, pit, ditch | Lifting equipment | Toll booth | Over charge |
|---------------------------|-----------|-----------------------------------------------|--------------------|----------------|--------|-----------|--------|-------------|-------------|------------------|---------------------|----------------|-----------------|-----------|-----------|
| Generator room           |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Fire-fighting high pressure cylinder |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Direct combustion engine |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Boiler                   |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Diesel pipeline          |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Gas facilities           |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Distribution room        |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Fire pump room           |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Diesel pipeline          |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Work area                |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Limited space (septic tank, sewage pool, etc.) |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Information Center       |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Archives Center          |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Kitchen                  |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Dormitory                |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Cistern                  |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Grill machine            |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Electricity              |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Over charge              |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Charging station         |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Toll booth               |          |                                               |                    |                |        |           |        |             |             |                  |                     |                |                 |           |           |
| Location                  | Toll lane | UPS equipment | Storage tank | Oil discharge port | Operation well | Vent | Filling machine | Service area (including gas station) | Distribution room | Generator room | Limited space (septic tank, etc.) | Gas facilities | Parking square vehicle |
|--------------------------|-----------|---------------|--------------|-------------------|----------------|------|----------------|-------------------------------------|-------------------|----------------|-------------------------------|----------------|------------------------|
|                          |           |               |              |                   |                |      |                |                                     |                   |                |                               |                |                       |


3. Selection of Risk Assessment Methods

3.1. Comparative Analysis and Selection of Risk Assessment Methods

At present, the methods of risk assessment are mainly divided into quantitative risk assessment method, qualitative risk assessment method and semi quantitative risk assessment method. It includes fault type and influence analysis method, pre danger analysis method, event tree analysis method, fault tree analysis method, relative risk index method, probability analysis method, analytic hierarchy process, fuzzy comprehensive evaluation method, risk matrix method and so on. The comparison of the risk assessment methods can be seen in the following table. Each risk assessment method has its own characteristics of use, and has certain applicability, but at the same time, there are their own limitations.

Table 2. Comparative analysis of risk assessment methods (Du Dong, 2008; Dai Shuhe, 2007).

| Evaluation method name | Advantages | Disadvantages |
|------------------------|------------|--------------|
| Fault type and influence analysis method | The method is simple, the result is clear, no large amount of calculation is needed, and it is suitable for the analysis of the device. | The results are not detailed, the accuracy is low, and the subjective factors of the risk assessor are easily affected. |
| Pre risk analysis | Risk factors, risk events, risk results, and risk control measures can be identified. | The subjectivity is strong and the risk level can not be determined |
| Analytic hierarchy process | Application to complex risk assessment system | The subjectivity is strong, and it is easy to ignore the essential safety of all factors |
| Event Tree Analysis | A way to determine the possible pathways and risk consequences of a risk event and a way to prevent the occurrence of a risk event | It is difficult to quantify the quantitative assessment and requires a large number of statistical data, and it is difficult to implement the data once the data is lacking. |
| Fault tree analysis | Direct expression of risk factors and risk events is beneficial to the formulation of risk control measures | The workload is large and it is difficult to assess the risk of complex risk events. |
| Probability analysis | A quantitative risk assessment method, combined with a variety of risk assessment methods, is practical. | Request the original data to be accurate and full |
| Risk matrix method | At the same time, considering the size and probability of risk factors affecting the system risk, it is widely applicable and easy to understand and operate | The evaluation subjectivity is strong, the assignment is inaccurate and the evaluation result is blurred |

Has its own characteristics in risk assessment of highway operation enterprises, compared with other evaluation object, the highway operation enterprise risk source unit is numerous, and there is greater independence; highway risk source content type, span, including basic road, maintenance work also includes a variety of ancillary facilities including physical static risk source also, including the risk sources of real-time mobile physical and so on. At the same time, the purpose of establishing risk assessment model is mainly to serve the object as the main body of expressway operation enterprise. The purpose of evaluation is to fully grasp the internal safety risk situation and rationally allocate limited prevention and control
resources. Therefore, the risk matrix method is selected for the establishment of this evaluation model.

3.2. Accident Possibility Model
In order to effectively cope with the characteristics of expressway operation enterprises and enhance the practical operability of the evaluation process, according to the principles of practicality, accessibility and dynamism, we select the evaluation criteria of accident possibility model and establish the evaluation criteria such as Table 3.

\[ P = \sum \frac{p_i}{3}, (i = 1, 2, 3) \]  

(2)

| Table 3. Criteria for judging the possibility of a static risk source. |
|---------------------------------------------------------------|
| **Index name**                      | **Level** | **Score** | **Index description**                                                                 |
|------------------------------------|-----------|-----------|--------------------------------------------------------------------------------------|
| The probability of the occurrence of similar accidents in enterprises P1 | more      | 4         | More than 5 more similar accidents have occurred in the past 10 years                |
|                                    | commonly  | 3         | The number of similar accidents in the past 10 years is more than 3 times, less than 5 times |
|                                    | Small     | 2         | The number of similar accidents in the past 10 years is less than 3 times             |
|                                    | less       | 1         | There have been no similar accidents in the past                                      |
| Basic management level of safety production P2 | bad      | 4         | There is a major hidden danger in the scene                                          |
|                                    | poor      | 3         | The number of common hidden dangers in the scene is more than 5 items               |
|                                    | good      | 2         | There are less than 5 general hidden dangers in the scene                           |
|                                    | Very good | 1         | No safety hazard on the spot                                                       |
| Safety production site management level P3 | bad      | 4         | Lack of security management system                                                 |
|                                    | poor      | 3         | The content of safety management system is not perfect                              |
|                                    | good      | 2         | A relatively perfect security management system has been set up                     |
|                                    | Very good | 1         | Set up a perfect safety management system                                           |
| Remarks                            |           |           | According to the probability of similar accidents in the enterprise, when a specific risk source may occur more than one kind of accident, the probability of a larger type of accident is taken as the criterion. If the number of enterprises is less than 10 years, the equivalent evaluation is made according to the number of times and the fixed number of years. |

3.3. Model of Severity of Accident Consequences
For the calculation of the severity of the accident consequences can fit with national laws and regulations, extract the corresponding indicators proposed from the present classification of production safety accidents in China is widely recognized and applied the “production safety accident reporting and investigation of treatment regulations”, including personnel deaths, injuries and direct economic losses. The criteria for evaluation of each index can be seen in Table 4.

\[ C = \text{Max}\{C_1, C_2, C_3\} \]  

(3)
Table 4. Criteria for evaluating the severity of the consequences of a static risk source.

| Level   | Score | Index description | Death toll C1                  | Number of injuries C2                   | Direct economic loss C3                  |
|---------|-------|-------------------|--------------------------------|----------------------------------------|----------------------------------------|
| Great   | 4     | More than 30 people | More than 100 people seriously injured | More than 100 million yuan             |                                        |
| Large   | 3     | More than 10 people are less than 30 | More than 50 people or more than 100 people | More than 50 million yuan and less than 100 million yuan |                                        |
| General | 2     | More than 3 people are less than 10 | More than 10 people are less than 50 | More than 10 million yuan and less than 50 million yuan |                                        |
| Small   | 1     | Less than 3 people | Less than 10 people | Less than 10 million yuan |                                        |

Remarks: When a specific risk source may occur more than one type of accident, a more serious type of accident is taken as the criterion.

3.4. Risk Matrix Model

According to the risk matrix theory, the risk matrix diagram is set up as follows: risk matrix evaluation method research and engineering application review (RUAN Xin, 2013):

Table 5. Risk matrix.

| Possibility | Unlikely 1 | Fortuitous 2 | Probable 3 | Likely 4 |
|-------------|------------|--------------|------------|---------|
| Severity    | General    | Larger       | Great      | Serious |
|             | 1          | 2            | 3          | 4       |

Among them, the risk source of high risk means that the risk is unbearable. Enterprises need to integrate risk management and control measures in various fields, such as engineering, management, emergency and other fields, such as linkage alarm, inspection frequency and full-time emergency rescue team. The risk level of high risk is only inferior to that of high risk. Therefore, enterprises need to take measures to control high risk and put the risk source of risk prevention and control force into focus. Medium risk source indicates the risk source that still has significant risks. Risk prevention and control measures should be taken without taking risk prevention and control measures, and measures taken should be continuously improved. Low risk sources represent general risks and need to be paid attention to. Risk prevention and control measures should be taken on the premise of conditions allowed.
4. Conclusion
The risk source of the expressway operation enterprise is long and wide, which is deeply influenced by the technology and ability of professional risk assessment. According to the evaluation practice as much as possible, and summarized the existing expressway enterprise risk sources and types of accidents may be caused by the national laws and regulations on the basis of organic into the risk assessment model theory, the assessment is more practical and practical value for the rational distribution of enterprise control measures, optimize the allocation of emergency resources earnestly implement the main responsibility for production safety, good enterprise, has the important guiding significance.

Acknowledgement
This study was supported by outstanding talents training and support for young backbone individual projects in Beijing (No. 2014400685627G276).

References
[1] ZHANG Chenchen, JIA Limin. Research on method for assessing expressway network operational risk [J]. China Safety Science Journal, 2016, 26(9): 135-139.
[2] SU Donglan, GUO Zhongyin, ZHOU Yafeng, LI Zhiyong. Study on Operation Risk Analysis and Dynamic Warning System of Expressway Tunnel [J]. Highway Engineering, 2016, 41(6): 10-15.
[3] LI Zhihong, KONG Lingqi, LUO Qiang. Operating Safety Assessment of Expressway[J]. China Safety Science Journal, 2008, 18(7): 139-143.
[4] Tian Wei. Research on Risk Assessment and Safety Management of Highway Special Maintenance Project [D]. Xi’an: Xi’an University of Architecture and Technology, 2011.
[5] Du Dong, Pang Qinghua, Wu Yan. Modern comprehensive evaluation method and case selection [M]. Beijing: Tsinghua University Press, 2008.
[6] Dai Shuhe. Technology of Risk Analysis for Engineering [M]. Beijing: Chemical Industry Press, 2007.
[7] RUAN Xin, YIN Zhiyi, CHEN Airong. A Review on Risk Matrix Method and Its Engineering Application [J]. Journal of Tongji University (Natural Science), 2013, 41(3): 381-385.