DRIVING SCENE COMPUTATIONAL MODEL AND ROAD GEOMETRIC DESIGN PARAMETER

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ABSTRACT

Driving scenes are a kind of two dimensional visual images which are shaped from three dimensional objects (e.g. highway, vehicles, roadside and surroundings along the highway). They are the most important perception sources for a driver using eyes as sensors to gain information and satisfy visual demands. During driving process, a driver combine observed environment information with his general knowledge together to derive actions. This paper focuses on analyzing highway at curved section design consistency based on driving scene for two-lane rural highways. Previous research showed that the centerline of a combined horizontal and vertical curve appears to drivers as a parabola. A new strategy of describing the parabola from driving scene has been brought forward in this paper. It shows that there are statistical relationships between characteristics of the parabola and highway geometric parameters. The characteristic of parabolas from five continual key frames of driving scenes are designed as independent variables. An ordered logical model is trained and applied to evaluate highway geometric design. Without knowing any highway alignments, the categorical design consistency could be identified only with a series of consecutive driving scenes.

1. INTRODUCTION

More than half of the fatalities on two-lane rural highways occur at curved sections, which contain horizontal curves and the corresponding vertical alignment [1]. Easa and Mehmood pointed out that the main causes for these accidents were improper speed variations and lack of geometric design consistency [2]. A consistent highway design can ensure that successive elements are coordinated in a harmonious manner [3] and it also conforms to drivers expectations [4]. In recent years, the design consistency check has become an effective tool for improving safety performance of a highway project during the new design stage and identifying safety issues for an existing highway project [5]. The operating speed approach has been typically regarded as the most efficient and quantified measure among the different existing measures for design consistency evaluation on two-lane rural highways for many years [6, 7]. There are usually two ways to evaluate the operating speed, one is calculating the difference between two successive elements of a highway and the other is calculating the difference between design speed and operating speed for a highway element [8]. If the speed difference is greater than a certain value, the design is considered inconsonance. In the past years, many models have been developed to predict the operating speed on two-lane rural highways based on two-dimensional or three-dimensional alignments [9, 10, 11, 12, 13 and 14]. Despite extensive studies as introduced above, there is, however, no single model which is universally accepted. Not only the independent variables of various models are different, but also the regression coefficients are substantially different. In fact, all these models are based on the same hypothesis: different horizontal curves corresponding to different vertical alignments will affect the driver's operating speed. These models are almost developed based on highway geometric parameters, such as horizontal curve radius, algebraic difference of vertical grades, with influence of overlapping vertical alignment on the perceived horizontal curve. As a complex task, driving requires drivers pay more attention to predict, recognize and track along highways mainly depending on the driver perspective view. Sometime, such information is not sufficient for drivers to make correct decision or misleading information make it easy for drivers to make mistakes. This is the reason why collision statistics show that about 90% of highway collisions are caused by driver error [15]. Obviously, driver perception view acts as a very import role in driving activities. Many researchers have carried out many studies about driver visual and operating vehicles. Easa and He studied driver visual demand on 3D highway alignments [16]. They developed a regression model between visual demand and the effects of variations of curve radius, deflection angle, etc. As a result, they can use the visual demand model to analyze highway design consistency. The results showed that there were similar trend between visual demand and operating speed. Wang and Easa estimated highway horizontal curvature using perspective view in their study [17]. They regarded the centerline or inside edge line of a highway with horizontal curves and vertical curves in driver perception view as parabolas or hyperbolas. Hassan and Easa studied the effect of vertical alignment on horizontal curves [18]. They found that horizontal curve looked sharper than it actually was compounding with a vertical crest while looked flatter compounding with a vertical sag curve. These erroneous perception views would cause drivers to maintain a higher or lower speed than design speed [19].

These existing researches have confirmed that changes in highway geometric alignment would impact driver perspective view, and different perception views would affect driver operating speed. Drivers operate vehicles mainly based on perspective view instead of reading geometric parameter directly. It means that driver perspective view is the best way to check highway 3D alignments design and their combination. In these studies, perspective views or video clips are only used as images for people to understand combinations of highway alignments in three-dimensional. There is no more useful information extracted from driver perception views or video clips. In fact, there are many characteristics of driver perspective view which are linked with highway geometric parameters, specially, at curved sections. Just as mentioned above, the changes of highway geometric parameters may affect the patterns of driver perspective view. It is not a simple linear relationship between the characteristics of driver perspective view and highway geometric parameters. Therefore, this paper is focused on a new approach to study relativity between design consistency and driver perspective view on two-lane rural highways at curved sections with an ordered logistic model.

In this approach, only characteristics of driver perspective view are considered, regardless of the highway geometric parameters and the way they combine with each other. Five continual key frames of driver perspective view in front of the current driver eye position are selected as samples, of which specific characterizations are extracted. A logistic model has been developed and trained to classify driver perspective views of current position into one of three catalogues. The catalogues are divided into three types based on the evaluation criterion of design consistency (1): it is $|V_{85}-V_D|<=10Km/h$, $10Km/h<|V_{85}-V_D|<=20Km/h$ and $|V_{85}-V_D|>20Km/h$. Here V_{85} means operating speed, V_D means design speed. This strategy is shown in detail in Figure 1. The centerline in driver perspective view is the most important information source for safe driving. Any sudden change of centerline shape will lead to nervous and tension while illegibility of change may lead to hesitation and confusion. So, from traffic safety point of view, ensuring visual consistency of the centerline in driver perspective view will be more appropriate than forecasting operating speed in evaluating design consistency. Not only the individual value of each horizontal and vertical geometry parameter, but also their combinations can affect the shape of the centerline in driver perspective view.

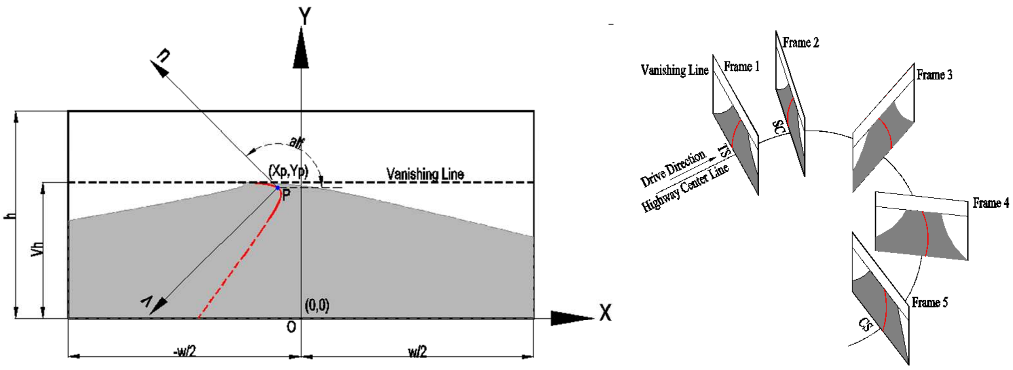
The study is divided into five parts: Part 1, analyzing driver perspective view; Part 2, determining independent variables; Part 3, creating likelihood function and training the ordered logical model; Part 4, ordered model interactive analysis; and Part 5, Conclusion and future work.

2. METHODOLOGY

More than about 90% of the information required for the driving task is perceive from the driver visual [20]. Generally speaking, drivers may maintain a relatively high or low speed when the highway curves are perceived flat or sharp. The erroneous driver perception has been particularly evident when horizontal and vertical curves overlap irrelevantly. The combination of a sag vertical curve with a horizontal curve may result in a perspective view that makes the horizontal curve appear flatter than it is in reality, whereas the combination with a crest vertical curve reveals opposite results [21]. It may be hazardous if the drivers perceive a sharp curve as a flat curve, and subsequently adopts a higher speed. Driver perspective view is the visual perception of highway horizontal and vertical alignment from the driver’s viewpoint. Therefore, design consistency can be interpreted as visual consistency to certain extent. “Visual consistency good” means that drivers may maintain an appropriate speed around design speed under the direction of consistency perception views. “Visual consistency bad” means there are many erroneous perception views and drivers often regard highway curves flatter or sharper than they actually are, respectively. So, there are three states along a highway: 1) Some driver perspective views are standard visually consistent, 2) Ones are inferior visually consistent and 3) Others are visually not consistent. A statistical model was developed to distinguish these three kinds of situations based on the characteristics of driver perspective view in our study.

2.1Driver Perspective View

In order to distinguish visual consistency about driver perspective view, mathematical description of driver perspective view is studied first. There are a centerline and two edge lines on a two lanes rural highway perspective view, which are principle visual information sources for a driver to operate vehicle. In fact, these lines are shaped according to the highway horizontal and vertical alignment from the driver's viewpoint. We only focus on the highway centerline in this paper, and the edge lines are ignored. In spite of position and shape will be changed with vehicles movement and the rotation of driver head, the centerline of highway in a driver perspective view will show several similar inherent characteristics in a certain way. Some researchers have observed that highway horizontal and vertical alignment curves appear to a driver as parabolas or hyperbolas [17, 22, 23 and 24]. But, there was no further description about parabolas in these literatures. We design a parabolas model, which is shown in Figure 1(a), to describe the highway centerline in a driver perspective view.



(a) Modeling a frame of driver perspective view (b) Using five frames difference

Figure 1—Design consistency check based on driver perspective view

There are two coordinate systems that are used in driver perspective view model. One of them is *XOY* and the other is *UPV*. The angle between axis *OX* and *PU* is *alf*. The coordinate origins of *XOY* and *UPV* are point *O* and point *P*, respectively. The coordinates of point P in *XOY* coordinate system is (x_p, y_p). In coordinate system *UPV*, the parabola's normal equation is:

$$v = A_p u^2, (A_p \neq 0) \tag{1}$$

Where, the coefficient *A* reflects the openness magnitude of the parabola (17), which can also be called as curvature at extreme point *P*. Firstly, perspective coordinates of several points at centerline in *XOY* are collected. Secondly, after the location of extreme point *P* is found, x_p, y_p and *alf* are calculated expediently. Finally, the coordinates $\{x_i, y_i\}$ in *XOY* can be transformed to $\{u_i, v_i\}$ in coordinate system *UPV* by using following formulas.

$$u = (x - x_p) \times \sin(alf) - (y - y_p) \times \cos(alf) \tag{2}$$

$$v = (x - x_p) \times \cos(alf) + (y - y_p) \times \sin(alf) \quad (3)$$

2.2 Analytical Framework

2.2.1 Statistical model selection

The driver perspective view is the most suitable 2D response of highway from 3D horizontal and vertical alignment. The objects shapes and locations in a driver perspective view are affected by two factors, one of which is perspective parameter, such as position of observer, height and vanishing distance, etc. The other is alignment parameter, such as radius of curves, grades and angles, etc. We cannot calculate accurate 3D value from 2D data, but we can estimate a scale under certain probability. It can be used to analyze the problem of highway visual consistency. Many regression models are widely used in studies of operating speed prediction [2, 8, 10, 11, 25 and 26]. But a linear regression is not suitable in our study, in other words, the relationships between dependent variables and independent variables are not linear. The logistic regression is a suitable technique to apply because it is developed to predict dependent variables as a function of predictor variables. The logistic regression model is widely used to deal with classified variables, such as traffic injury severity levels studies [27]. In this paper, design consistency classifier is a case of ordered. The ordered dependent variables (classifiers categories) might range from 0(|△V|≤10Km/h) to 1(10Km/h<|△V|≤20Km/h) and 2 (|△V|>20Km/h), respectively. In standard ordered response models, the cumulative probability Pr(X|Y≤k) of operating speed belonging to categories 1 to k is calculated from:

$$\text{logit}\ (Pr(X|Y\le k))=\ln(Pr(X|Y\le k)/(1- Pr(X|Y\le k))= \alpha+\beta X \quad (4)$$

$$OR=Pr(X|Y\le k)/(1- Pr(X|Y\le k)) \quad (5)$$

Where, α is the regression intercept, β is a vector of parameters to be estimated and X is a vector of independent variables, OR is called the odds ratio and it ranges from 0 to positive infinity. If OR is >1, operating speed difference belongs to categories 1 to k, otherwise it belongs to k+1 to k. Cumulative probability Pr(X|Y≤k) is calculated according to the following form formula:

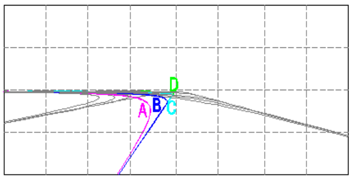
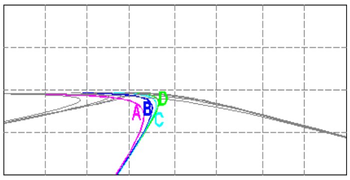
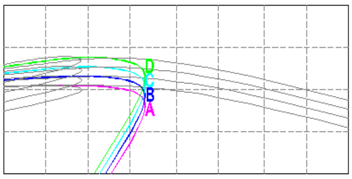
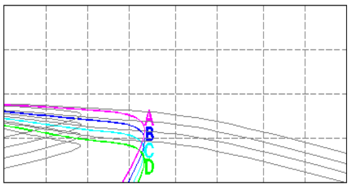
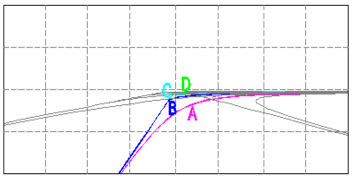
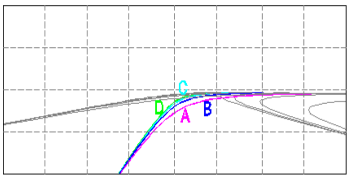
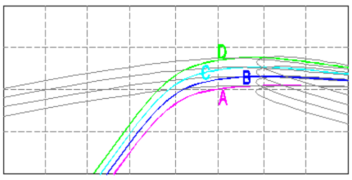
$$Pr(X|Y\le k)= e^{\alpha+\beta X} /(1+e^{\alpha+\beta X}) \quad (6)$$

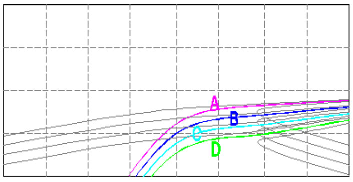
Finally, operating speed difference belongs to the category k which has a maximum probability Pr (X|Y=k). These classifications are depended only on features of driver perspective view.

2.2.2 Independent variables

For any frame of driver perspective view, it is related to the perspective parameter and highway horizontal and vertical alignment curves. Parameters A_p, x_p, y_p and *alf* are calculated from every frame perspective view. There are more than four characteristics of driver perspective view that could be selected as independent variables. With constant vertical sag, crest curve or deflection angle, the larger horizontal curve radius is the smaller and flatter curvature A_p will be. With constant horizontal curve radius and deflection angle, vertical crest curve leads larger and sharper curvature A_p than sag curve does. It is found that y_p/h only has a strong relation with vertical grade, but no obvious relation with horizontal curve radius. With a constant horizontal curve radius and deflection angle, y_p/h increases with upward grade. There are details in Table 1.

Table 1—Summary of A_p, x_p/h, y_p/h and *alf*

1		***Horizontal Radius***: 200m ***Vertical Alignment***: flat ***Eye position***: A: at TC point; B: before TC 50m; C: before TC 100m; D: before TC 200m	A_p x_p/w y_p/h *alf* A: 0.0096 /-0.094/0.409/163.5 B: 0.0195/-0.063/0.433/164.2 C: 0.0243/-0.025/0.462/165.6 D: 0.0267/-0.020/0.483/167.8
2		***Horizontal Radius***: A: 200m; B: 400m; C: 600m;D: 800m ***Vertical Alignment***: flat ***Eye position***: at TC point	A_p x_p/w y_p/h *alf* A: 0.0096/-0.095/0.409/162.8 B: 0.0152/-0.064/0.419/164.8 C: 0.0181/-0.026/0.434/166.5 D: 0.0219/-0.021/0.448/168.1
3		***Horizontal Radius***: 200m. ***Vertical Alignment***: Crest grade, A: 1.5%; B: 3.0% C:4.5% ;D:6.0% ***Eye position***: at TC point	A_p x_p/w y_p/h *alf* A: 0.0104/-0.096/0.434/159.5 B: 0.0110/-0.095/0.490/159.4 C: 0.0114/-0.094/0.547/159.2 D: 0.0117/-0.093/0.620/159.1
4		***Horizontal Radius***: 200m. ***Vertical Alignment***: Sag grade, A: -1.5%; B: -3.0% C:-4.5% ;D: -6.0% ***Eye position***: at TC point	A_p x_p/w y_p/h *alf* A: 0.0086/-0.084/0.322/140.8 B: 0.0080/-0.085/0.266/140.7 C: 0.0059/-0.086/0.209/140.6 D: 0.0048/-0.087/0.151/140.4
5		***Horizontal Radius***: 200m ***Vertical Alignment***: flat ***Eye position***: A: at TC point; B: before TC 50m; C: before TC 100m; D: before TC 200m	A_p x_p/w y_p/h *alf* A: 0.00104/0.038/0.408/215.5 B: 0.00222/0.005/0.434/247.5 C: 0.00295/0.004/0.464/248.4 D: 0.00321/0.003/0.482/248.6
6		***Horizontal Radius***: A: 200m; B: 400m; C: 600m;D: 800m ***Vertical Alignment***: flat ***Eye position***: at TC point	A_p x_p/w y_p/h *alf* A: 0.00104/0.064/0.408/210.7 B: 0.00194/0.075/0.418/238.4 C: 0.00225/0.065/0.434/238.5 D: 0.00230/0.055/0.444/238.7
7		***Horizontal Radius***: 200m. ***Vertical Alignment***: Crest grade, A: 1.5%; B: 3.0% C:4.5% ;D: 6.0% ***Eye position***: at TC point	A_p x_p/w y_p/h *alf* A: 0.00112/0.154/0.434/237.1 B: 0.00118/0.155 0.490/237.2 C: 0.00126/0.156/0.547/237.4 D: 0.00130/0.156/0.620/237.6

8		***Horizontal Radius***: 200m. ***Vertical Alignment***: Sag grade, A: -1.5%; B: -3.0% C:-4.5% ;D: -6.0% ***Eye position***: at TC point	A_p ***x_p/w*** ***y_p/h*** ***alf*** A: 0.00095/0.0625/0.322/227.8 B: 0.00084/0.0624/0.266/227.6 C: 0.00064/0.0623/0.209/227.5 D: 0.00049/0.0623/0.151/227.4

2.2.3 *Approach*

We use characteristic of five continual key frames of driver perspective views to classify the type visual consistency at highway curved sections. The strategy is shown in Figure 1(b). Frame 1 is located at TS (Tangent and Spire Curve) point, frame 2 is selected at SC (Spire Curve and Circle curve) point, frame 5 is selected at CS (Circle curve and Spire Curve) point and frame3 and frame4 are located at circle curve between frame2 and frame5.

If the type of driver perspective view at curved section is determined as “visual consistency poor or bad”, this position will be marked and detailed auditing or redesign will be applied. For a new highway to be built, the frames of perspective view come from computer animation or driving simulator. For an existing highway, they can come from videos captured along the highway. Regardless of driver perspective views source, characteristic of every frame of driver perspective view can be calculated.

3. DATASET AND TRAINING MODEL

In order to develop a logistic regression model that identifies the factors affecting design consistency, a data set is needed that would include the operating speed, highway horizontal and vertical alignment geometrical parameter. The data set is created based on the types of alignment combination. A digital camera is installed on a van to cover the similar view angles of driver. The eyes of the driver are set at 1.5m to the right side of the highway centerline and 1.0m above the highway surface, with no limits on sight distance (18). While the van is moving, the video of the camera is captured and the velocity of van is recorded at the same time with GPS.

3.1 Dataset

We use rural two-lane highway alignments combinations which have been used in China national highway G217. The design speed is kept constant at 60 Km/h. Horizontal alignments consists of four curves (R=300m, 400m, 500m and 600m) with 200m tangents separating the curves. Only the first horizontal curving turns left and the others turn right. Vertical alignments contain four vertical curves (crest or sag) which are completely overlapped with horizontal curves. It means that the middle points of vertical curves correspond to the middle points of horizontal curves. The length of each vertical curve equals to the corresponding horizontal curve length. The values of vertical curvature K (the ratio of vertical curve length to algebraic difference in grade) are 40, 60 and 80 for sag curves, -40, -60 and -80 for crest curves, respectively. The combination of K is distributed along alignment in random order. For each group of K, the first grade and second grade of each vertical curve should be calculated. Meanwhile, it is made certain that the absolute value of each grade is less than 8%. A total of eight sets of K combination are selected in our study.

3.2 Data Collection

The data collection process is divided into two parts. One of them is that the operating speed profile should be established and the other is that characteristics of every perspective view (A_p and y_p/h) should be extracted. We are interested in the difference between operating speeds of different segments of the highway instead of the absolute values of operating speeds. The velocity differences of test van can be seen as basically the operating speed differences between two successive segments of the highway. Based on the consistency evaluation criterion of operating speed (1), if the difference of operating speeds of two consecutive segments is less than 10km/h, it is classified as 0, which means “design consistency good”. If the difference is more than 20 km/h, it is classified as 2, which means “design consistency bad” for the same stretch. It is classified as 1 if the difference is between10km/h to 20km/h, which means “design consistency poor”.

After the video along highway G217 are collected, computer software is performed to extract driver perspective view characteristics. Since we only focus on shape and position of highway centerline on perspective view, only centerline and two edge lines of the rural two-lane highway are identified on perspective view. There are $8 \times 60 = 480$ samples (nearly 3Km highway) for every parameter (V_{85}, A_p and y_p/h). Some of them are summarized in Table 1. Set a horizontal curve corresponding a vertical sag or crest as a highway element. It means that horizontal curve length equals vertical curve length and midpoint of horizontal curve coincides with the midpoint of the vertical curve. Driver perspective views from various combinations of highway elements are captured by camera at start point of every element. After the characteristics of driver perspective view at all location had been calculated, the differences between them are acquired. The threshold of classification criterion is provided in Table 2. According to classification criterion, differences of driver perspective view characteristics (A_p and y_p/h) are classified from 0 to 2, which are shown in Table 3. All the data are used to train a logistic model of operating speed difference on a rural two-lane highway.

3.3 Relations of A_p and y_p/h between Horizontal and Vertical Curves

In the present study, the value of curvature A_p from horizontal curve right turn is nearly 1/10 from left turn. The value of y_p/h from both left turn and right turn is almost the same. Therefore, A_p from right turn is multiplied by 10 in the following analysis. This case can be affirmed by comparing data of items 1 to 5, 2 to 6, 3 to 7 and 4 to 8, as shown in Table 1. With a constant horizontal curve radius, the farther the distance of eye position from TC (horizontal tangent connecting circular arc) is, the larger (or sharper) curvature A_p and the value of y_p/h will be (Tab.1 item1 and item 5). Similarly, the larger horizontal curve radius is the smaller (or flatter) curvature A_p and the value of y_p/h will be (Tab.1 item 2 and item 6). It means driver perspective view with a smaller horizontal curve radius appears as "lower" (y_p/h is smaller) or "nearer" to the watcher eyes than with a larger horizontal curve radius. With a constant radius of horizontal curve, curvature A_p from corresponding crest vertical curve is larger than that from the corresponding sag vertical curve. It confirms that superimposition of a sag vertical curve with a horizontal curve may result in a perspective view that makes the horizontal curve appear flatter than it is in reality (to compare item 4-A with item 2-A or item 8-A with item 5-A in Table 1), whereas superimposition of a crest vertical curve reveals opposite results (to compare item 3-A with item 2-A or item 7-A with item 5-A in Table 1). The values of y_p/h are affected by highway vertical alignment obviously. There is a strong relationship between vertical curve and y_p/h. The relation between horizontal curve and y_p/h is also interrelated. Both the horizontal and vertical alignment can cause driver perspective view to move along vertical direction and it is difficult to distinguish which one is the primary factor.

3.4 Threshold Values of Classification Criterion for $\triangle A_p$ and $\triangle y_p/h$

When the driver eye positions are located at two different points of highway elements, two pieces of perception view are created and characteristics of A_p and y_p/h can be calculated. We are interested in $\triangle A_p$ and $\triangle y_p/h$ which can be simply calculated using A_p and y_p/h of one highway element to subtract others. The highway elements are obtained from the guidelines of FHWA RD-99–173(5). With horizontal curve radii corresponding to different vertical curves, the ranges of $\triangle A_p$ and $\triangle y_p/h$ are computed and shown in Table 2, data is based on left turn, and data of right turn is transformed to left turn.

Table 2 —General range of $\triangle A_p$ and $\triangle y_p/h$

	I	II	III	IV	V	VI
I	0.009~0.018 / 0.051~0.121	0.013~0.028 / 0.092~0.238	0.019~0.058 / 0.152~0.374	0.059~0.088 / 0.212~0.581	0.053~0.071 / 0.315~0.628	0.069~0.098 / 0.417~0.703
II	0.013~0.028 / 0.092~0.238	0.006~0.019 / 0.046~0.152	0.016~0.039 / 0.086~0.247	0.027~0.060 / 0.113~0.322	0.043~0.063 / 0.295~0.419	0.057~0.073 / 0.375~0.546
III	0.019~0.058 / 0.152~0.374	0.016~0.039 / 0.086~0.247	0.005~0.022 / 0.046~0.152	0.025~0.031 / 0.056~0.253	0.037~0.058 / 0.207~0.396	0.043~0.067 / 0.234~0.438
IV	0.059~0.088 / 0.212~0.581	0.027~0.060 / 0.113~0.322	0.025~0.031 / 0.056~0.253	0.018~0.050 / 0.164~0.305	0.067~0.092 / 0.336~0.571	0.032~0.060 / 0.304~0.633
V	0.053~0.071 / 0.315~0.628	0.043~0.063 / 0.295~0.419	0.037~0.058 / 0.207~0.396	0.067~0.092 / 0.336~0.571	0.020~0.061 / 0.136~0.171	0.019~0.052 / 0.183~0.213
VI	0.069~0.098 / 0.417~0.703	0.057~0.073 / 0.375~0.546	0.043~0.067 / 0.234~0.438	0.032~0.060 / 0.304~0.633	0.019~0.052 / 0.183~0.213	0.016~0.048 / 0.155~0.169

1) I: Horizontal curve on grade -9%~-4%; II: Horizontal curve on grade -4%~0%; III: Horizontal curve on grade 0%~4%; IV: Horizontal curve on grade 4%~9%; V: Horizontal curve combined with sag vertical curve; VI: Horizontal curve combined with crest vertical curve.

2) Numerator of fraction is general range of $\triangle A_p$; Denominator is general range of $\triangle y_p/h$.

Based on the study results, the threshold values of classification criterion for $\triangle A_p$ are determined as 0.024, 0.048 and 0.072. Thresholds of $\triangle y_p/h$ are 0.09, 0.21 and 0.33. Details are shown at Table 3 and the factors are characterized by a series of dichotomous variables that are summed to unity for each factor. One of the variables must be used as a reference in model. The effects of identified factors on design consistency are studied by examining the odds (OR) against the reference case. The reference case for $\triangle A_p$ is >0.072, for $\triangle y_p/h$ is >0.33.

Table 3 —Descriptive Statistics of Variables and Estimation Results

Explanatory variables	Description of variables	Mean	S.D.
(1)Curvature difference of perspective center line $\triangle A_p$			
0.024-0.036	If $\triangle A_p$ <=0.024 =0; >=0.036 =2;otherwise=1	.5677	.4967
0.036-0.048	If $\triangle A_p$ <=0.036 =0; >=0.048 =2;otherwise=1	.2188	.4145
0.048-0.060	If $\triangle A_p$ <=0.048=0; >=0.060 =2;otherwise=1	.1563	.3640
0.060-0.072	If ΔA_p <=0.060 =0; >=0.072=2;otherwise=1	.0573	.2330
(2) odds ratio difference for x of extreme point P to width of driver perception view $\triangle y_p/h$			
0.09-0.15	If $\triangle y_p$ /h <=0.09 =0; >=0.15 =2; otherwise=1	.3698	.4840
0.15-0.21	If $\triangle y_p$ /h <=0.15 =0; >=0.21 =2; otherwise=1	.3594	.4810
0.21-0.27	If $\triangle y_p$ /h <=0.21 =0; >=0.27 =2; otherwise=1	.1979	.3995
0.27-0.33	If Δy_p /h <=0.27 =0; >=0.33 =2; otherwise=1	.0729	.2607

Variables	*Odds ratio*	*B*	*p-Value*
(1) *ΔA_p (relative to >0.072)*			
0.024-0.036	0.012	-4.440	0.001
0.036-0.048	0.027	-3.630	0.005
0.048-0.060	0.121	-2.112	0.002
0.060-0.072	1.000	0.000	0.000
(2) *$\Delta y_p/h$ (relative to >0.33)*			
0.09-0.15	0.050	-3.002	0.025
0.15-0.21	0.085	-2.462	0.035
0.21-0.27	0.314	-1.157	0.269
0.27-0.33	1.000	0.000	0.000
(3) Constant	6.852	1.925	0.119

4. PARAMETRIC STUDIES AND APPLICATION

The results for the final logistic model are shown in Table 3. Based on the *p*-values of the t-tests, 7 variables from 8 factors are found to be significant ($p<=0.05$). One variable with low statistical significance ($p=0.269$) might be retained in the model because it belongs to the variable ($\triangle y_p/h$) which has significant effect on perspective view. Although it may reduce the efficiency of the model, it can be adopted for case comparison and interpretation of this model.

4.1 Parametric Studie*s*

Apparently, when $\triangle A_p$ and $\triangle y_p/h$ are smaller, the possibility of being visual inconsistency is lower. If $\triangle A_p$ of two driver perspective views between 0.024-0.036, the possibility of visual inconsistency is 98.8% lower than the reference case (OR=0.012). If $\triangle A_p$ is between 0.036-0.048, the possibility is 97.3% lower than the reference case (OR=0.027). If $\triangle A_p$ is between 0.048-0.060, the possibility is 87.9% lower than the reference case (OR=0.121). This means that there is a little impact on visual inconsistency when $\triangle A_p$ is smaller than 0.05. Only when $\triangle A_p$ is larger than 0.05, the effect will become significant gradually. The case ($\triangle A_p$ >0.072) is found to bear equal possibility in determining visual inconsistency or visual consistency (OR=1.00). Relatively speaking, $\triangle y_p/h$ brings more considerable inference on visual inconsistency than $\triangle A_p$. If is between 0.09-0.15 the possibility of visual inconsistency is 95.0% lower than the reference case (OR=0.050). If $\triangle y_p/h$ is between 0.15-0.21, the possibility is 91.5% lower than the reference case (OR=0.085). If $\triangle y_p/h$ is between 0.21-0.27, the possibility is only 68.6% lower than the reference case (OR=0.314). The case ($\triangle y_p/h$ >0.33) is found to have equal possibility in determining visual inconsistency or visual consistency (OR=1.00).

The above parametric studies only change one variable by one unit at a time and other variables kept constant. The objective of such a study is to understand the mechanism of two variables ($\triangle A_p$ and $\triangle y_p/h$) affecting the possibility of visual inconsistency. In practical applications, $\triangle A_p$ and $\triangle y_p/h$ would be used together to calculate OR.

4.2 Application

The ordered logistic model is applied to check design consistency of national highway G217 in China and results were compared with the operating speed V_{85} which was calculated using the model developed by Fitzpatrick et al. (7). Initial data is shown in Table 4. Driver perspective views with eye positions located along the highway were simulated on computer and $\triangle A_p$, $\triangle y_p/h$ of every position were established. Odds could be estimated through the ordered logistic model. The operating speed difference and odds are shown in Table 5.

1) Check design consistency according to $\triangle V_{85}$ Model

In segment I and II, $\triangle V_{85}$=15Km/h (10Km/h<$\triangle V_{85}$<*20Km/h*). In segment III, $\triangle V_{85}$=5Km/h (<$\triangle V_{85}$<*10Km/h*).

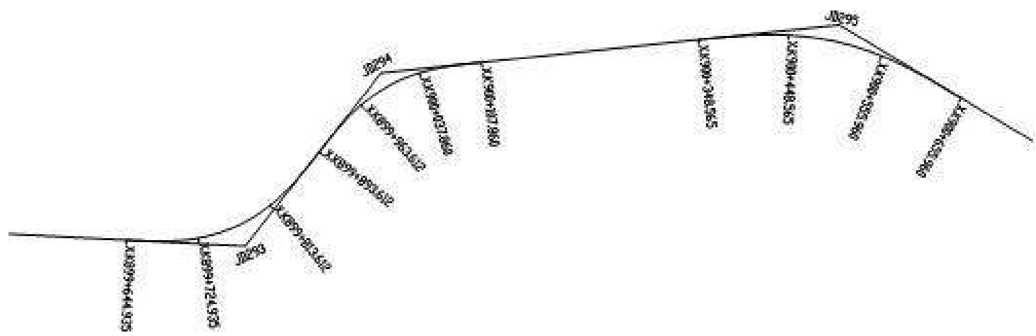
2) Check design consistency according to perspective view

In segment I, Pr0=Pr(X|Y=0)= 2.999%, Pr1=Pr(X|Y=1)= 96.999%,Pr2=Pr(X|Y=2)= 0.002%, the maximum probability is Pr1, it means design consistency is classified into category 1 (10Km/h<|△V|≤20Km/h). In segment II, Pr0=Pr(X|Y=0)= 34.930%, Pr1=Pr(X|Y=1)= 65.069%,Pr2=Pr(X|Y=2)= 0.001%, the maximum probability is Pr1, it means design consistency is classified into category 1 (10Km/h<|△V|≤20Km/h). In segment III, Pr0=Pr(X|Y=0)= 89.518%, Pr1=Pr(X|Y=1)= 10.091%,Pr2=Pr(X|Y=2)= 0.391%, the maximum probability is Pr0, it means design consistency is classified into category 0 (|△V|≤10Km/h)

The result of probability shows nearly similar trends with operating speed V_{85}. It can be found that utilizing characteristics of driver perspective view can be a promising technique in analyzing design consistency.

Table 4 —Initial data comes from highway G217

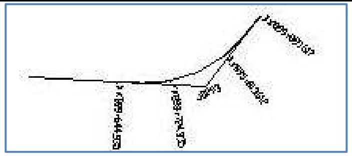
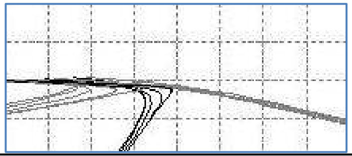
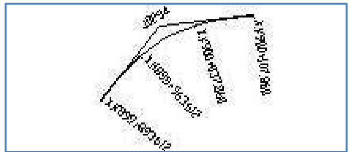
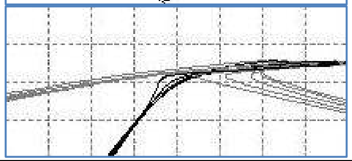
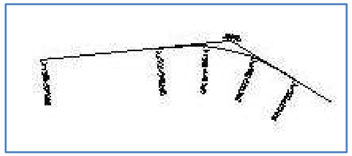
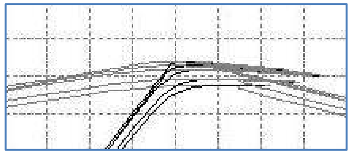
Highway Map



Horizontal curves					
IP Station	Deflection angle	Radius	Spiral curve	Tangent length	Curve length
K899+777.036	54d42'27.6"	176.657	80	132.101	248.677
K900+005.306	45d57'41.3"	179.82	70	111.694	214.248
K900+506.448	37d08'02.2"	320.00	100	157.883	307.395

Vertical curve				
IP Station	First grade	Second grade	Radius	Tangent length
K899+040.000	-1.85	0.455	8810.573	100
K899+300.000	0.455	0.765	50000	77.5
K899+520.000	0.765	-0.455	12000	73.2
K899+760.000	-0.455	1.9	8500	100.087
K899+980.000	1.9	5	7736.29	119.912
K900+250.000	5	3	8000	80
K900+500.000	3	-3.3	3200	100.8
K900+940.000	-3.3	1.1	4500	99

Table 5 —Analyzing highway design consistency based on driver perspective view

	sketch map	No	Station	V_{85}	Δ V_{85}	A_p	Y_p/h	Δ A_p	Δ y_p/h	Pr0	Pr1	Pr2
I	 	1	K899+585.935	70.0	15.0Km/h	0.0214	0.511			2. 999%	96.999%*	0.002%
		2	K899+640.935	70.0		0.0180	0.469	0.0034	0.042			
		3	K899+682.935	70.0		0.0143	0.457	0.0037	0.012			
		4	K899+724.935	55.0		0.0125	0.457	0.0018	0.001			
		5	K899+759.935	55.0		0.0122	0.474	0.0003	0.018			
II	 	1	K899+850.612	55.0	15.0Km/h	0.00271	0.609			34.930%	65.069%*	0.001%
		2	K899+887.612	70.0		0.00204	0.592	0.00067	0.017			
		3	K899+925.612	55.0		0.00162	0.586	0.00042	0.006			
		4	K899+963.612	55.0		0.00144	0.585	0.00018	0.001			
		5	K899+998.612	65.0		0.00137	0.604	0.00007	0.020			
III	 	1	K900+283.565	70.0	5.0 Km/h	0.00203	0.683			89.518%*	10.091%	0.391%
		2	K900+338.565	70.0		0.00192	0.647	0.00011	0.037			
		3	K900+393.565	65.0		0.00176	0.603	0.00016	0.043			
		4	K900+448.565	65.0		0.00177	0.520	0.00001	0.083			
		5	K900+487.565	70.0		0.00181	0.466	0.00004	0.054			

5. CONCLUSION AND FURTURE WORK

This paper summarizes our preliminary research in applying driver visual technique to evaluate design consistency of highway geometry. Since more than 80% driving information comes from visual perception, visual consistency becomes important for design consistency. In fact, visual consistency includes not only highway geometry design consistency but also other visual demands, such as environment and landscape, etc. Everything that is observed by drivers will affect their behavior during driving. Hence, in order to ensure driving safety and comfort, visual consistency and other demand should be provided. Based on this study, the following conclusions are made:

(1) There is a strong relationship between driver perspective views and highway alignments, especially, combination of horizontal curves and vertical curves. Meanwhile, eye position of drivers is also an important factor affecting the shape of a driver perspective view.

(2) The study of driver visual technique can not only help engineers in evaluating design consistency of highways but also help drivers operate vehicles safely. As a potential technique, it will assist drivers to rapidly scan visual environment in the front on highways, which may help to avoid serious accidents.

(3) The logistic model was developed in this study for two lanes rural highway to check design consistency and only highway alignment was addressed. Therefore, future research should explore other types of highways (for example, expressways) and other factors, such as pedestrians, vehicles, traffic signs and objects on the roadside.

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REFERENCES

1. Lamm, R., Psarianos, B., and Mailaender, T. (1999). Highway design and traffic safety engineering handbook, McGraw-Hill, New York.
2. Easa, S. M. and A. Mehmood. Establishing highway horizontal alignment to maximize design consistency. Canadian Journal of Civil Engineering 34.9(2007): 1159-68.
3. Gibreel, G. M., et al. State of the art of highway geometric design consistency. Journal of Transportation Engineering-ASCE 125.4 (1999): 305-13.
4. Nicholson, A. Super elevation, side friction, and roadway consistency. Journal of Transportation Engineering-ASCE 124.5 (1998): 411-18.

5. Margaret Gibbs, Sany R. Zein, Dan Nabors, Louisa Ward and Craig Allred. Road Safety Audits, FHWA Case Study Program. Transportation Research Record, 1969 (2006):79–84.
6. Fitzpatrick, K., and Collins, J. Speed profile model for two-lane rural highways. Transportation Research Record, 1737(2000): 42–49.
7. Fitzpatrick, K., etc. (1999) Alternative design consistency rating methods for two-lane rural highways. FHWA-RD-99–173 <http://www.tfhrc.gov/safety/ihsdm/libweb.htm> (July 2009).
8. Misaghi, P. and Y. Hassan. Modeling operating speed and speed differential on two-lane rural roads. Journal of Transportation Engineering-ASCE 131.6 (2005): 408-17.
9. Gibreel, G. M., S. M. Easa, and I. A. El-Dimeery. Prediction of operating speed on three-dimensional highway alignments. Journal of Transportation Engineering-ASCE 127.1 (2001): 21-30.
10. Gibreel, G. M., S. M. Easa, and I. A. El-Dimeery. Prediction of operating speed on three-dimensional highway alignments. Journal of Transportation Engineering-ASCE 127.1 (2001): 21-30.
11. Hassan, Y., T. Sayed, and V. Tabernero. Establishing practical approach for design consistency evaluation. Journal of Transportation Engineering-ASCE 127.4(2001): 295-302.
12. Hassan, Y., T. Sayed, and Shaun Bidulka. Influence of Vertical Alignment on Horizontal Curve Perception, Phase II: Modeling perceived Radius. Transportation Research Record, 1796(2002): 24–34.
13. Krammes, R., etc. Horizontal alignment design consistency for rural two-lane highways, Federal Highway Administration, Washington, D.C, (1995).
14. McFadden, J., and Elefteriadou, L. Evaluating horizontal alignment design consistency of two-lane rural highways: Development of new procedure. Transportation Research Record, 1737(2000):9–17.
15. Schlegel, R. E. Driver mental workload. Automotive ergonomics, B. Peacock and W. Karwowski, eds., Taylor and Francis, London, (1993) 359–382.
16. Easa, S. M. and W. L. He. Modeling driver visual demand on three-dimensional highway alignments. Journal of Transportation Engineering-ASCE 132.5(2006): 357-65.
17. Wang, F. J. and S. M. Easa. Validation of Perspective-View Concept for Estimating Road Horizontal Curvature. Journal of Transportation Engineering-ASCE 135.2 (2009): 74-80.
18. Hassan, Y. and S. M. Easa. Effect of vertical alignment on driver perception of horizontal curves. Journal of Transportation Engineering-ASCE 129.4(2003): 399-407.
19. Shaun Bidulka, Tarek Sayed and Yasser Hassan. Influence of Vertical Alignment on Horizontal Curve Perception, Phase I: Examining the Hypothesis. Transportation Research Record, 1796(2002): 12–23.
20. Alexander, G. J., and Lunenfeld, H. (1986). Driver expectancy in highway design and traffic operations. Rep. No. FHWA-TO-86-1, Federal Highway Administration, 1986.
21. Smith, B., and Lamm, R. Coordination of horizontal and vertical alignment with regard to highway esthetics. Transportation Research Record, 1445(1994): 73–85.
22. Taiganidis, I. and G. Kanellaidis. Approximate perspective design of roads. Journal of Transportation Engineering-ASCE 125.4 (1999): 314-23.

23. Ten Brummelaar, T. The reversal point in the perspective road picture. Aust. Road Res., 13.2(1983):123–127.
24. Zakowska, L. (1999). “Road curve evaluation based on road view perception study.” Transportation Research Record. 1689(1999): 68–72.
25. Hassan, Y., G. Gibreel, and S. M. Easa. Evaluation of highway consistency and safety: Practical application. Journal of Transportation Engineering-ASCE 126.3(2000): 193-201.
26. Polus, A. and C. Mattar-Habib. New consistency model for rural highways and its relationship to safety. Journal of Transportation Engineering-ASCE 130.3 (2004): 286-93.
27. Tay, R., S. M. Rifaat, and H. C. Chin. A logistic model of the effects of roadway, environmental, vehicle, crash and driver characteristics on hit-and-run crashes. Accident Analysis and Prevention 40.4 (2008): 1330-36.