Safety Evaluation of Highway Transportation Environment in Water Sensitive Sections: Case Study of Boshen Highway in China

Shu Liu¹, Xiaochun Qin ², Xingxing Qi²

1 Environmental Impact Assessment Center of the Ministry of Ecology and Environment, Beijing 100012, China
2 Beijing Jiaotong University, Beijing 100044, China
*Corresponding author e-mail: 110843281@qq.com

Abstract. China was striving to build "Smooth, Efficient, Safe, Green" comprehensive transportation system, which demanded highways to meet traffic safety functional requirements and regional ecological environmental safety requirements as well. A lot of researches in highway traffic safety and highway ecological environment evaluation at home and aboard had been made and achieved considerable results. However, there were few researches to combine highway traffic safety and highway ecological environment safety together. In this paper, the concept of highway transportation environment safety was proposed firstly based on the combination study of highway traffic safety and highway ecological environmental safety. The prediction model of highway traffic accidents was built using horizontal and vertical alignment, traffic volume, traffic composition and other data, and the evaluation system of water environment along highway was also established include the main indicators of water environment function, water quality, service population and water supply area. The method of safety evaluation of highway transportation environment in water sensitive sections was developed through the prediction of highway traffic safety and the sensitivity evaluation of water environment along highway. Though the case study of Boshen highway in Guangdong Province in China, the evaluation method of highway transportation environment safety was validated and it was proved the protective countermeasures can improve the efficiency of highway safety facilities, which would have an important theoretical and practical significance in building the safe highway transport environment system and the promotion of highway ecological environmental protection and sustainable development in China.

1. Introduction
On the one hand, highway transport vehicle accidents cause heavy casualties and huge economic losses, and highway traffic safety has been a national tickler that badgers traffic experts and the government; the other hand, water resources are widely distributed in China and there are many water environmentally sensitive areas along the highway [1]. Highway traffic accidents are likely to result in water pollution and seriously affecting water bodies’ safety along the highway. Therefore, highway vehicle accidents have been the main water environmental risk factors during highway operation period [2].

In terms of highway traffic safety, research fellows both in developed countries as well as in China have made studies in highway transport accidents aiming at the worsening traffic safety situation. In-
depth and systemic researches have been launched in the following fields and made a lot of achievements: the influences of highway conditions on traffic safety, the relationships of highway conditions and traffic accidents, affecting factors of highway traffic safety, etc. [3]

In terms of water environment safety of highway, the United States, the United Kingdom, Australia, New Zealand and other countries have made a lot of research on the adverse impact factors of highway construction in water environment and the resulting ecological risks, including the direct reduction of biological survival area, emissions of polluting substances and the changes of roadside hydrological conditions during highway construction [4-6]. The series of negative impact of highway construction and operation on water environment have also gradually attracted the attention of Chinese scholars. Different levels of researches have been made in the methods, means and index system of water environmental impact assessment of highway, the criteria and methods of highway ecological safety evaluation, and water ecological safety evaluation indicators, etc., and also made some progress [7-10].

However, as the important factors affecting highway transportation environment quality, highway traffic safety and regional ecological environmental safety have not combined together to be studied in the previous researches. In water environmentally sensitive areas, highway transportation need fully guarantee the health and sustainable development of the water environment on the basis of meeting the requirements of traffic safety. Therefore, combining highway traffic safety and water environment safety together, and making the entire highway transport environment safety as the evaluation object, rating the impact of highway conditions on traffic safety and water environment sensitivity and dynamic changes, establishing transportation environmentally safety evaluation system of highways in water sensitive areas, and analyzing the protective countermeasures, would have important theoretical and practical significance in building a safe highway transport environment system, promote water environment ecological protection and sustainable development along the highway and meet the national environmental safety strategy social needs.

2. Methods

2.1 Prediction of highway traffic accident numbers

For the highway project in ecologically sensitive environment, it needed to select the technical indicator that can best embody accidents risk to estimate the safety and environmental impact of the highway. The prediction of highway traffic accident numbers described the relationship between traffic accidents frequency and affecting factors from the quantity perspective, and reveals the features and relationships of accident numbers under certain conditions. The prediction model of highway traffic accident was based on the negative binomial distribution. The implementation steps of highway accident prediction model included affecting factors determination, highway unit division, the model parameter calculation and accident number prediction. In this model, highway environment, traffic conditions, control conditions and other specific factors were independent variables, and the number of accidents in the corresponding section was the dependent variable. Makes mainly use of horizontal and vertical alignment, traffic volume, traffic composition and other data for predictive analysis and considering high-risk limits, the model was as follows:

$$\lambda_i = \text{EXPO} \cdot \text{EXP}(-2.676614 + 0.0071095 \cdot \text{Ave}_\text{angle} + 0.737331 \cdot \text{VC} + 0.2539619 \cdot \text{Ave}_\text{slope} + 6.14963 \cdot \text{Truck}%)$$

(1)

$\lambda_i$ - the accident prediction numbers of section i; EXPO - exposure variables; Y -the prediction year of duration; L - the length of section I; Ave_angle- the average rotation of horizontal curve s of section i; VC- the vertical curve indicator, the weighted slope change value; Ave_slope -the vertical curve indicator, the weighted slope of longitudinal profile; Truck- the ratio of annual carts of section i, %.
2.2 Sensitivity evaluation of water environment along highway

2.2.1 Establishment of evaluation indicators System. Environmental sensitivity referred to the tolerance of different environmental elements to human activities. Therefore, environmental sensitivity analysis can provide us some reference for the determination of the safety design criteria.

Ecological environment contained many elements. According to the generalized concept of ecological environment, which included water, air, soil, plants and animals, etc. And the various environmental elements influenced each other. In this paper, we choose water environmentally sensitive areas most closely related with highway traffic safety as the research subject in order to establish a new research method. In environmental impact assessment, the delineation of water environmentally sensitive areas of highway was to maintain water conservation and protect water quality and regional water supply safety. The specific evaluation indicator was determined and shown in Figure 1:

![Fig.1 The evaluation indicator system of highway sensitivity in water environment section](image)

2.2.2 Quantitative classification of the sensitivity evaluation of water environment along highway. There was no uniform standard for the determination of environmental sensitivity indicators at present. James Roberts has used a hierarchical assignment method to divide the effect degree of human activity on the environmental factors into six grades and standards, assigned 5, 4, 3, 2, 1, 0. Taking the assignment method for reference, in the study evaluation indicators of highway water environment was chosen to make the sensitivity evaluations of water environment along highway according to the specific conditions of different types of water environment. Expert scoring method was employed to assign the evaluation indicator with a five-point scale. Quantitative classification criteria of the evaluation were shown in Table 1 below.

| Number | Evaluation indexes                        | classification                   | Rating scores | Sensitivity evaluation |
|--------|------------------------------------------|----------------------------------|---------------|------------------------|
| 1      | Function of water environment             | drinking water sources           | 4~5           | highly sensitive       |
|        |                                          | Fishery water                    | 3~4           | moderately sensitive   |
|        |                                          | Industrial water and flood control | 2~3        | light sensitive        |
|        |                                          | Agricultural irrigation and landscape | ≤2         | insensitive            |
| 2      | Service population (Million)              | ≥5                               | 4~5           | highly sensitive       |
|        |                                          | 2~5                               | 3~4           | moderately sensitive   |
|        |                                          | 1~2                               | 2~3           | light sensitive        |
|        |                                          | ≤1                                | ≤2            | insensitive            |
Water Quality (GB3838-2002) Class I 4~5 highly sensitive
Class II 3~4 moderately sensitive
Class III 2~3 light sensitive
Class IV or Class V ≤2 insensitive

Based on Table 1, it could be qualitatively classified into four levels as "insensitive", "light-sensitive", "moderately sensitive" and "highly sensitive" with a five-point scale for sensitivity evaluation of water environment along highway, and the evaluation criteria was shown in Table 2.

Table 2. Sensitivity evaluation criteria of water environment along highway

| Number | Rating scores | Sensitivity evaluation |
|--------|---------------|------------------------|
| 1      | 4~5           | highly sensitive       |
| 2      | 3~4           | moderately sensitive   |
| 3      | 2~3           | light sensitive        |
| 4      | <2            | insensitive            |

2.3 Evaluation method of highway transportation environmental safety in water sensitive sections

2.3.1 Evaluation steps. Fuzzy comprehensive evaluation method was used and the specific steps were as follows: (a) To determine the evaluation object set; (b) To determine the evaluation factors set; (c) To determine the evaluation class range; (d) To establish fuzzy relation matrix; (e) To determine the weights set of evaluation factors; (f) Results of fuzzy comprehensive evaluation.

2.3.2 The classification standards for highway transportation environmental safety indicators. Taking the predicted number of accidents and ecological environment sensitivity into account, highway transportation environmental safety matrix was formed.

| Highway traffic accident prediction numbers | Sensitivity evaluation of water environment along highway |
|--------------------------------------------|--------------------------------------------------------|
| 0~1                                         | Class I       Class I       Class II      Class III      |
| 2~5                                         | Class I       Class II      Class III      Class IV       |
| ≥6                                         | Class II      Class III      Class IV       Class IV       |

3. Results and discussion

3.1 Evaluation case study
Boshen Highway is an important component part of the highway in the Highway Network Planning of Guangdong Province, and was taken as the study cases to validate the evaluation indicators system and evaluation method of Boshen highway transposition environment safety.

The evaluation results of highway transportation environmental safety of Boshen Highway in water sensitive section was analyzed and shown in Table 4.

| Number | Name of sections | Traffic accident prediction numbers | Sensitivity level | Transportation environmental Safety Level |
|--------|------------------|-------------------------------------|-------------------|-------------------------------------------|
| 1      | East River section | 3                                  | moderately sensitive | Class III                                |
Shigu reservoir section 5 moderately sensitive Class IV
Aobei reservoir section 4 light sensitive Class II
Qiye reservoir section 3 highly sensitive Class IV
Qinglinjing reservoir section 6 moderately sensitive Class III
Guanjintou reservoir section 7 highly sensitive Class IV
Yantian reservoir section 8

3.2 Strategic countermeasure based on evaluation results
According to the transportation environmental safety evaluation results, the protective countermeasures in terms of transportation environmental safety of Boshen Highway in water sensitive section was analyzed and determined and shown as follows.

Table 5. The protective countermeasures for transportation environmental safety of Boshen Highway

| Number | Name of sections | countermeasure |
|--------|------------------|----------------|
| 1      | Aobei reservoir section | (1) To reinforce sight line guidance, set up the active luminous linear guidance sign, set up the forced facilities of speed reduction, and force the large vehicle stay in the outer lane. (2) To improve collision protective level of the guardrail, using the guardrail no less than SA in the reservoir section, and no less than SB at the bridge connection section. |
| 2      | East River section /Guanjintou reservoir section | (1) To set up the forced facilities of speed reduction and force the large vehicle stay in the outer lane. (2) To improve collision protective level of the guardrail, using the guardrail no less than SA in the reservoir section, and no less than SB at the bridge connection section. |
| 3      | Shigu reservoir Section /Qiye reservoir section /Qinglinjing reservoir section /Yantian reservoir section | (1) To set up the forced facilities of speed reduction, and force the large vehicle stay in the outer lane. (2) To improve collision protective level of the guardrail, using the guardrail no less than SA. |

4. Conclusions
The concept of highway transportation environment safety was proposed based on the combination study of highway traffic safety and highway ecological environmental safety. Highway transportation environment safety evaluation was made through the prediction analysis of highway traffic accident and the sensitivity evaluation of water environment along highway.

The prediction model of highway traffic accident was built in use of horizontal and vertical alignment, traffic volume, traffic composition and other data and described the relationship between traffic accidents frequency and affecting factors.

The evaluation indicators system of highway ecological environmental safety in water sensitive sections was also established. And the sensitivity of water environment along highway was qualitatively classified into four levels as "insensitive", "light-sensitive", "moderately sensitive" and "highly sensitive" for the evaluation criteria.

Evaluation method of highway transportation environmental safety in water sensitive sections was developed based on the prediction of highway traffic accidents and the sensitivity evaluation of water environment along highway. classification standards for highway transportation environmental safety was made at four levels as "Class I", "Class II", "Class III" and "Class IV".

The case study of Boshen Highway in Guangdong Province in China was made to validate the safety evaluation of highway transportation environment in water sensitive sections, and the preventive countermeasures were proposed to guarantee the highway transportation environment safety.
Acknowledgments
The research work was supported by National Natural Science Foundation of China under Grant No. 51108216. We will be very grateful for the helpful comments and criticisms of the anonymous reviewers.

References
[1] Ali S. Al-Ghamdi, Analysis of traffic accidents at urban intersection in Riyadh, Accident Analysis & Prevention, (2009) 28-36.
[2] A. Boequilha, Leitao, J. Ahern, Applying landscape ecological concepts and metrics in sustainable landscape planning. Landscape and Urban Planning, (2002) 26.
[3] E.S. Park, P. J. Carlson, Safety effects of wider edge lines on rural, two-lane highways Original Research Article. Accident Analysis & Prevention, 48(2012) 317-325.
[4] MarcGaudry, S. Lassarre.Structural Highway Accident Models. PERGAMON, 9(2008).
[5] MarcGaudry, S. Lassarre, Structural Highway Accident Models. Transportation Research, 17(2000).
[6] M. Abdel-Aty, J.Y. Lee,Geographical unit based analysis in the context of transportation safety planning. Transportation Research Part A: Policy and Practice, 49(2013) 62-75.
[7] P. D. Hamilton, P Gale, A commentary on recent water safety initiatives in the context of water utility risk management Original Research Article, Environment International, 32(2006) 958-966.
[8] Transportation and Planning Research Institute, Study into the key technology of environment protection and landscape design concept of Chuanjiu Highway, (2004) 42-46.
[9] Z.G. Wu, R.J. Shen, Safety Evaluation Model of Highway Construction based on Fuzzy Grey Theory Original Research Article. Procedia Engineering, 45(2012) 64-69.