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Research Article

Study on the Deocclusion of the Visibility Window of Traffic Signs on a Curved Highway

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Highway navigation is often affected by complex topography, and the flat curve plays an important role in the horizontal alignment design of a highway. Many curves are formed, where visibility could be decreased. Thus, the indicative function of a traffic sign plays a crucial role in ensuring driving safety at the curve. Due to the blocked visibility, the probability of the traffic sign occlusion at the curve of operating highways is quite high. It is urgent to consider the clearing obstructions around traffic signs at curves during highway construction. In this study, the potential of visual occlusion for traffic signs on curved highways was investigated. Firstly, the driver's visibility window that contains traffic signs was defined and criteria of visual occlusion were proposed. Secondly, a geometric occlusion design formula was established to mimic the visual recognition process of traffic signs on a curved highway, yielding the formula to calculate the visibility window. Finally, the occlusion design formula was applied into a case study of the Beijing-Hong Kong-Macau Expressway (Hunan section), in which visibility windows were calculated and analyzed. The obtained results verified the correctness and effectiveness of the occlusion design formula developed in this study.

1. Introduction

Highways that cross over mountainous terrain are often curved due to having to navigate the complex topography. To address these issues, the horizontal alignment design of the highway is dominated by flat curves, and traffic signs placed on the curved roads can effectively eliminate the interference on both sides of the highway and the traffic, attract the driver's attention, and, to a certain extent, determine the occurrence of highway traffic accidents.

In the national survey of traffic accident in the past three years (2013–2015) [1], the highest mortality rate was in Guizhou Province, 69.43 per 100 accidents, followed by Yunnan Province (53.32) and Qinghai Province (51.07), which are much higher than that in Guangdong Province (20.76) according to the statistics from the Ministry of Public Security. In fact, the former three provinces mostly consist of mountainous terrrain. Another data analysis from the Regional Distribution of Heavy Traffic Accidents in the Mountainous Areas of Guangdong Province (2010–2015) shows that Shaoguan, Qingyuan, and other areas in northern Guangdong, which are located in mountainous terrain, are the areas with high-accident rates [2].

From the accident data acquired on several highways in the Hunan section (Highway Nos. G4, G60, and G72) from 2013 through 2016 and the overall major accident data of the highways in the Hunan Province from 2002 to 2018, some conclusions can be drawn: (a) high-accident rates are often on the highways that are of complex lines, curved roads, and curved slopes; (b) more than eighty percent of the total accidents are curved-road related; (c) five percent of curved-road related accidents occurred on the main travel lane; and (d) the cause of the accidents are attributed to the fact that the horizontal alignment design of the highway is dominated by flat curves and the form of the curve is complicated, while the highway traffic signs that provide directions and warnings or prohibition information for vehicles and pedestrians have a certain potential impacts on the occurrence of accidents. According to relevant research, seventy percent of road traffic accidents are related to the design and the locations of traffic designs [3]. Therefore, it is an urgent need to study on the deocclusion of the visibility window of traffic signs on a curved highway.

Many factors could contribute to the occlusion of a traffic sign. The driver's visibility of the traffic sign could be affected by a variety of variables, including roadside plants, passing or stationary vehicles, the slope of the highway, a central divider or sound insulation wall, monitoring facilities, or even other signs. All of these variables can inhibit the driver's ability recognizing traffic signs in terms of inadequate reading time, insufficient information, or even misreading the sign. Mistakes in information recognition lead to operational errors or misjudgments that can result in traffic accidents, such as rear-end collisions and rollovers. Through the statistical analysis of the roadside traffic signs of the Changyi section of the Beijing-Hong Kong-Macau Expressway in Hunan Province, we investigated the occlusion of a total of 839 traffic signs on curved roads. Results showed that up to 15% of traffic signs on curved roads were occluded by the roadside plants, approximately 3% by terrain and slope and approximately 5% by other barriers such as bridges, central separation belts, and monitoring facilities. More importantly, up to 15% of traffic signs on curved roads were obstructed by the passing-by vehicles during high traffic volume, see Table 1. These data indicate high probability of the occlusion of traffic signs on curved roads.

Table 1: The impacting factors on the occlusion of traffic signs.

Impacting factors	Percentage (%)
The roadside plants	15
Terrain and slope	3
Other barriers such as bridges, central separation belts, and monitoring facilities	5
The passing-by vehicles during high traffic volume	15

The issue of traffic sign obstruction has recently become a key topic for domestic and international scholars with the rise in development of intelligent vehicle technology and the trend of maintaining large data in the traffic signs. The following study will focus on two aspects: first, the study aims at removing traffic signs obstruction with computer science and electronic engineering; the second aim of the study is to determine the probability traffic sign obstruction due to same-direction traffic. In the early stages, clearing traffic sign obstruction using computer science and electronic engineering was designed through analyzing images obtained from a car camera, including exposure level, the contrast of the foreground and background colors, the color distribution histogram, and the image texture [4–6]. Recently, mobile laser scanning, photogrammetry, and 3D point cloud technology had been shown to be able to detect the traffic signs, making 3D measurement and 3D visualization possible and subsequently solving the problem of occlusion and provided valuable data towards providing a solution to traffic sign occlusion [7–13]. The probability of traffic sign obstruction by other same-direction driving vehicles was also studied. The occlusion model was designed using visual recognition, by which the effects of the two-dimensional visible geometric relationship (i.e., size, driving speed, relative position, and relative distance) on the traffic sign obstruction could be obtained. Next researchers added complex factors, such as traffic volume, spatial relationship, and time, and used software and computer technology to establish an occlusion probability model, which was used to determine solutions to reduce the occlusion of the traffic signs by the same-direction vehicles [14–29]. To date, the research on the occlusion of traffic signs focuses mainly on predicting the probability of obstruction from a unidirectional vehicle. For example, Bramson calculated the likelihood that the car driver's visibility window could be occluded [14]. Additionally, Pietrucha et al. established an occlusion model based on a probability theory, in which the driver's visibility window was found to be related to the relative position of surrounding vehicles and traffic volume [20]. Agarwal and Chakroborty used linear programming and probability theory to construct the probability calculation model of gantry-style traffic sign occlusion [15]. Al-Kaisy et al. developed software that simulates obstruction of driver's visibility window and the process of traffic signs being missed [18]. Regarding highway curvature, research mainly studied the line of curvature alignment and safety facilities, and very little research is focused on the occlusion of traffic signs due to the curvature. To this end, this work aims to investigate the visual occlusion of traffic signs on a main-line curved highway and to examine problems needing solutions to obstruction.

Since traffic signs play a major role in alerting and guiding the driver on the highway, this research aimed at providing analysis of the occlusion of the traffic signs in the operating highways. The visibility window of the traffic signs on curved roads, coordinated by the center of the circle on the curved roads, was investigated using the visibility window equations, which includes variants during the traffic sign recognition process while driving. This study establishes a dynamic equation for the visibility window of traffic signs on curved roads, as well as a three-dimensional equation, which is more advanced than the 2D modeling previously used in a similar literature. The ability to provide a basic theoretical model for intelligent-assisted driving system and automatic self-driving vehicles and maintenance of traffic signs is incredibly significant in which it provides a theoretical basis for determining the location of traffic sign installation and clearance control of traffic signs. These models provide foundational research for regulating driving behaviors and ensuring driving safety.

2. The Visual Occlusion of Traffic Signs on Curved Highway

2.1. The Definition of Visibility Window. The visibility window is defined in this study as the area ranging from the driver's highest viewpoint to the signboard boundary, as shown in Figure 1. It is the base of a square pyramid, formed

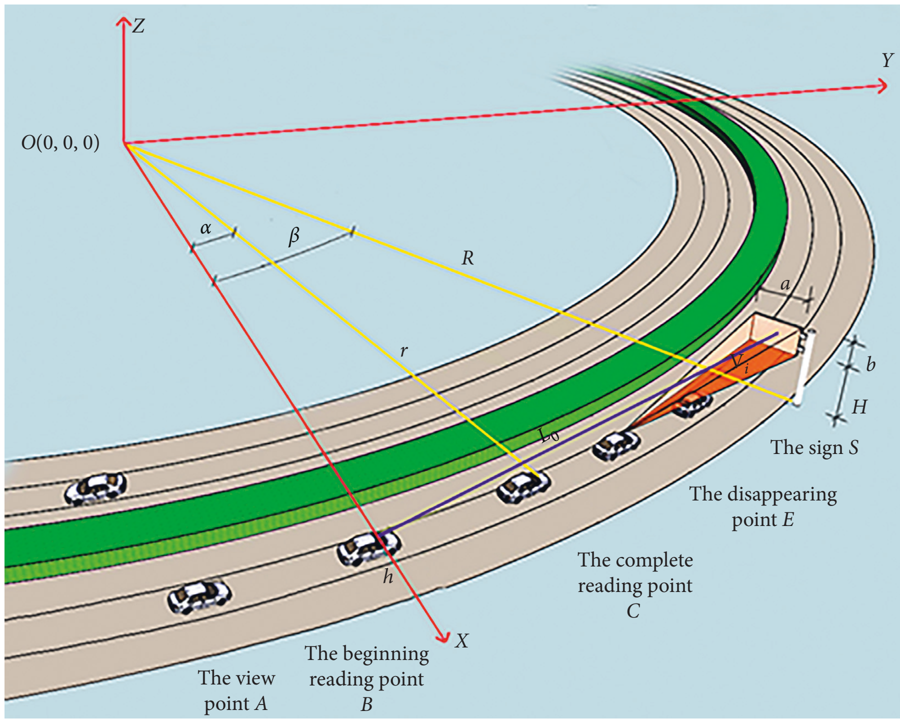

Figure 1: The visual occlusion of traffic sign on the curved highway (for details, refer to the text).

by the driver's high point (h), the length of the sign (a), and the width of the sign for a rectangular sign (b), otherwise defined as radius R for a round sign or length (a) and altitude (b) for a triangular sign.

When the vehicle moves from the beginning reading point B to the complete reading point C (see Section 2.1 and Figure 2 for details), sign recognition problem will occur if obstacles are in the visibility window, which is also considered as the visual occlusion of a traffic sign. Due to the small volume of the visibility window of the traffic sign, driver's ability to read the sign is prone to be influenced by obstructions.

2.2. Analysis of Occlusion Factors. Within the curvature of a highway, a traffic sign can be easily blocked by plants, slopes, central dividers, codirectional vehicles, soundproof walls, overpass bridges, and other signs (as shown in Figure 3), which may result in difficulty for the driver to correctly discern the upcoming traffic patterns or recognize the information described by the sign. Consequently, the driver cannot take corresponding actions, which can cause an accident.

2.2.1. Plant Occlusion. Plant obstruction on traffic signs was very common on the highways under our investigation. Due to the constricting conditions of the land use of China's highways, plants commonly become visual barriers in driver's visibility window, thus obscuring traffic signs.

2.2.2. Slope Occlusion. Due to the significant influence of terrain, some highways were constructed with roadside slopes. Within the curvature of the highway, the visibility window can be obstructed by the slope and impacted by the slope's volume, which affects the driver's ability to correctly judge upcoming traffic patterns.

2.2.3. Dynamic Occlusion from Codirectional Vehicles. Vehicles traveling codirectionally in adjacent lanes could form a certain visual obstruction for the driver of the following vehicle. Studies have shown that when the vehicle is driving close to the sign on a curved highway, large vehicles can become a visual barrier for the driver of small vehicles on the inner lane, which inhibits his ability to obtain traffic information from the traffic sign. This could result in an accident if the driver fails to recognize sign information and respond accordingly [8–10].

2.2.4. Occlusion from a Central Divider. In the design of the central divider at curves, plant height requirements for antiglare purpose are often considered. However, poor visual distance surrounding the central divider is often not realized as a possible issue, especially on small-radius curves, where the road ahead or the traffic sign could be blocked by overheight plants at the central divider.

2.2.5. Occlusion from Soundproof Wall, Monitoring Facilities, Lighting Devices, and Vehicles Parked on the Emergency Lane. The construction of these structures along the curvature of a road or the roadside parked vehicles may become a visual occlusion if they are within the visibility window.

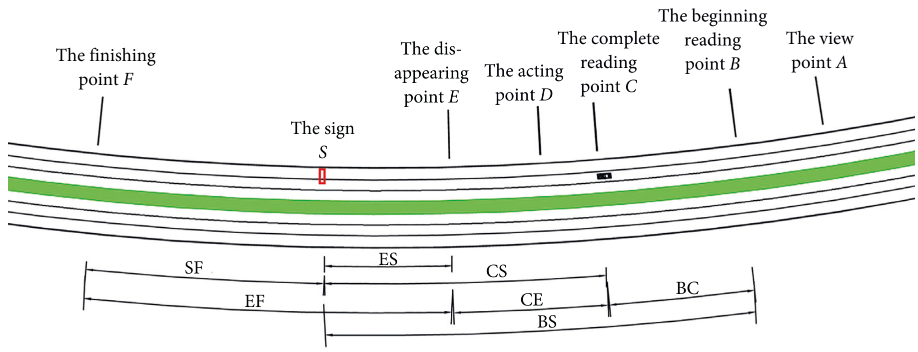

Figure 2: The traffic sign recognizing process on the curved highway (for details, refer to the text).

Figure 3: Illustration of occlusion factors (for details, refer to the text). (a) Plant occlusion. (b) Slope occlusion wall. (c) Dynamic occlusion of codirectional vehicles. (d) Occlusion from central divider. (e) Occlusion of monitoring facilities. (f) Occlusion of traffic signs.

2.2.6. Occlusion from Other Traffic Signs. Some traffic signs lack adequate distance of separation. The second sign may be blocked by the one in the front view. Small signs may not be visible among large signs, for example, huge billboards.

3. Geometric Design Formula for the Visibility Window of Traffic Signs on a Curved Highway

3.1. Determination of Visual Occlusion on Curved Highway. According to the analysis of the traffic sign recognition process in the "Handbook for Highway Traffic Signs and Markings" (JTGD82-2009) [30], the visual recognition process and the sign setting of a curved road are shown in Figure 2.

In Figure 2, the mark S is installed on the roadside of the curve as required by the specification. Usually, the driver can see sign S at the point of view A. At point B, the driver is able to read the content of the sign. At point C, the sign information can be completely acquired, where the distance $\overline{BC}$ is called the acquiring distance. After reading the sign, the driver can make judgment within the distance from point C to point D; the distance $\overline{CD}$ is considered as the judgment distance. Finally, the driver can respond at point D until the action is completed at point F; the distance $\overline{DF}$ is called the distance of action. The distance from point B to sign S is called the viewing distance $\overline{BS}$. When the driver approaches the sign, the distance between the points where the driver cannot see the sign due to the blind angle and the barriers in the visibility window and the sign location S is called the disappearing distance $\overline{ES}$. The distance from the point where the sign information can be acquired completely to the location of the sign is $\overline{CS}$ [27, 28].

Suppose the car is driving at a constant speed v, then the viewing distance is

$$\overline{BC} = v \cdot t. \tag{1}$$

In (1), t is the time required to read the traffic sign:

$$\overline{ES} = \frac{H-h}{\tan\theta}. \tag{2}$$

In (2), H is the height of the sign, which is from the ground to the lowest level of the sign; h is the driver's viewpoint height; and θ is the disappearing angle, which is the angle between the disappearing point and the roadside or dangling traffic sign (see Figure 4):

$$\overline{CS} = 5.67h^*. \tag{3}$$

In (3), h^* is the effective character height (m), which is the actual text height on the sign being multiplied by the text correction coefficient, the running speed correction factor, and the Chinese character complexity correction coefficient [30]. An experimental estimated value of 5.67 is obtained from the Japan Institute of Civil Engineering [30].

If the distance $\overline{CS}$ is shorter than the distance $\overline{ES}$, the disappearing point E appears before the complete reading point C, which will result in insufficient time for the driver to read the sign and accurately interpret the sign content. If $\overline{CS} = \overline{ES}$ (i.e., the reading point C coincides with the disappearing point E), then the value corresponding to traffic sign reading distance would be limited. Herein, we define the range of visual occlusion to effectively provide the tolerance of the traffic sign recognition time: $\overline{CS} > \overline{ES}$. Meanwhile, from the initial reading point B to the disappearance point E, we exclude any barriers in the visibility window of traffic sign reading. Therefore, the visual occlusion range of this study is defined as the reading distance $\overline{BE}$:

$$\begin{aligned}\overline{BE} &= \overline{BC} + \overline{CS},\\ \overline{ES} &= v.t + 5.67h^* - \left(\frac{H-h}{\tan\theta}\right).\end{aligned} \tag{4}$$

3.2. Design Formula for the Visibility Window of Traffic Signs on a Curved Highway. As shown in Figure 4, the vertical height from the center of the signboard to the ground is $h_1 = H + b/2$ (m), and the vertical height from the signboard center to the driver's viewpoint height is $h_2 = H + b/2 - \mathrm{h}$ (m).

As shown in Figure 1, when the vehicle's travel speed is v (km/h), the space rectangular coordinate system is established with the center of the arc of the vehicle's traveling path. If the space coordinates of the signboard are $R\cos\beta$, $R\sin\beta$, and $H + b/2$, then

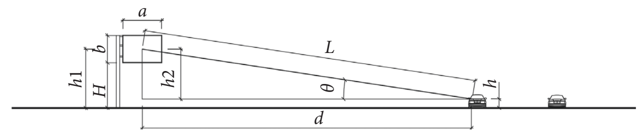

Figure 4: The cross-section of traffic sign setting on the curved highway (for details, refer to the text).

$$\begin{aligned}d &= \sqrt{L^2 - \left(H + \frac{b}{2} - h\right)^2},\\ d^2 &= R^2 + r^2 - 2Rr\cos\beta,\\ \beta &= \cos^{-1}\frac{R^2 + r^2 - d^2}{2Rr}.\end{aligned} \tag{5}$$

In Figure 1, d is the horizontal distance from the driver's viewpoint to the sign, L is the distance from the driver's viewpoint height to the center of the sign, b is the height of the sign, R is radius distance from the center of the circle to the sign location S, r is radius distance from the center of the circle to the car, and β is the angle between the straight line of the sign to the center of the circle and the horizontal line (positive x-axis).

According to formula (4), the speed of the vehicle remains unchanged at v km/h after passing the reading point B but prior to the driver taking any actions; the traveling time from the beginning of reading point B to the disappearing point E is set to t_i. Between these two points, the distance between the driver's viewpoint height to the sign will vary with the traveling time. Suppose that at any point in time ranging from 0 to t_i, an arc distance traveled by the vehicle is defined as $\overline{BC} = v.t_i$.

The angle that the car turns from 0 to t_i (in radians) is relative to the positive x-axis:

$$\alpha = \frac{v \cdot t_i}{3.6r}, \tag{6}$$

where α is the angle of motion formed by the car on a circular curve and t_i is the time change of the reading process [13].

If the coordinates of the driver's viewpoint height at the time of t_i is ($r\cos\alpha$, $r\sin\alpha$, and h) and the distance from the driver's viewpoint height to the sign is L_i, then

$$\begin{aligned}L_i &= \sqrt{(R\cos\beta - r\cos\alpha)^2 + (R\sin\beta - r\sin\alpha)^2 + \left(H + \frac{b}{2} - h\right)^2}\\ &= \sqrt{\left(R\cos\beta - r\cos\frac{vti}{3.6r}\right)^2 + \left(R\sin\beta - r\sin\frac{vti}{3.6r}\right)^2 + \left(H + \frac{b}{2} - h\right)^2},\end{aligned} \tag{7}$$

where L_i is the distance in the reading process as changing time to t_i.

As shown in Figure 1, if the distance from the driver's viewpoint height to the center point of the signboard is L at the starting point B, then the distance of L_0 is $L_0 = \mathrm{BC} + \mathrm{CS} = \mathrm{v}t_0 + 5.67\,h^*$ at time t_0.

At the time of t_i, the volume of the quadrangular pyramid formed by the driver's viewpoint height to the sign is

$$\vee = \frac{1}{3ab}\sqrt{(R\cos\beta - r\cos\alpha)^2 + (R\sin\beta - r\sin\alpha)^2}. \quad (8)$$

If α is replaced by a function of time t, then a function of volume with respect to time t is obtained:

$$\vee_i = \frac{1}{3ab}\sqrt{\left(R^2 + r^2 - 2Rr\cos\left(\beta - \frac{v.t_i}{3.6r}\right)\right)}, \quad (9)$$

where a is the length of the sign, V is the volume of the visual occlusion of the traffic sign on a curved highway, and V_i is the volume of the visual occlusion of the traffic sign on a curved highway as a function of traveling time.

4. Application of the Visual Occlusion Design Formula

The Hunan section of the Beijing-Hong Kong-Macau Expressway is 531.8 kilometers long and has been in operation for more than 20 years (since 1996). The route is a typical highway in a mountainous terrain located in the south-central part of the Hunan Province surrounded by mountains (south, east, and west). The mountainous area accounts for about half of the total area. It belongs to the typical hilly area highway, and the mileage of curved highways accounts for about 80% of the total length. In this study, we selected curved roads on the Beijing-Hong Kong-Macau Expressway in the Hunan Province with a high-accident rate as an example to verify the visual occlusion design formula.

4.1. Selection of Relevant Parameters

4.1.1. Road Cross-Section. The width of the road section is shown in Figure 5, which is approximately 28 m with two 3.75 m wide driving lanes (hard shoulder 3.5 m) and a 4.5 m wide central divider.

4.1.2. The Calculation Only Considers the Radius of the Circular Curve. As shown in Table 2, the general value of the minimum radius of the circular curve in the "Design Specification for Highway Alignment" (JTG D20-2017) [31] is used, which is divided into two types: inner curve and outer curve.

4.1.3. Traffic Sign Related Parameters. The signs are divided by shapes (squares, circles, and triangles) and structural forms (cantilever, gantry, and single column). According to the survey, the cantilevered signs within the Hunan section of the Beijing-Hong Kong-Macau Expressway are mainly used for traffic guidance, which is the most important information for drivers. If the occlusions on such signs occur frequently, traffic accidents will occur. Because of their popularity and significance, we selected cantilever-shaped rectangular sign for this pilot study. The cantilever-shaped rectangular sign has a length of 4.8 m, width b of 3 m, and a set height H of 5.2 m. Other types of traffic signs are calculated in the same way.

4.2. Verification of the Occlusion Design Formula.

We simulated the volume of the traffic sign visibility window at different speeds using a Matlab design formula by substituting the relevant parameters, as shown in Figures 6–9.

4.2.1. The Principle of the Visibility Window of a Traffic Sign

(1) Since the recognition of traffic sign is an instantaneous process, the traffic sign visibility window has a very narrow time frame (about 2.5 s), and the calculated volume of the visibility window for the cantilevered rectangular traffic sign at curved road is in the range of 550 m^3 to 1000 m^3. The volume is relatively small so that during the short period of time, no obstacles should be in the visibility window. Otherwise, it will cause obstruction.

(2) The volume of the traffic sign visibility window decreases linearly as function of traveling time. The closer to the sign, the less effect it has on the volume of the visibility window.

(3) As shown in Figures 6 and 8, when the driving speed is 40 km/h, the volume of the window at the curve is reduced from approximately 900 m^3 to 800 m^3 for 0–2.5 sec; when the driving speed is 120 km/h, the volume of the window at the curve is reduced from approximately 1000 m^3 to 600 m^3. Varying driving speeds and radii of the circular curve have a distinct effect on the visibility window, where the faster the driving speeds (within the reading time), the greater the slope of the change of the volume of the visibility window at the curve. This indicates that a faster travel speed has a greater effect on the volume of the visibility window that varies with the travel time. The change is relatively slow with the travel time at low speeds.

4.2.2. The Principle of the Visibility Window of a Traffic Sign at an Inner Curve. As shown in Figure 7, the traffic sign was located at the inner curve of the road. While the vehicle is approaching, the "clear width" range of the inner curve formed by the projection of the visibility window onto the ground gradually becomes smaller. When viewing from point A, the obstructed object does not appear in the visibility window; when moved to the starting point B, the obstruction appears in the visibility window of the traffic sign. When the point C is reached, the obstruction is outside the visibility window again. The instantaneous occlusion affects the driver's ability to recognize and respond to the information conveyed by traffic signs.

The visibility window at inner curves is often occluded by roadside plants, slopes, soundproof walls, monitoring

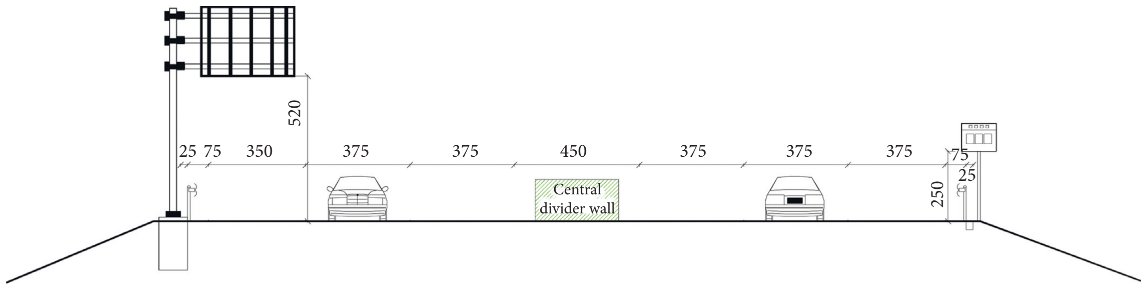

FIGURE 5: The cross-section of the Hunan section of the Beijing-Hong Kong-Macau Expressway (for details, refer to the text).

TABLE 2: General values of minimum radius [31].

Design speed (km/h)	120	100	80	60	40
General values of minimum radius Rr (m)	1000	700	400	200	100

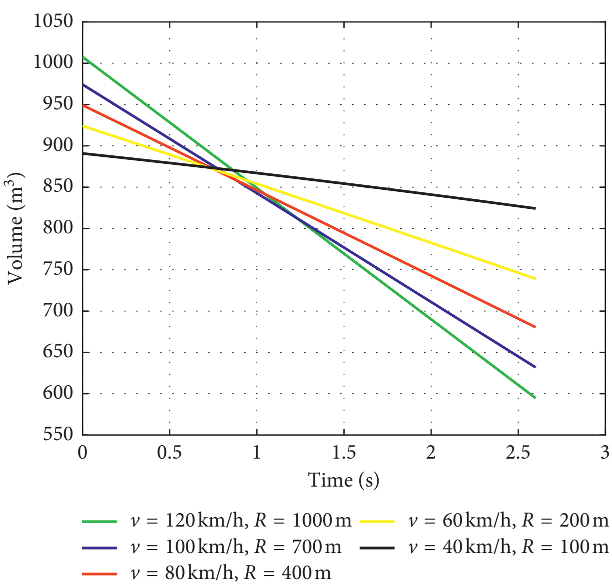

FIGURE 6: The volume of visibility window as function of speed on the inner curved highway (for details, refer to the text).

facilities, vehicles in the right lane, and parked vehicles on the emergency lane.

4.2.3. The Principle of the Visibility Window of a Traffic Sign at an Outer Curve. Figure 9 depicts an example of a traffic sign located at the outer curve of the expressway. While the vehicle is approaching, the range of the left clearance distance of the outer curve, formed by the projection of the visibility window onto the ground, gradually becomes smaller. As for the central divider, at viewing point A, the central divider appears in the visibility window and disappears on approaching point C. Since the purpose of the central divider is to be antiglare, we should take into account of its potential of being an obstruction to the traffic sign.

It can be seen from Figure 9 that the visibility window of the traffic sign at the outer curve can be occluded primarily by the middle band, the overpass bridge, the gantry sign, and other elements.

4.3. Solutions for Deocclusion of the Traffic Sign on Curved Roads. Utilizing the results from the current study, the following measures are suggested to be taken to prevent the visibility window of the traffic sign from being occluded during the construction and the placement of highway traffic sign.

4.3.1. The Clearance Control Standard for Traffic Signs on a Curved Highway. We herein established the clearance control standard for traffic signs on a curved highway based on the volume of the visibility window and boundary characteristics. The clearance control of the traffic signs on a curved highway consists of two parts: clearance height control and clear width control. The clearance control projects the volume onto the ground and facade; the facade is clear height control, and the ground is clear width control. According to the equation of the volume of visibility window, the clear width control is the distance from the start of point B to the line of the traffic sign being projected on the ground of the curved highway. The clear height control is the distance between the line connecting the point B and the traffic sign at the ground level, as shown in Figure 10.

Using the case from Section 3.2, the clearance control range is calculated at approximately 100 m and the clear height is controlled at a range of 1.2 m to 5.2 m. The outer curved clear width is controlled at a distance of approximately 5 m away from the road, and the inner curved clear width is controlled to be about 3 m in the central divider.

Tall vegetation should not be placed within the range of the clearance control, and the growth process of the vegetation should be monitored in order to avoid subsequent occlusions by plants. Vegetation that has been formed within the range of clearance control should be regularly trimmed to reduce or eliminate occlusion [26, 27]; as for the occlusion formed by the uncontrollable vegetation within the clearance control range, it is recommended to acquire more buffering space (land) to reduce the occlusion of signs by plants or other elements. When setting the traffic sign, it is not recommended that the sign is set on the top of a slope. Considerations should also be given to coordinating sign placement with other built structures, such as overpass bridges, monitoring and lighting facilities, soundproof walls, and emergency parking belts. For example, a traffic sign should not be set behind the flyover bridge and the monitoring facilities should be at a certain distance from the traffic sign. By taking these appropriate measures, the stated

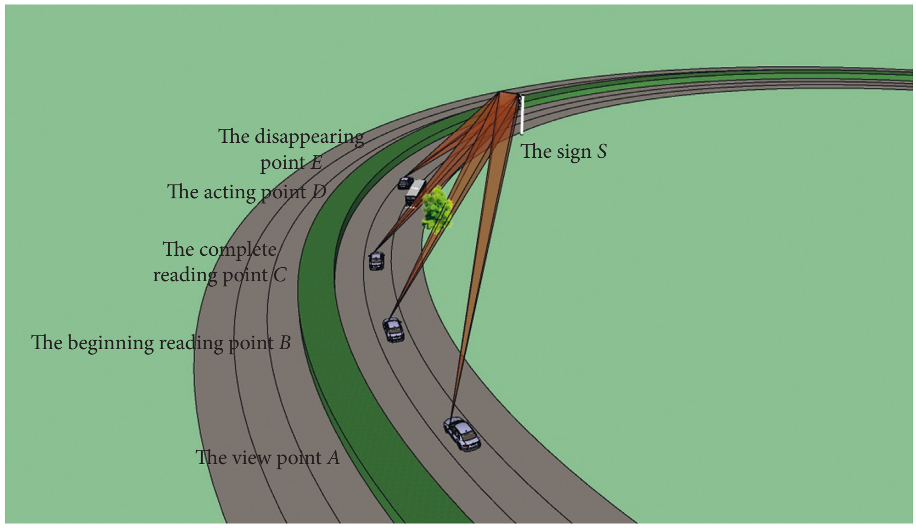

Figure 7: Simulation diagram of the affected visibility window at the inner curve. (for details, refer to the text).

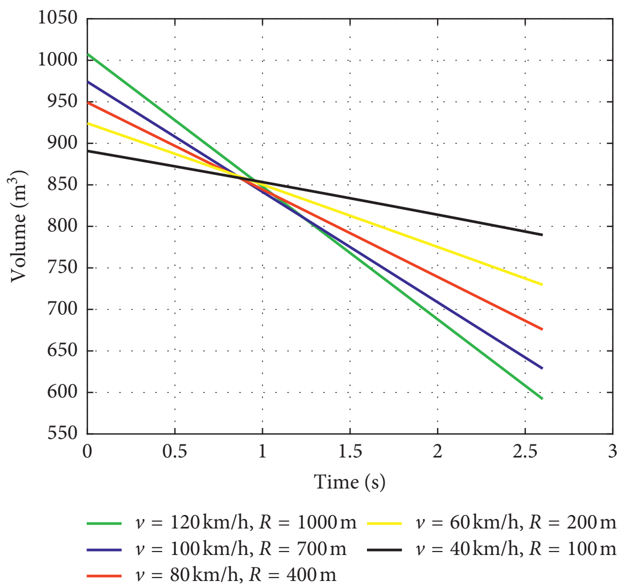

Figure 8: The volume of visibility window as function of speed on the outer curved highway (for details, refer to the text).

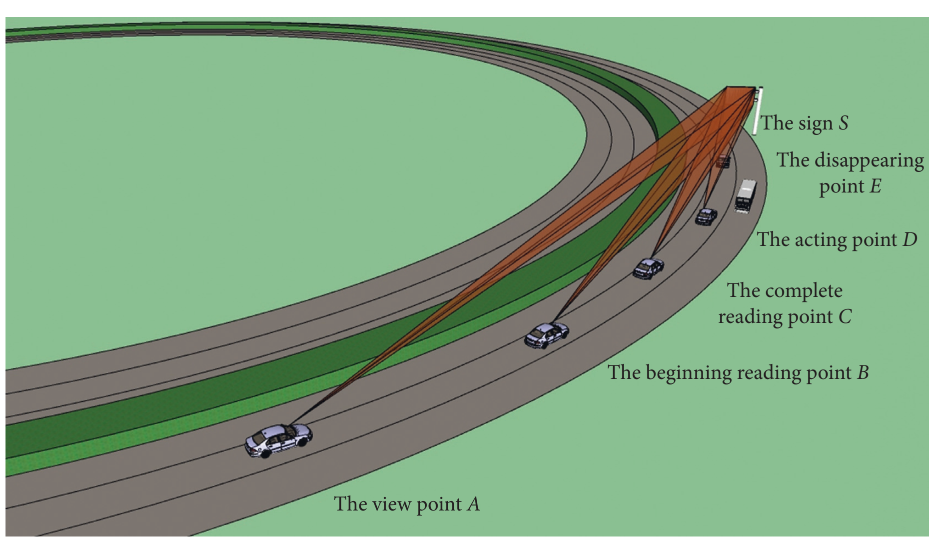

Figure 9: Simulation diagram of the affected visibility window at the outer curve (for details, refer to the text).

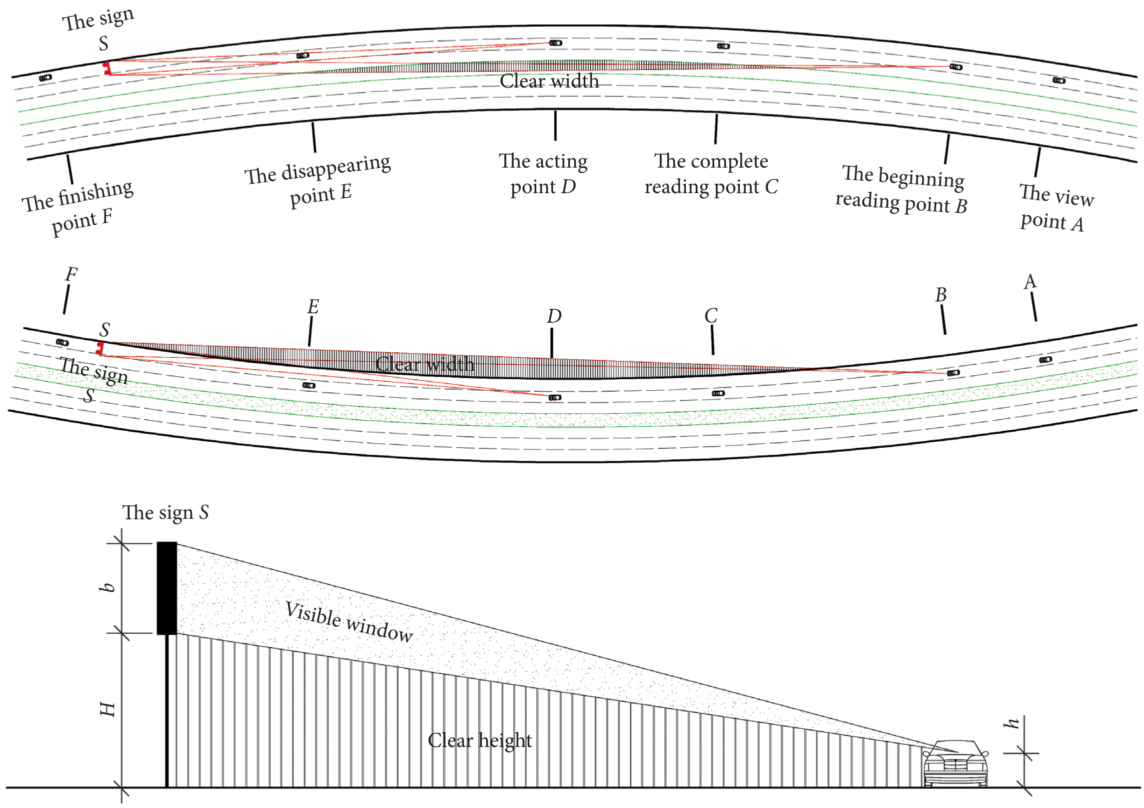

Figure 10: Schematic diagram of sign clearance control.

occlusion elements can be eliminated from the visibility window of the traffic sign.

4.3.2. A Moving Occlusion Appearing in the Visibility Window of a Traffic Sign. When considering the obstruction of the visibility window due to a same-direction driving vehicle, a solution is to set repeating traffic signs without an overload of information. This measure reduces the probability of moving occlusion and subsequently improves the functionality of the sign [22]. Additionally, the driving distance in the time period of sign recognition is increased through considering the safety following distance in this study. The probability of a moving occlusion can be reduced by controlling the safety following distance of the vehicle. Secondly, the sign reading is now integrated into intelligent assisted driving systems, which also reduce the probability of moving occlusions.

4.3.3. Special Conditions. In some areas, traffic sign occlusion may be unavoidable due to topography and geomorphology. In some circumstances traffic sign occlusion can be reduced by setting the sign on the slope, that is, on the opposite side of the middle band or using visual enhancements in the design to clearly draw driver's attention to the sign and clearly guide oncoming traffic. For example, intelligent assisted driving and navigation systems and advanced technology, such as perspective laser scanning. Driver can obtain sign information from the vehicle intelligent system in addition to the visual information, which would improve the effectiveness of sign recognition.

5. Conclusions

In this work, we studied the visual occlusion of traffic signs based on the visual recognition process of a driver. We developed a visual occlusion design formula and verified the design formula in a case study of the Hunan section of the Beijing-Hong Kong-Macao Expressway. The dynamic equation of the visibility window of the traffic sign studied in this work provides research support for appropriate criteria and enhancements in areas such as in setting of traffic signs on curved highways, "sign clearance" control, and intelligent assisted driving systems. Our findings offer a reference for effectively removing obstructions from the visibility window of the traffic sign on curved highway in the hilly area, which was the primary focus of this study. However, the vertical curve elements of the highway, such as the variants of driver viewpoint heights, have not been included in the study at this time. The "sign clearance" control of various sign types and positioning has not yet been systematically studied, but "sign clearance" control values for a cantilevered sign was obtained. Further in-depth studies are ongoing, such as introducing a boarder range of speeds.

Data Availability

No data were used to support the findings of this study. However, details of modeling and calculation, such as original/raw data, or experiment notes, might be available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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