Study on the Evaluation Method for the Expressway Alignment Consistency Considering Visual Information

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ABSTRACT

At present, there are lack of quantitative evaluation indexes and methods for the expressway alignment consistency at home and abroad. In order to study the method, an eye tracker is used to collect dynamic vision data and vehicular GPS is used to collect actual operation speed. Considering the drivers' visual feelings on the expressway alignment, the video information is used to get the quantitative relationship between the drivers' dynamic vision and vehicles' actual operation speed. Based on the relationship between the rate of expressway accidents and the rate of visual information change, the evaluation model is built, which uses the rate of visual information as the index for evaluating the alignment consistency. In addition, the evaluation model is corrected by the operation speed. The practical engineering applications show that this evaluation model is reasonable and practical. The evaluating results are consistent with the conclusions of related standards.

INTRODUCTION

At present, the main studies on the safety evaluation of expressway alignment are focused on evaluating the expressway alignment consistency. Most research results are based on the relationship between the operation speed and the expressway alignment. Lamm and Choueiri (1987) first gave three evaluating standards of alignment consistency considering operation speed, which are the D-value of operation speed and design speed, the $\Delta V85$ at the adjacent continuous sections, and the vehicle's stability evaluation expressed by the D-value between the predictive and the needed lateral friction coefficient. McFadden and Elefteriadou (2000) developed a new parameter of 85MSR based on the speed difference theory of Hirsh, and the parameter described the max $\Delta V85$ (Gibreel et al., 2001) of the same drivers or vehicles at the adjacent continuous sections. However, the operation speed prediction model has not obtained application and dissemination because it is not supported by statistics in China. In the actual expressway alignment consistency evaluation, the technical difficulty of applying the speed distribution index to evaluate the alignment consistency is how to predict the discrete degree of operation speed somewhere during the expressway design stage. Studies abroad on the 85MSR (Gibreel et al., 2001) introduce new thinking for alignment consistency evaluation based on the prediction model of operation speed, but the relevant applicative evaluation standards are absent. In order to solve this problem, this paper put forward that there is relevance among the driver's dynamic visual field, operation speed, and traffic accidents on the basis of driver's dynamic visual characters. Then, the experiments prove the relevance of using eye-tracker and vehicular GPS. The quantitative relationship between driver's dynamic visual field and traffic accident is analyzed, so as to determine the change rate of driver's dynamic visual field area as a new index for evaluating the expressway alignment consistency.

THE DRIVERS' DYNAMIC VISUAL FIELD

The static visual field (Jia et al., 2008) is the full range that the eyes can see when the driver's gaze is ahead and his/her head/sight is fixed. If the head is fixed, the full range that the eyes can see freely is called the dynamic visual field. People's visual field can be examined by perimeters. If a driver's visual field is too small, the driving is not safe. When the vehicle is running at high speed, the driver can feel that the images of far fixed objects such as trees and houses stay on the retinas in a very short time, and it is too late to distinguish the objects' details. Therefore, the drivers' visual field may be more and more narrow with the speed increasing.

The driver's gaze position and visual field are related to the vehicle's operation speed (Guo et al., 2006). When the running speed increases, the driver's gaze position moves ahead and the visual field gets narrower with the horizontal angle decreasing. Traffic accident happen easily because the perimeter feeling's decreasing leads to visual field defects with traffic information influenced. Table 1 (Pan et al., 2004) shows the relationships between the driver's visual width, gaze distance, and the vehicle's operation speed.

Table 1. Relationships Among the Drivers' Visual Field and the Operation Speed

Operation speed/(kmh^{-1})	0	40	60	80	100	120
Visual width/°	170	100	86	60	40	22
Gaze distance/m	80	180	355	377	564	710

The driver watches ahead continuously and observes the environment changing during driving. His/her vision changes with the operation speed and environment. He/she always determines driving speed according to the visual field. When the visual field decreases because of turning or longitudinal slope in the front, the driver may decrease speed. When the visual field increases because of long straight lines or a plane curve with a large radius, the driver would increase speed. So, there is correlation between the driver's dynamic visual field and operation speed.

RELATIONSHIP BETWEEN DYNAMIC VISUAL FIELD AND OPERATION SPEED

For the sake of studying the correlation between a driver's dynamic visual area and operation speed, dynamic eye-tracker and vehicular GPS are used to collect initial data to be analyzed. A dynamic eye-tracker collects the driver's dynamic visual field information and vehicular GPS collects the information of vehicle operation speed. Because the expressway alignment is rarely sheltered in the space, the highway information plays a leading role in controlling the driving. As a result, the changes in dynamic visual field can be approximately represented by the change of highway surface area. The relationship between the driver's dynamic visual field and operation speed is determined according to the relationship between the change of highway surface area in the driver's vision and the operation speed.

Experiment equipment introduction

The experiment equipment for collecting dynamic visual field information is a dynamic eye-tracker called iView X HED system, which is produced by SMI, Senso Motoric Instruments Company in Germany. It is shown in Figure 1. Its maximum screen resolution is 768×576 pixels. This eye-tracker records the eyes' position with high-speed. The frequency of data collection is 50Hz, as collecting one datum point every other 20ms. This equipment is of high precision and is easy to carry. It can record the visual information in real-time, including the gaze position, papillary size, and visual scene.

The experiment equipment for collecting speed is shown in Figure 2. It is a vehicular GPS called NovAtel DL-V3, produced by NovAtel Company in Canada, with sub-meter as the positioning precision of a single point. This equipment can provide the centimeter position information in real time with the rate of 20Hz every second, applying the technology of NovAtel Advance RTK. The vehicular GPS tachymeter is composed of a satellite receiver, data processor, and power supply. Features include as easy installation, simplicity of operation, small volume and easy carrying, and large data collection.

Figure 1. SMI eye-tracker

Figure 2. NovAtel vehicular GPS

Experiment data processing

Xi'an to Hanzhong expressway is the test section. The overall length of the expressway mainline is 258.65 km, constructed by the expressway standard of two-way, four-lane. According to the terrain condition grading, the design speed is from 60 to 100 km/h, and the width of subgrade is from 20 to 26 m. This expressway alignment and the vertical and horizontal indexes are complex and full of changes. Thus, while driving on this expressway, the change of driver's visual field is of high frequency and extensiveness, meanwhile the change frequency and size of speed is large. It would be beneficial to analyze the multitude of test data.

Using the dynamic eye-tracker, the real-time highway environment video data is collected, which is the visual range eyes watched during driving. The video play software is used to save the dynamic video data from eye-tracker every second as static color image files. Then, the image files are grayed so as to gain the highway surface area in the images. The specific operation methods are described as follows.

Gray the color image

To gray the image is to transform 24 bits of true color image into 8 bits of 256 colors gray image, and the former includes three colors of R (red), G (green) and B (blue) in every pixel. Except for the RGB, there is the other method describing image color called YIQ, and the physics meaning of Y is the image brightness. Therefore, the method of transforming the RGB image into gray image is to transform RGB image into the YIQ space and to determine the Y value as the gray value. After transformation, the calculating relationship between the pixel gray value H and the RGB is shown in formula (1).

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.144 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$H = 0.299 \times R + 0.587 \times G + 0.144 \times B \qquad (1)$$

The gray result is shown in Figure 3.

Figure 3. Grayed the color image information

Binary the gray image

To binary the image means that the gray values in the whole image are only 0 and 1, and there are no shades of gray between them. This paper uses the method of threshold binary, which is focused on the selection of threshold T and binary the image based on the threshold. If the initial gray image is described as f(x, y) and the binary image after transformation is described as g(x, y), the threshold binary process can be described by Equaiton (2).

$$g(x,y)=\begin{cases}0, f(x,y)<T\\1, f(x,y)>T\end{cases} \qquad (2)$$

The result of threshold binary is shown in Figure 4.

Figure 4. Threshold binary of gray image

Data statistics and analysis

The binary data results are progressively scanned from bottom to top. The number of the element 0 in each line is recorded, and the scanning is stopped when the element 1 happens in the whole line at the division line between highway and background. The total numbers of the element 0 are gathered statistics, which is the pixel value of highway be taken in the image. The value of the driver's dynamic visual field is gained according to the all pixel values of highway images.

Testing data analysis

On the basis of analysis below combined with Figure 5 and Figure 6, it is indicated that the driver's dynamic visual field area is correlated to the operation speed. The operation speed may increase accordingly as driver's dynamic visual field increases, while it may decrease accordingly as the field decreases.

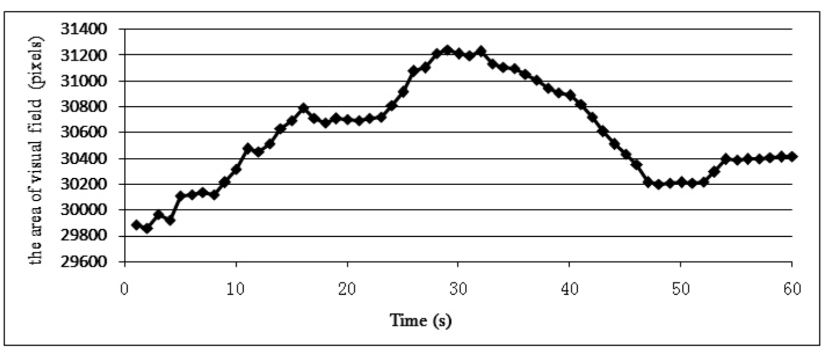

Figure 5. Variation diagram of dynamic visual field

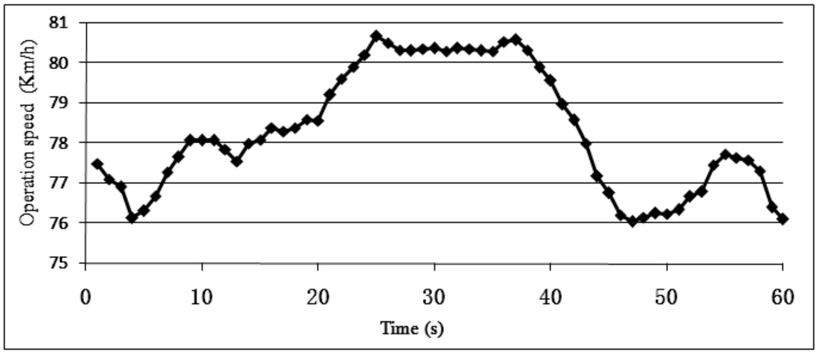

Figure 6. Variation diagram of operation speed

CONSISTENCY EVALUATION OF THE EXPRESSWAY ALIGNMENT APPLYING INFORMATION

The relationship between rate of dynamic visual field change and expressway safety

After statistical analysis was performed on the accident rate of several expressways and corresponding dynamic visual field at different regions, the study results indicate that the absolute value of dynamic visual field is not correlated strongly to the expressway accident rate, but the rate of dynamic visual field change has a good positive relationship with the accident rate, as shown in Figure 7.

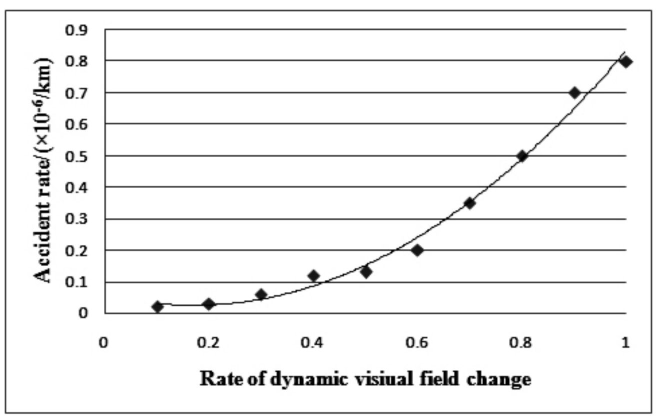

Figure 7. Relationship between the rate of dynamic visual field change and the accident rate

The relationship model is obtained by curve-fitting, as shown in formula (3).

$$M = 1.17(\Delta Sq/L)^2 - 0.398(\Delta Sq/L) + 0.059 \ (R^2 = 0.989) \qquad (3)$$

Where, M is the accident rate; ΔSq is the change value of dynamic visual field, which $\Delta Sq = Sq_i - Sq_{i-1}$; L is the length of a road section; and $\Delta Sq/L$ is the rate of ΔSq along with L.

As the rate of dynamic visual field changes, $\Delta Sq/L$, is well-correlated with expressway safety, this paper takes it as the evaluation index and defines SHS=$|\Delta Sq/L|$ to evaluate the expressway alignment consistency.

The evaluation standard of expressway alignment consistency based on dynamic visual field

In order to improve the accuracy of the evaluation model and standard, it is not enough for the only rate of dynamic visual field change. That is because even under the condition of a large rate of dynamic visual field change, the driver can still drive correctly and avoid accidents if he/she has enough time to receive and process visual information when the operation speed is low. Otherwise, when the speed is too high, accidents can still happen even when the rate of dynamic visual field change is small. For this reason, this paper has built a preliminary standard to evaluate expressway alignment consistency based on the rate of dynamic visual field, and then the evaluation standard is created by use of the operation speed.

After analysis for the traffic accident data of existing expressways, Figure 8 shows the cumulative frequency of accidents on the expressway.

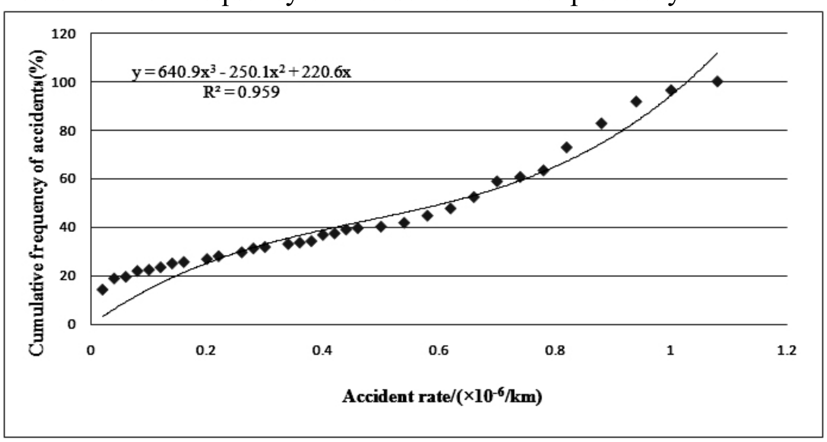

Figure 8. Relationship between accident rate and cumulative frequency of accidents

In Figure 8, it can be found out that the cumulative frequency of accidents is only about 20% when the accident rate is below 0.15, while the cumulative frequency of accidents increases when the accident rate is above 0.5. About 60% of accidents happen above 0.5. Therefore, the accident rates of 0.15 and 0.5 are as the two critical evaluation points for evaluation alignment consistency. It can be checked in Figure 7 that the corresponding SHS are 0.5 and 0.8 when the accident rates are 0.15 and 0.5. Then, the initial evaluation standard for the expressway alignment consistency based on dynamic visual field is constructed and shown in Table 2.

Table 2. Initial Evaluation Standard for the Expressway Alignment Consistency Based on Dynamic Visual Field

Evaluation index	Alignment consistency	Explanation
$SHS \leq 0.5$	good	good for alignment consistency
$0.5 < SHS \leq 0.8$	general	to optimize alignment forward
$SHS > 0.8$	bad	need to re-modify alignment

Because of the certain relationship between the operation speed variation and alignment consistency, $RV = (v_i - v_{i-1})/v_{i-1}$ is determined to be the impact index through trial and compares repeatedly. Where, v_i and v_{i-1} are the predicted operation speed corresponding to the calculation points at the two adjacent dynamic visual field sections. Figure 9 shows the relationship between RV and the cumulative frequency of expressway accidents.

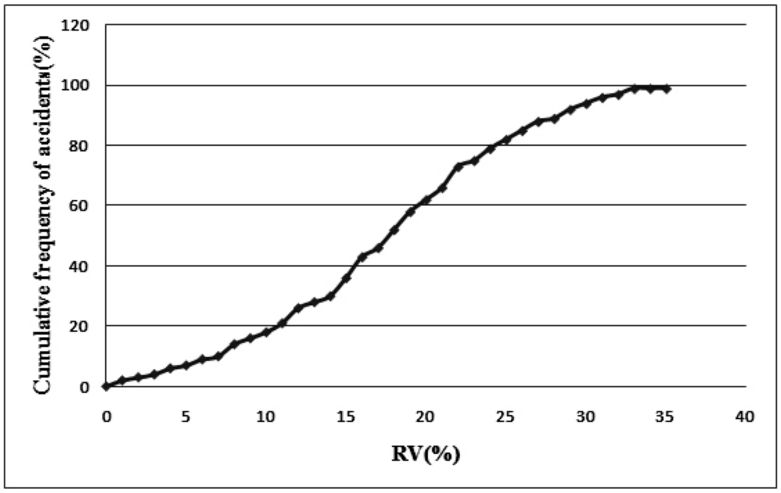

Figure 9. Relationship between RV and cumulative frequency of accidents

From Figure 9, it is noted that accident numbers increase with RV increasing, while the accident probability will increase greatly when RV≥10%. When RV is between 10% and 20%, the accident cumulative frequency may be a ladder and more growth. About 60% accidents occur in this range. Thus, the correction factor of operation speed is confirmed to (1+RV), and $SHS = |(1+RV) \bullet \Delta \mathrm{Sq/L}|$.

After the correction the new evaluation standard is shown in Table 3.

Table 3. Evaluation Standard for Expressway Alignment Consistency Based on Dynamic Visual Field

Evaluation index	Alignment consistency	Explanation
$SHS \leqslant 0.55$	good	good for alignment consistency
$0.55 < SHS \leqslant 0.88$	general	to optimize alignment forward
$SHS > 0.88$	bad	needs to re-modify alignment

CASE STUDY

There is a new expressway with the design speed of 80 km/h, two-way four lanes and the width of subgrade of 24.5m. According to the horizontal and vertical design data from K11+000 to K22+000, the area value of dynamic visual field for each section is calculated as equal station spacing. The result is shown in Figure 10.

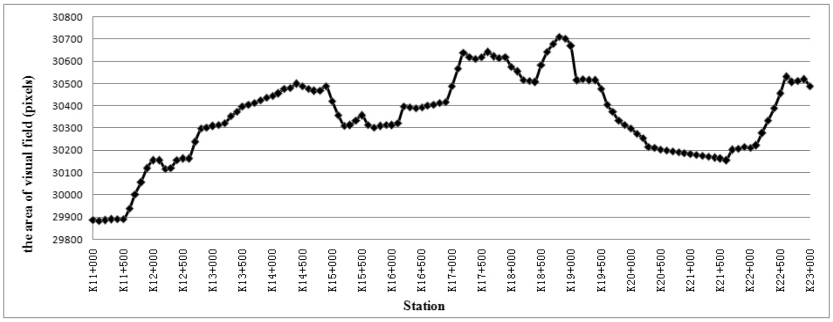

Figure10. Area of Dynamic visual field on a new expressway

Calculating the rate of dynamic visual field change ($\Delta Sq/L$) and the correction factor of operation speed, the evaluation results of alignment consistency according to SHS for each section are shown in Table 4. From Table 4, it is observed that three sections are bad alignments: from K11+500 to K12+000, from K17+000 to K17+, and from K21+000 to K21+500; five sections are good alignments: from K11+000 to K11+500, from K12+500 to K13+500, from K14+000 to K15+000, from K16+500 to K17+000, and from K19+000 to K20+000. Others are general. The evaluation conclusion is basically the same as the results of other evaluation methods, such as the method according to Safety Evaluation Guidance for Highway Project (JTG/B05-2004).

Table 4. Evaluation for A New Expressway Alignment Consistency

the Beginning and end pile	SHS	Alignment consistency
K11+000~K11+500	0.22	good
K11+500~K12+000	0.92	bad
K12+000~K12+500	0.61	general
K12+500~K13+000	0.31	good
K13+000~K13+500	0.19	good
K13+500~K14+000	0.58	general
K14+000~K14+500	0.34	good
K14+500~K15+000	0.25	good
K15+000~K15+500	0.68	general
K15+500~K16+000	0.76	general
K16+000 ~K16+500	0.71	general
K16+500 ~K17+000	0.18	good
K17+000 ~K17+500	0.96	bad
K17+500 ~K18+000	0.67	general
K18+000 ~K18+500	0.75	good
K18+500 ~K19+000	0.82	general
K19+000 ~K19+500	0.43	good

K19+500 ~K20+000	0.35	good
K20+000 ~K20+500	0.71	general
K20+500 ~K21+000	0.75	general
K21+000 ~K21+500	0.90	bad
K21+500 ~K22+000	0.60	general

CONCLUSION AND RECOMMENDATIONS

This paper put forward the driver's dynamic visual field, which can be used to describe the capacity of the driver's gathering of visual information during practical traffic activities. On the basis of the rate of visual information change, a new index of evaluating the expressway alignment consistency is studied. There are three main conclusions as follows:

1. By analyzing the result of eye-tracker tests creatively and processing the video result with a binary method, this paper calculates the area of the expressway surface in the range of the driver's dynamic visual field.

2. It is found that there is a good correlation between the data of vehicular GPS and the driver's dynamic visual field. By further analyzing the relationship between the change rate of driver's visual field area and traffic accidents, this paper gives a index, SHS, as a new index for evaluating the expressway alignment consistency.

3. The new index, SHS, can be obtained conveniently from analysis of eye-tracker data. The evaluating result is highly consistent with the actual situation and will be useful for engineering applications.

This study has laid a good foundation for subsequent research. The following is a list of the recommended future research:

1. The present study only takes the expressway surface as a planar index. In the future, it would be beneficial to add the elevation of driver's visual field to the index system and build the spatial volume of visual field to evaluating the expressway consistency.

2. Increasing the number of test expressways to analyze the relationship between driver's dynamic visual field and operation speed would help to build the prediction model of operation speed, which can correlate with the driver's visual field and the vertical and horizontal indexes.

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