Method for detecting recognition efficiency of guide signs at signalized intersection under haze condition

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Abstract: It is necessary to evaluate the recognition efficiency of traffic signs at intersections under different fog intensities, provides a reference for the addition of traffic signs to the domestic fog and haze weather, and to ensure the safety of drivers and maintain the smooth flow of traffic. In this paper, first, the driver's recognition model of urban road intersection signs is established through his psychological reaction on the road under the normal weather condition, and calculated the recognition time under different speed through the recognition model. Second, using this data can fit the relationship between visibility of fog and haze and recognition time, and we can get the relation equation. Finally, the driver was tested by wearing an Eye Movement Apparatus on the head under the condition of normal weather and different haze levels, then the driving trajectory was recorded. Through the analysis, the driver’s blink time, glance time and visual time of the intersection signs were marked, the driver's recognition time was finally obtained. Through the analysis of the recognition time of the 12 signs, it was verified that the models for fog and recognition time were reasonable and accurate.

1. Introduction
At present, most of China is suffering from haze weather. According to the statistics of the traffic management department, the number of traffic accidents under the haze weather is three times more than usual, and the mortality rate increased by 33%, which brings great harm to traffic safety. The natural scene and traffic environment at the intersection are complex. Research of the recognition efficiency of guide signs at intersection is the basic field in intelligent transportation. It is of great significance to this research under the haze weather condition to effectively ensure driving safety and avoid traffic accidents.

2. Visual characteristics of drivers
2.1 Process of driver's visual searching
According to the research, driver perceived traffic guide by the human sense during driving, visual accounted for 80%, hearing accounted for 14%, while others only 6%[1-2]. Therefore, visual system is the most important channel for obtaining outside guide for the driver. Besides, the driver’s visual search process is that driver passes the glance from one gaze point to next point, and then continue to searches for the target within visual field until the useful guide is searched for the next gaze, and moves in circles. Therefore, through the experimental analysis of the driver's eye movement, the process of driver searches and deals with the visual scene can be better understood.
2.2 Visual characteristics of drivers
The driver’s visual judgment is related to the speed of the vehicle while driving, visual field will be narrow as it looks far away when vehicle at high speed. According to experimental research, when the speed is 40km/h, the field is about 100°, when it is 60km/h, the field is less than 75°, and the corresponding field at 100km/h is surprisingly under 40°[3].

Visual is divided into three types: static vision, dynamic vision, and night vision. The object studied in this paper is dynamic vision. As the speed of the vehicle changes, with the speed increases, the dynamic vision decreases[4]. For example, when the vehicle is traveling at a speed of 60 km/h, the driver can see the traffic sign clearly at 240 m from the vehicle. But when the speed is 80 km/h, the traffic sign from the vehicle 160m is not clear.

3. Research on detection method of recognition efficiency

3.1 The calculation model of recognition efficiency
There is a certain time interval between the driver's response to the guide signs and the arrival of the destination. Therefore, a prepositive distance must be set in front of the signs at intersection to remind the driver to take measures. The process of driver recognizing guide signs and then making reactions is shown in Figure 1.

![Diagram](image)

Figure 1. The picture of drivers’ recognition process of the road guide signs.

In the figure 1, b represents recognition distance; c represents distance of sign vanish; d represents prepositive distance of signs; J represents judgment distance; K represents reaction distance; e represents distance from end point of reading to the sign point; s represents visual recognition distance; L represents the action distance.

The traffic signs must be set up to meet two conditions as the following:

First, point C must appear before point D, that is, the sign reading completion point appears before the disappearing point, so that the driver has enough time to find and read the guide signs.

Second, the EG should satisfy driver's completion of the deceleration and lane change operations, that is, the relevant location of the sign appears after the driver's operation is completed, so that the driver has sufficient time to make decisions and complete the driving operation. The formula is as following:

\[
L \geq (n - 1) L' + L_i
\]  \hspace{1cm} (1)

In the formula, L' is the distance required for the driver to change one lane, and Li is the distance traveled during the vehicle deceleration. From the Figure 1 can get:

\[
S + d = L + K + J + b
\]  \hspace{1cm} (2)

When the point of sign vanishing coincides with the judging completion point, the prepositive distance d of the sign must meet the standard, and then:

\[
d \geq L + K - C
\]  \hspace{1cm} (3)
- Calculation process of visual distance

The visual recognition distance \( s \) can be directly calculated by the relationship between the speed and visual recognition distance. The reading distance \( b \), judgment distance \( J \), reaction distance \( K \), single lane change distance \( L' \) and the deceleration distance \( L_i \) are calculated as following formulas:

\[
b = \frac{v}{3.6} t_b, \quad J = \frac{v}{3.6} t_j, \quad k = \frac{v}{3.6} t_k, \quad L' = \frac{v}{3.6} t_l, \quad L_i = \frac{v^2 - v_0^2}{2 \times 3.6^2 i}
\]  \( \text{(4)} \)

In the formulas, \( v \) is the speed that the driver is driving while starting to read the guide signs, \( v_0 \) is the speed after deceleration and completion of the lane change, and is generally 0.8 times the speed before deceleration; \( T_b \) is the recognition time; \( t_j \) is the driver's judgment and decision time, and generally value at 2.0s-2.5s, taking 2.0s in this paper; \( T_k \) is the driver's reaction time, generally 1.5s-2.0s, taking 1.5s; \( t_l \) is the single lane change time, generally 6.0s-6.9s, taking 6.0s; \( i \) is the deceleration of the vehicle[5].

The research study shows that when the driving speed is 20km/h, the driver's visual distance to the guide sign is 134m; when speed is 40km/h, the distance is 109m and the corresponding distance at 60km/h is 92m [6]. The relationship between visual distance and speed is shown in Figure.2.

![Figure 2](image.jpg)

Figure 2. The relation of visual distance to speed.

The relationship between visual distance and speed in Figure as following:

\[
y = -1.05x + 153.67
\]  \( \text{(5)} \)

In the formula, \( x \) is the speed, \( y \) is visual distance.

- Calculation process of disappearance distance \( c \)

According to the dynamic characteristics of the driver's vision, the driver can only recognize the traffic information within vision, which is called the perceived search range of the driver's sight. When the horizontal angle \( \alpha \) between the driver's sight and the set point of guide sign is sufficiently large to exceed the driver's viewing angle threshold, the driver will not be able to see the sign. Similarly, when the vertical angle \( \beta \) with the sign is sufficiently large to exceed the driver's viewing angle threshold, the sign will also disappear, so the disappearance distance \( c \) is divided into two situations as horizontal and vertical, and the horizontal disappearance distance is determined as shown in the Figure.3, and take the maximum value. Let \( W \) be the distance from the center line of the lane where the vehicle is located, and the horizontal angle is \( \alpha \). The vertical disappearance distance is determined as shown in Figure.4. Let \( H \) be the height of the upper edge of the signboard from the ground, and \( h \) be the height of the driver's horizontal sight.
According to Figure 3 and Figure 4, the horizontal vanishing distance $m_1$ and the vertical vanishing distance $m_2$ can be calculated, and finally the larger values are selected as the vanishing distance. Formulas (6) can all be obtained as following:

$$m_1 = \frac{w}{\tan \alpha}, \quad m_2 = \frac{H - h}{\tan \beta}, \quad m = \max(m_1, m_2)$$

(6)

### 3.2 Calculation process of recognition under the normal condition

The research objects selected urban road intersections with 4 - 6 lanes in both directions in this article. The width of a single lane is 3.5m, and the speed at which drivers recognize signs is 30km/h, 40km/h and 50km/h. The road signs are installed in a cantilever manner on the side of the road, and the signal lights at the intersections are red lights. The driver performs two lane changes. Since the leading lanes at the entrance to the urban road intersection are usually not less than 30m, the prepositive distance value calculated according to the formula needs to be added with this distance to get the accurate prepositive distance of the traffic sign.

- **vision time**

  When the vehicle traveling speed $v$ is 30km/h, 40km/h and 50km/h, respectively, it is calculated according to formula (5).

- **disappearance distance**

  According to the height relationship between the speed and the text, the height of the character is 0.35m-0.5m, the width of the signboard is $12h$, and the height is $6.5h$. Calculated by a larger value, the calculated signboard width is 6 meters. The height is 3.25 meters.

  $H = 3.25 + 2.5 = 5.75$

  $h = 1.2m$

  $m_1 = \frac{w}{\tan \alpha} = (3.5 + 3.5 + 1.75) / \tan 15 = 33m$

  $m_2 = \frac{H - h}{\tan \beta} = (5.75 - 1.2) / \tan 7 = 37m$

  $m = \max(m_1, m_2) = 37m$

- **The prepositive distance**

  It is obtained by the formulas (4), (5): when the vehicle is driving at different speeds, the judgement distance $J$, the reaction distance $K$, the distance traveled by the lane change $L'$, the deceleration distance $L_i$, and the action distance $L$ are as shown in Table 1.

| Speed (km/h) | 30  | 40  | 50  |
|--------------|-----|-----|-----|
| the judgement distance $J$ | 16.7 | 22  | 27.8|
| the reaction distance $K$   | 12.5 | 16.7| 21  |
the distance traveled by the lane change $L'$

| $L'$ | 50 | 66 | 83 |
|-----|----|----|----|
| the deceleration distance $L_i$ | 12.5 | 22 | 35 |
| the action distance $L$ | 112 | 154 | 201 |

According to formula (3), when the driving speed is 30km/h, 40km/h, 50km/h, the prepositive distances of the guide signs are 87m, 133m, 185m, respectively, due to the entrance of the city road intersection. The guiding lane of not less than 30m is usually set before, so the accurate prepositive distance of the guide signs must be added by 30m.

The value and distance of the driver's visual distance to the intersection signs are shown in Table 2.

| Table 2. The relation of visual distance and prepositive distance to speed under normal condition. |
| Speed v/km/h | Visual distance s/m | Prepositive distance /m |
|---------------|---------------------|------------------------|
| 30            | 122                 | 117                    |
| 40            | 111                 | 163                    |
| 50            | 101                 | 215                    |

- **The recognition time**

The recognition time calculated by the formulas (2) and (4) is shown in Table 3. The relationship between the recognition time and the speed is shown in Figure 5.

| Table 3. The relation of recognition time to speed. |
| Speed (km/h) | V=30 | V=40 | V=50 |
|---------------|------|------|------|
| Recognition time (s) | 11   | 7.32 | 4.77 |

3.3 Calculation process of recognition under the haze condition

- **The haze grade**

The haze grade can be divided into three levels: mild, moderate, and severe. The visibility of mild smog is 2000-3000m, the visibility of moderate smog is 1000-2000m, and the visibility of severe smog is <1000m. For the convenience of calculation, the intermediate value is taken in the calculation, and the value is shown in Table 4 as following.

| Table 4. Haze rating. |
|-----------------------|
| Haze grade | normal | mild | moderate | severe |
| Value (m)  | 3500   | 2500 | 1500      | 500    |

- **The visual distance under the different haze grade**

From the Table 4, the visibility under normal haze rating is 3500 m, and the visual distance is $s_i=122$ m. If the visibility is 2500m under mild haze, the visual distance decreases as the visibility decreases. If the visual distance is proportional to the smog visibility, there is a formula:

$$\frac{N_n}{S_n} = \frac{N(n+I)}{S(n+I)}$$

(7)

In the formula, $N$ means visibility, $S$ means the visual distance, $n$ means the haze grade.
When the driving speed of the vehicles is 30km/h, 40km/h, and 50km/h, respectively, the formulas of (7) can be calculated separately. At the same driving speed, the viewing distances under different smog levels are as shown in Table 5.

Table 5. The visual distance under the different speed and haze rating.

| Haze grade | Speed (km/h) | normal | mild | moderate | severe |
|------------|--------------|--------|------|----------|--------|
| 30         | 122          | 87     | 52   | 18       |
| 40         | 111          | 79     | 48   | 16       |
| 50         | 101          | 72     | 43   | 14       |

- The recognition time under the different haze grade

When \( v = 30 \text{km/h} \), the visual distance under normal conditions is \( s_1 = 122 \text{m} \), the recognition time \( t_1 = 11 \text{s} \), and the visual distance under mild haze conditions is \( s_2 = 87 \text{m} \). Set the recognition time under mild haze to \( t_2 \). In order to drive safety, the driver must recognize the information of the guide signs within a certain period of time. If the recognition time is proportional to the visual distance, there is a formula:

\[
\frac{S_n}{t_n} = \frac{S(n+1)}{t(n+1)}
\]  

In the formula, \( S \) means the visual distance, \( t \) means recognition time, \( n \) means the haze grade.

When the driving speed of the vehicles is 30km/h, 40km/h, and 50km/h respectively, the formulas of (8) are calculated separately. At the same driving speed, the recognition time under different smog levels are as follows. Table 6 shows.

Table 6. The recognition time under the different speed and haze rating(s).

| Haze grade | Speed (km/h) | normal | mild | moderate | severe |
|------------|--------------|--------|------|----------|--------|
| 30         | 11           | 8.37   | 5.00 | 1.73     |
| 40         | 7.32         | 5.21   | 3.17 | 1.06     |
| 50         | 4.77         | 3.40   | 2.03 | 0.66     |

- The relationship between the recognition time and the visibility of the haze level

According to the relationship between the visual time and the visibility of the haze level, and the relationship between the visual time and the recognition time, the relationship between the recognition time and the visibility can be calculated is shown in Figure 6.

Figure 6. The relation of recognition time and haze rating under the different speed.

Based on the psychological reaction process of the driver while driving, a set of detection efficiency detection method for the intersection signs is obtained under the haze condition. When the driving speed of the driver is 30km/h, 40km/h, 50km/h, the detection method of the guide signs is as shown in formulas (9) respectively:
In the formula, $x$ means the visibility of the haze level, $y$ means the recognition time of guide signs. The detection method is based on theoretical calculations, whether it is accurate or not needs to verify. The verification value is verified when the identification of the guide signs is recognized.

4. Verification of recognition time by using the Eye Movement Apparatus

4.1 Data analysis

The experiment arranged for the driver to wear the Eye Movement Apparatus and to recognize the twelve signs of intersection, they passed along the way under normal conditions and different haze conditions, the driving speed is 30km/h, 40km/h, 50km/h. Finally, the driver's glance time, blink time and visual time of these signs can be gathered. By studying the sum of the driver's glance time, blink time and visual time, that is the recognition time, it is verified whether the driver's recognition time of the guide signs at intersection meets the detection method of signs in Chapter 2. The experiment starting point and the end point of the experiment are the Xinmofan road subway station and the Nanjing Train Station subway station. The route follows the XinmoFan road - Nanru Road - Heilongjiang Road - Fujian Road - Bridge South Road - Jianning Road. The driver's blink time, glance time, and visual time are obtained as shown in Figure 7.

Through the analysis, the average recognition time of the guide signs when drivers are driving the intersection is obtained, and then the average error is obtained according to the average error formula. Finally, the value range of recognition time is as shown in Table 7. (The average error formula is: $z=\frac{1}{n}\sum_{i=1}^{n}|\bar{t}-t|$. $\bar{t}$ represents the average recognition time, $t$ represents the recognition time, and $n$ represents the number of the signs.)

Table 7. Average recognition time, average error, and acceptable recognition time range under the different speed.

| Speed and Time | Haze grade | normal | mild | moderate |
|---------------|-----------|--------|------|----------|
| 30km/h        | Average recognition time $\bar{t}$ (s) | 10.580 | 7.704 | 5.307    |
|               | Average error $z$ (s)                   | 0.584  | 0.785 | 0.440    |
|               | Acceptable recognition time range (s)   | [9.996,11.164] | [6.919,8.489] | [4.867,5.747] |
| 40km/h        | Average recognition time $\bar{t}$ (s) | 7.280  | 5.222 | 3.768    |
|               | Average error $z$ (s)                   | 0.530  | 0.571 | 0.619    |
|               | Acceptable recognition time range (s)   | [6.750,7.810] | [4.651,5.793] | [3.151,4.385] |
| 50km/h        | Average recognition time $\bar{t}$ (s) | 4.402  | 3.740 | 2.255    |
### 4.2 Verify data and analyse

From Table 7, it can be concluded that the time range of drivers can recognize the guide signs at the intersection under the different conditions. Comparing the available recognition time value with the theoretical value calculated before under the same conditions, it can be found that the theoretical calculation value is within the available range value. Therefore, the detection method for the recognition efficiency of the intersection guide signs under different haze conditions is shown in Table 8.

| Average error z (s) | 0.665 | 0.48 | 0.404 |
|---------------------|-------|------|-------|
| Acceptable recognition time range (s) | [3.737, 5.067] | [3.260, 4.220] | [1.851, 2.659] |

#### Table 8. The detection model of guide signs.

| Speed (km/h) | 30  | 40  | 50  |
|--------------|-----|-----|-----|
| Detection model | $y = 0.0031x + 0.15a$ | $y = 0.0027x + 0.05$ | $y = 0.0012x + 0.434$ |

*a y represents recognition time. x represents the visibility of the haze level.*

## 5. Conclusion

Today, with the rapid development of urbanization, the haze weather is getting more and more serious, and the visibility of the atmosphere is reduced, which causes the driver's sight to be enslaved, and seriously affects driving safety. This paper studies the behavioral characteristics of the driver while driving, and established the recognition model of the intersection guide signs. Through research, the following conclusions are drawn:

- The higher the level of smog, the shorter the visual distance, and the shorter the recognition time of the driver's guide signs;
- Under the conditions of different speeds and different smog levels, the relationship between the smog visibility value and the driver's recognition time of the guide signs is obtained through experimental analysis.

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