Accident Analysis and Prevention 129 (2019) 7–20

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

An approach for evaluating the effectiveness of traffic guide signs at intersections

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ARTICLE INFO

Keywords:
Traffic guide signs
Evaluation method
Information demand
Comprehension
Driving simulator
Grey relational analysis

ABSTRACT

Traffic guide signs play important roles in people's daily lives. However, the effectiveness and performance of traffic guide signs at intersections are significantly impacted by many factors, such as the types of information on traffic signs, their information volume and comprehensibility, the behavioral attributes of drivers, the geometric features of roadways, and weather and visibility conditions. When deploying traffic guide signs, efforts are needed to clarify whether the installation of a traffic guide sign is warranted. In this study, a generic approach is developed to examine and evaluate the effectiveness of traffic guide signs using simulation experiments. A traffic guide sign evaluation method (TGSEM) is developed and illustrated using examples of traffic guide sign schemes in suburban Beijing. The questionnaires showed that most drivers feel that the current traffic guide signs in suburban Beijing are insufficient and need to be rectified. Then, simulation experiments were conducted. Based on subjective experiments, the ergonomic evaluation model (DCI, the abbreviation of demand, comprehension, and information volume) was obtained. Of the four schemes, scheme 3 was shown to be the most popular. During driving simulation experiments, the analyses of average speed, standard deviation (SD) of speed, average acceleration, standard deviation of acceleration, travel time, braking frequency and throttle power showed that scheme 2 had a better impact on drivers' behavioral data. Finally, Grey relational analysis showed that scheme 2 has the highest degree of correlation and can be recommended to traffic management departments. The experimental tests and analysis results revealed that the TGSEM is suitable. The proposed approach provides a generic framework with which to assess the performance of traffic guide signs and their effectiveness at intersections, including their experimental design, data analysis, the implementation of simulation models, and data interpretation.

1. Introduction

Traffic guide signs are of practical importance and have the following effects: they fulfill needs, convey clear messages, and provide adequate time for road users to respond (Pline, 1992). The selection of reasonable information is crucial to improving the efficiency of drivers' trips. Furthermore, a reasonable layout design also plays a key role.

There is a problem in Beijing, China, which is that the rules of downtown and suburban traffic guide signs are inconsistent. A schematic diagram of a downtown guide sign is shown in Fig. 1 a). Downtown guide signs contain only information about selected roads, including those that are directly ahead (A Street), intersect the current street (C Street) and are further ahead (D, F and G Streets). However, suburban guide signs that should contain a large scope of information show selected district information and do not show select road information. Remote information usually refers to the adjacent district, which is approximately 10 km from the guide sign's location. Proximal information usually refers to the next village along the route, which is approximately 1 km from the guide sign's location. Suburban guide signs include information about proximal (L, H and J Districts) and remote districts (M, I and K Districts). The standard Road traffic signs and markings (GB 5768– 2009) stipulates that the layout of districts follows the principle of "the district on the right is further than that on the left, and that on the bottom is further than on the top". For example, M district is further than L district, and I district is further than H district, as is shown in Fig. 1 b).

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https://doi.org/10.1016/j.aap.2019.05.003
Received 1 December 2018; Received in revised form 26 April 2019; Accepted 3 May 2019
Available online 14 May 2019
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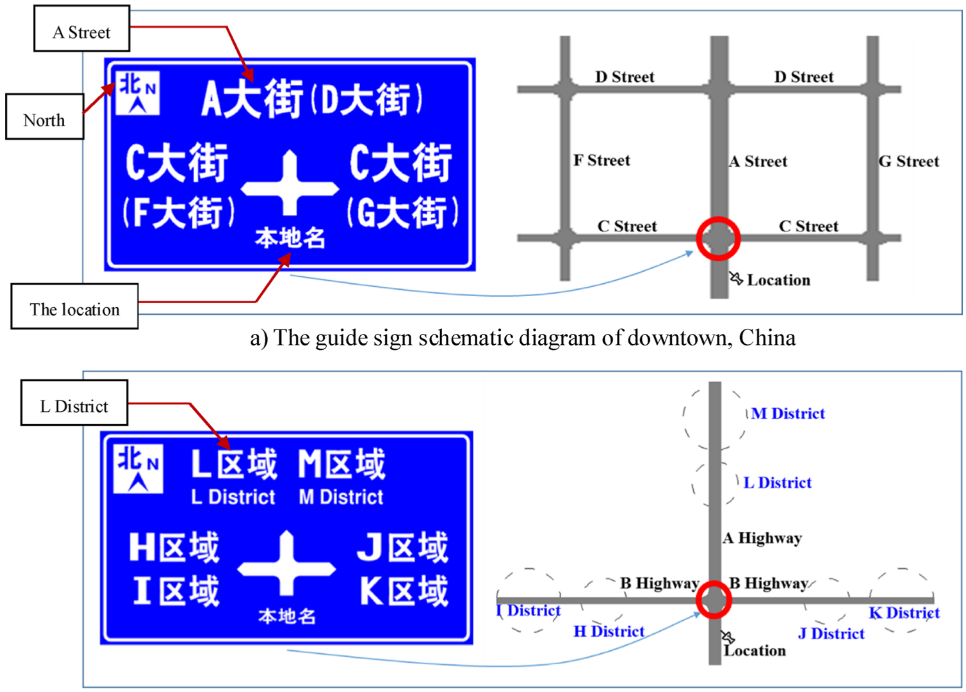


a) The guide sign schematic diagram of downtown, China

b) The guide sign schematic diagram of suburban, China

Fig. 1. The guide sign schematic diagram.

In fact, there are different criteria for the setting of guide sign facilities domestically and abroad. Chinese traffic signs use the standard Road traffic signs and markings (GB 5768– 2009). The design principles of downtown and suburban guide signs all conform to this criterion and are reasonable in their application scope. The Code for layout of urban road traffic signs and markings (GB 51038–2015) introduces the rules of information selection for downtown traffic signs, including urban expressways, trunk roads and branch roads. For example, Section 8.1.5 specifies the following: *The downtown traffic signs should select road information as far as possible and ensure that information is continuous*. There are also some local specifications. The Beijing highway traffic sign system setting guidebook compiled by the Beijing Municipal Highway Administration specified the classification, grading and selection of highway guide sign information in Beijing. In America, the setting of traffic signs uses the Manual on uniform traffic control devices (MUTCD). The manual provides a detailed description of technical standards. For example, Section 2A.16 specifies the following: *Information of a less critical nature should be moved to less critical locations or omitted.* Because of cultural and geographical differences, the problem mentioned in China may not appear in the US. In addition, under particular circumstances, certain rules in the MUTCD are not feasible in China. For example, at intersections, there are differences between China and America in terms of traffic guide signs. The differences are mainly included the style, layout, color and character of the guiding signs. In research, scholars have conducted many studies on three aspects: visual cognition, comprehension and behavior. Therefore, the effectiveness of traffic signs can be evaluated in terms of these three aspects. These research findings also support the establishment and application of criteria.

Some researchers have studied drivers' visual cognition. Juan (2005) in Shanghai Jiaotong University focused on the driver understanding of traffic signs based on cognitive psychology, and two factors influencing the recognition of traffic signs were summarized as follows: driver factors and traffic signs' physical performance. Du (2008) in Wuhan University of Technology used an EMR-HM8 eye tracker system to study the relationship between information quantity and the visual cognition of traffic guide signs. Darja et al. (2016) used eye-tracking technology to study and detect driver responses to roadside traffic signs and advertisements. Some researchers studied drivers' comprehension of sign information. An assessment of drivers' comprehension was conducted by Hashim and Janahi (2002) based on drivers' personal and social characteristics. The results indicated that drivers' personal characteristics are primarily associated with their understanding capabilities. To study drivers' understanding of overhead freeway exit guide signs, Arup et al. (2014) proposed and evaluated alternative ways of signing exits on an advanced fixed-base driving simulator. Tamar and Shinar (2015) tested the effects of presentation conditions on road sign comprehension times for young and older drivers. Neill et al. (2016) believed that the effectiveness of a traffic sign is collectively influenced by the sign's understandability, legibility distance, glance legibility, and learnability; however, understandability has been repeatedly identified as one of the most important effectiveness measures. Apart from cognition and comprehension aspects, drivers are more influenced by traffic signs from the behavioral aspect. Some researchers have studied the impact on drivers' behavior from traffic signs. To measure the effectiveness of traffic guide sign layouts, Liu and Zhang (2015) established an ergonomics evaluation model based on drivers' behavior. Ding et al. (2015) tested the effectiveness and adaptability of speed reduction markings (SRMs) in downhill sections of urban roads with distinct roadway grades. Empirical data, including vehicle speed and acceleration, were collected in a driving simulator. Zhao et al. (2015) revealed the safety impacts of inside shoulders on urban expressways using driving simulator experiments. The empirical data, including subjects' eye movement data and heart rate (HR) and the lateral position of vehicles, were collected in a driving simulator. The safety impacts of the inside shoulder were evaluated. Huang (2017) used a driving simulator to study drivers' behavior in response to different diagrammatic guide signs and found the optimal settings using this method. Mansoureh et al. (2017) studied the integration of a driving simulator and a traffic simulator and explored drivers' behavior in response to variable message signs.

These findings and results provided important information for the

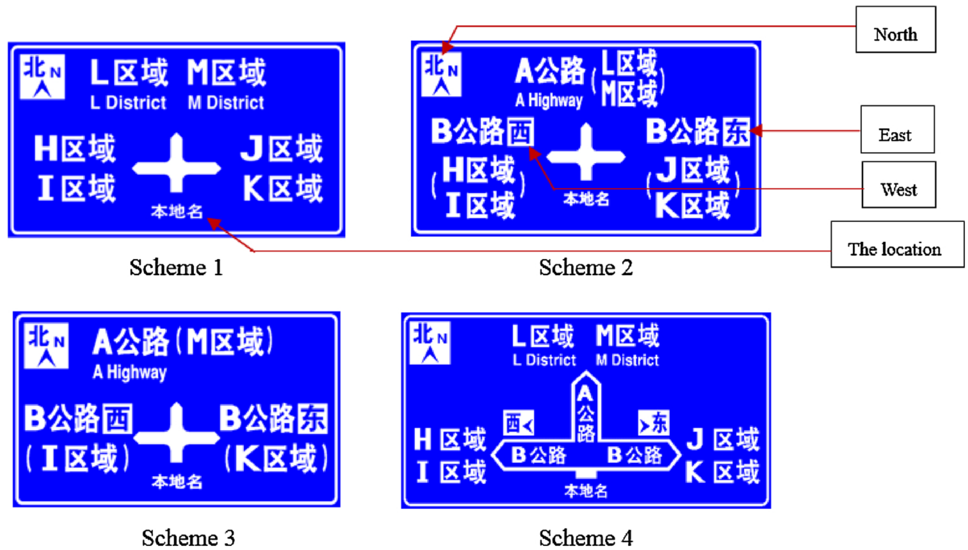


Fig. 2. Four guide sign schemes.

specification of future sign design guidelines and for the improvement of road safety. The above literature indicates that these aspects demonstrate that the evaluation of sign effectiveness and reasonable design is important. Traffic signs affect the visual cognition and behavior of drivers. The research methods used in the literature mainly include a questionnaire, desktop experiment, driving simulation experiment and field test. To fully assess their roles, the demands of drivers' visual cognition, comprehension and behavior should be satisfied.

At present, traffic guide signs between downtown and suburban areas of Beijing are inconsistent. To better satisfy drivers' cognition and the transition between downtown and suburban areas, this paper proposed a general method to help optimize the layout of traffic signs. In this paper, four guide sign schemes were proposed and are shown in Fig. 2, which are all in accordance with national criteria. Scheme 1 (i.e., the current status of suburban areas) does not select road information. Scheme 2 selects proximal district information and road information. Scheme 3 does not select proximal district information. Scheme 4 has a different guiding arrow and is more common in southern China. All four schemes select remote district information. The goal of this paper is to choose the most suitable of these four schemes. The transition between downtown and suburban traffic signs is a common problem faced by developing countries during urban expansion. Therefore, the problem of traffic sign comparison is generality. To solve this problem, this paper proposes the following method to evaluate the effectiveness of traffic signs from the aspects of drivers' cognition, understanding and behavior. Through desktop experiments, the demand and understanding of traffic guide information can be obtained. Using a driving simulator, behavioral data can be obtained. Specifically, a traffic guide sign evaluation method (TGSEM) is formulated. Then, using the four schemes in Beijing as cases, the method is introduced and demonstrated.

2. Evaluation method

Here, the TGSEM is developed to assess the effectiveness of traffic guide signs and further select the most appropriate guide sign schemes. Fig. 3 illustrates the flow of the proposed TGSEM, which can statistically examine the safety performance of traffic guide signs. The major steps involved in the TGSEM are expressed as follows.

2.1. Step 1: information demand experiment

To evaluate the effectiveness of guide sign schemes in terms of ergonomics, two subjective experiments were carried out.

Satisfying the information demand of road users is the fundamental principle of traffic sign design. If the information required by drivers is displayed on the traffic sign, this means the sign has great ergonomics. To determine which traffic information is more important for road users while driving, an information demand experiment was designed in this paper. In the experiment, the demand degree (D) will be obtained.

2.2. Step 2: sign understanding experiment

Whether traffic sign information is easy to understand determines the difficulty that drivers have in processing information. If the sign information is easy to understand correctly, this means that the sign has great ergonomics. To study the understanding degree of sign information, a sign understanding experiment was designed in the paper. In this experiment, the understanding degree (C) was obtained. Then, these two indexes were used to build the DCI ergonomic model.

2.3. Step 3: DCI ergonomic model

Based on the above experiments, this paper used the information demand degree and sign understanding degree as evaluation indexes. Then, the ergonomic evaluation model (DCI, the abbreviation of demand, comprehension, and information volume) of the traffic guide signs was established. The steps of the model are as follows. First, a basic model can be obtained. Then, some coefficients are corrected. Finally, the final model is established.

2.3.1. S1, basic model

$$D_k = \frac{\sum_{j=1}^{I_k} \frac{\sum_{i=1}^{n} D_{ijk}}{n}}{I_k} \tag{1}$$

$1 \le i \le n,\ 1 \le j \le m,\ 1 \le k \le p,\ i, j, k, n, m, p \varepsilon Z^{*}$

D_k: The degree to which guide sign k satisfies the subject's information demand of the road network.

D_{ijk}: The frequency of information on subject i selection j for guide sign k. When j is selected, the value is 1; otherwise, the value is 0.

I_k: The number of pieces of road and district information on guide sign k. In the case of Beijing, scheme 1 and scheme 3 have 6 pieces of information, while scheme 2 and scheme 4 have 9 pieces of information (i.e., $I_1 = 6$, $I_2 = 9$, $I_3 = 6$, $I_4 = 9$).

n: The number of subjects.

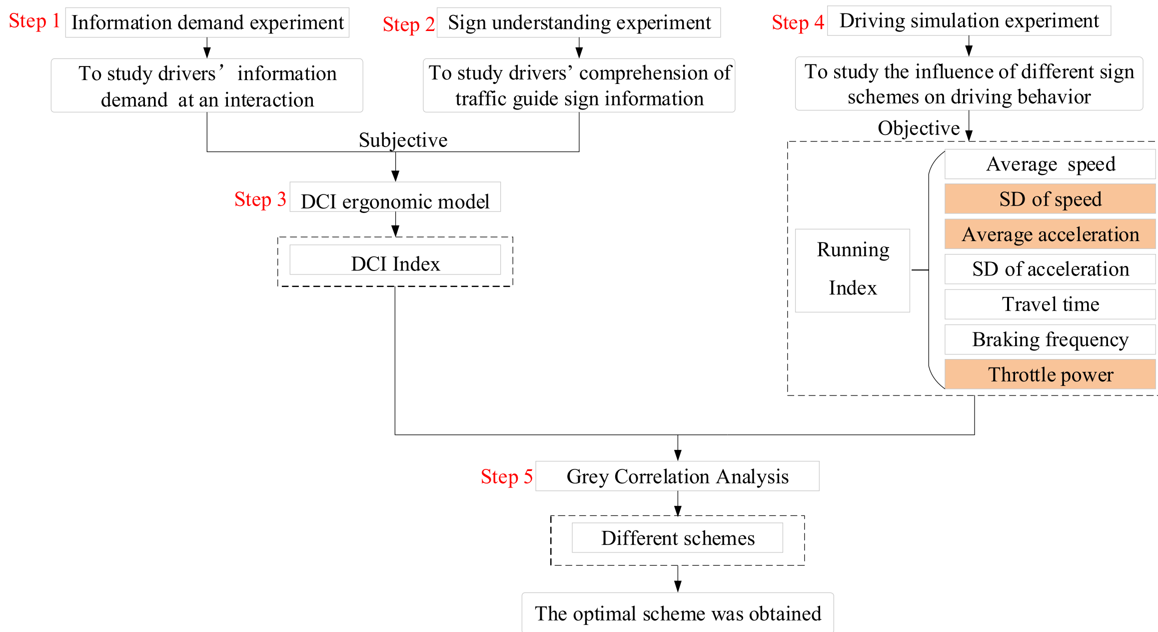


Fig. 3. The flow chart of the TGSEM.

m: The number of pieces of road and district information in the road network. In this case, the road network has 9 pieces of road information and 6 pieces of district information. So, $m = 15$.

p: The number of guide sign schemes to be evaluated. There are 4 schemes in this case, so $p = 4$.

2.3.2. S2, rectify coefficient

$$\alpha_k = \frac{\sum_{j=1}^{I_k} \frac{\sum_{i=1}^{n} C_{ijk}}{n} \cdot \frac{\sum_{i=1}^{n} D_{ijk}}{n}}{\sum_{j=1}^{I_k} \frac{\sum_{i=1}^{n} D_{ijk}}{n}} \tag{2}$$

$1 \le i \le n,\ 1 \le j \le m,\ 1 \le k \le p,\ i, j, k, n, m, p\varepsilon Z^*$

α_k: Coefficient of the subject's degree of understanding of the guide sign.

C_{ijk}: The frequency at which subject *i* correctly understood information *j* on guide sign *k*. When *j* is correctly understood, the value is 1; otherwise, the value is 0.

$$\beta_k = \begin{cases} \frac{I_k}{I}, & I_k \le I \\ \frac{I}{I_k}, & I_k > I \end{cases} \tag{3}$$

$I\varepsilon\{5, 6, 7\},\ I, \le k \le p,\ k, p\varepsilon Z^*$

β_k: Coefficient of the guide sign's information volume.

I: The optimal information volume, with values of 5, 6 or 7. According to the principle of maximum threshold, I = 7 was selected (Zhang et al., 2011).

2.3.3. S3, final model

$$DCI_k = D_k \cdot \alpha_k \cdot \beta_k = \begin{cases} \frac{\sum_{j=1}^{I_k} \sum_{i=1}^{n} C_{ijk} \sum_{i=1}^{n} D_{ijk}}{I \cdot n^2}, & I_k \le I \\ \frac{I \cdot \sum_{j=1}^{I_k} \sum_{i=1}^{n} C_{ijk} \sum_{i=1}^{n} D_{ijk}}{n^2 \cdot I_k^2}, & I_k > I \end{cases} \tag{4}$$

DCI_k: DCI model index of guide sign *k*. The ergonomics of guide sign *k* take a value of 0 ˜ 1. The greater is the value, the better are the ergonomics of the guide sign. The product of the three variables represents the final model obtained after considering the three factors of information demand, understanding and volume.

2.4. Step 4: driving simulation experiment

The DCI ergonomic model was used to study drivers' subjective cognition. However, to better evaluate the effectiveness of the sign, the objective behavior aspect should be evaluated similarly. It is well recognized that driving simulator-based experimental tests are a cost-efficient and nearly risk-free means of acquiring objective behavior data. In the field, changing traffic signs could be expensive and potentially cause hazards. Using a driving simulator, different test scenarios can be easily established by changing traffic sign schemes to verify their performance under different conditions. Therefore, a driving simulation experiment was carried out.

When the participant completed the experiment, the program automatically collected his driving behavior data and vehicle operation data. The data were collected at a frequency of 30 times per second. In the case of Beijing, the following seven indexes were selected to study for each participant: average speed, standard deviation (SD) of speed, average acceleration, SD of acceleration, travel time, braking frequency and throttle power. The indexes are explained below.

- The average speed (km/h) refers to the speed when subjects pass through the intersection, starting the calculation from 200 m before the sign. The segment is defined as the area of influence of the traffic guide sign. A higher average speed indicates a better performance.
- The standard deviation (SD) of speed reflects the change in speed when subjects pass through the intersection. A lower SD of speed indicates a smoother and steadier drive.
- The average acceleration (m/s2) refers to the rate of speed change when subjects pass through a segment. Higher values indicate better performance.
- The SD of acceleration indicates the stability of speed variations through a segment. The lower the value, the lower are the rapid acceleration and deceleration.
- Travel time indicates the time that it takes the subjects to complete the scenario. The lower the value, the better is the performance.
- Braking frequency refers to the number of subjects braking during the driving process. The greater the value, the more hesitant is the

driver.

- Throttle power is reflected in the maneuvering behavior of the driver in the test section. In the driving simulator system, the throttle pedal depth is divided from 0 to 100. The depth of the pedal is 0 when the pedal is not pressed, and the depth of a completely pressed pedal is 100. The physical meaning of throttle power (PGas) is shown as follows:

$$P_{Gas} = \int_0^T f(t)dt \quad (5)$$

T: The driving time;
f(t): The pressing intensity of the throttle pedal at time *t*.

2.5. Step 5: grey relational analysis

The relationship between subjective experiments and driving simulation experiments, however, has not been discovered. Because the goal of this paper is to choose the best of the schemes, the problem is a multi-objective decision-making problem. To explore the correlation between subjective and behavioral data, Grey relational analysis must be used. It can take multiple indexes into account and does not need to consider the significance of the indexes. Moreover, it does not require large numbers of samples. The interactions among all indexes were studied via this analysis method (Yu and Zhao, 2012). A comprehensive evaluation of the index system for determining which is the most suitable of the four schemes is shown in Fig. 4 (N. Mei et al., 2013 & W. Cao et al., 2008).

The procedure of the Grey relational analysis is as follows.

1 **Building index sets.** Hypothesize that the system has n schemes, with a set of $A=\{A_1, A_2...A_i... A_n\}$. Each scheme has m indexes, with a set of $C=\{C_1, C_2...C_j... C_m\}$. Define x_{ij} to express the value of the No. j evaluation index in scheme i. Then, the index attribute matrix $X= [x_{ij}]_{n\times m}$ can be formed. Generally, the evaluation index can be divided into two types (i.e., benefit type and cost type). A greater benefit index is better, and a smaller cost index is better.
2 **Normalize the matrix.** The following algorithm is used:

$$y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \quad (6)$$

A normalized attribute matrix $Y= [Y_{ij}]_{n\times m}$ can be obtained using Eq. (6).

3 Determine the ideal scheme set $Y_{0j} = (y_{01}, y_{02},...,y_{0j})$.
4 Compare the ideal scheme set Y_{0j} with the normalized attribute matrix $Y= [Y_{ij}]_{n\times m}$. The index set $Y_{ij} = (y_{i1}, y_{i2}..,y_{im}, i = 1,2...n)$ is used as the comparison sequence of the scheme, and Grey relational analysis is carried out with the target set of the ideal scheme being $Y_{0j} = (y_{01}, y_{02},...,y_{0j})$. The following algorithm is applied:

$Z_{ij} = |Y_{0j} - Y|$ (7)

5 Then, find the correlation coefficient:

$$\gamma_{ij} = \frac{\min\min|y_{0j} - y_{ij}| + \rho\max\max|y_{0j} - y_{ij}|}{|y_{0j} - y_{ij}| + \rho\max\max|y_{0j} - y_{ij}|} \quad (8)$$

Here, ρ is called the resolution coefficient. Generally, $\rho = 0.5$.

6 Finally, the degree of correlation is obtained:

$$u = \frac{1}{m}\sum_{j=1}^{m} \gamma_{ij} \quad (9)$$

The TGSEM consists of the 5 steps mentioned above. Through this method, subjective and objective data were obtained, and the relationship between them was explored. A comprehensive evaluation index system has been developed. Therefore, the general method is used to solve further problems.

3. Case study

The goal of the general TGSEM method is to assess the effectiveness of traffic guide signs and then select the most appropriate guide sign scheme. In this section, such a case is analyzed. The four traffic guide sign schemes in Beijing described above were evaluated by the TGSEM.

3.1. Participants

A total of 32 participants (23 men and 9 women; average age ± SD = 34.19 ± 10.61 years, range: 23–56 years; average driving experience ± SD = 9.03 ± 7.22 years, range: 1–31 years) was recruited from universities and social organizations. Based on the proportions used in the selection of subjects and literature (Xu et al., 2018), we think that 2–3 times as many males as females is appropriate, and it is consistent with the current proportion of Chinese drivers (Ministry of Public Security of China, 2018). Each participant had a driver's license and more than one year of actual road driving experience. Moreover, each participant had normal vision (or corrected to normal) over 0.9.

A contract was signed before the experiment. In the pre-experiment instructions, subjects were told to drive normally, that the experiment would not cause harm to people, and that researchers would not leak subjects' personal information. Since human beings were selected as

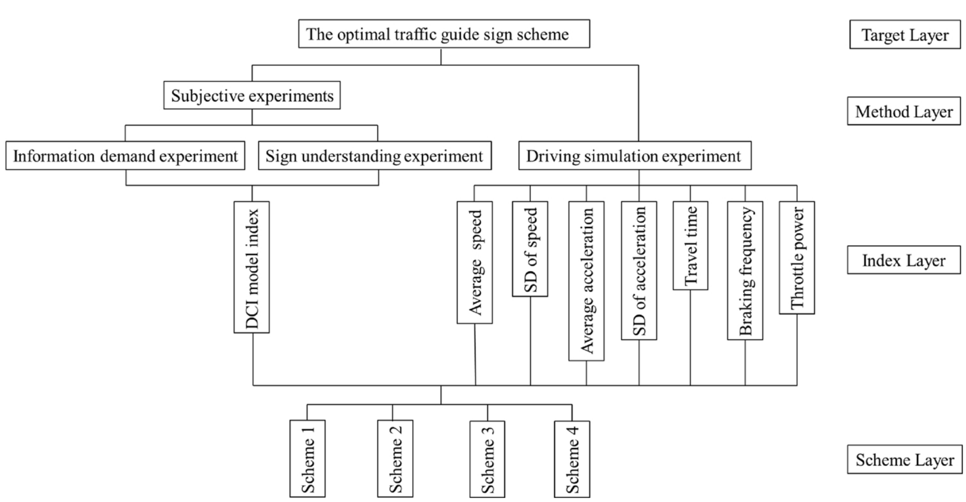
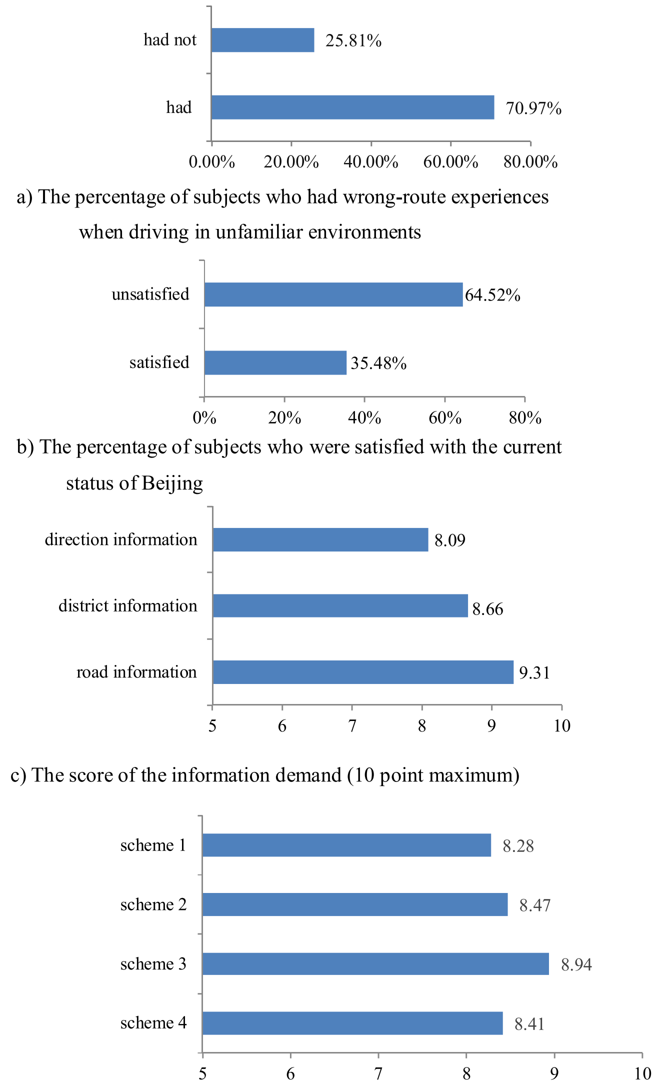


Fig. 4. Comprehensive evaluation of the index system of the four schemes.



a) The percentage of subjects who had wrong-route experiences when driving in unfamiliar environments

b) The percentage of subjects who were satisfied with the current status of Beijing

c) The score of the information demand (10 point maximum)

d) The score of understanding of the four schemes (10 point maximum)

Fig. 5. Results of subjective questionnaires.

subjects in the experiments, the Declaration of Helsinki should be conformed. All the procedures of the experiments were carried out in accordance with relevant laws and guidelines, and human subjects were informed and agreed.

3.2. Questionnaires

To determine the general situation of people's perception of traffic guide signs, before the experiments began, the subjects completed a questionnaire. The questionnaire mainly included four parts: the wrong-way experience, the satisfaction of the current status of Beijing's traffic guide signs, the demand for different types of information and the understanding of different schemes. After statistical analysis, as shown in Fig. 5 a), 70.97% of subjects had wrong-route experiences when driving in unfamiliar environments, which were mostly caused by guide signs. Only 35.48% of subjects were satisfied with the current status in suburban Beijing, as shown in Fig. 5 b). Therefore, it is necessary to carry out this study. To study the drivers' demand, subjects were asked to rate information. As shown in Fig. 5 c), road information is the most important (9.31 points, mean score), followed by district information (8.66 points) and direction information (8.09 points). In terms of the drivers' understanding, scheme 3 is easiest to understand (8.94 points), followed by scheme 2 (8.47 points), scheme 4 (8.41 points), and scheme 1 (8.28 points), as shown in Fig. 5 d).

There are differences between the information demands for guide signs from old and young drivers. Young drivers prefer guide signs that show proximal districts but do not show directions. However, old drivers prefer the opposite. A Pearson correlation analysis of the subjects' age and direction information preference was conducted. The result shows that the two variables are positively related ($R = 0.332$, $p < 0.05$), which means that drivers are more inclined toward guide signs that include direction information as their age increases.

The questionnaires confirmed that it is imperative to optimize the traffic guide signs in suburban Beijing. To evaluate the effectiveness of guide sign schemes in terms of ergonomics, subjective experiments were carried out.

3.3. Step 1: information demand experiment

3.3.1. Apparatus

The experiment was carried out in an indoor desktop simulation environment. Under the conditions of a given road network, subjects were required to put information on a blank sign.

The materials required for the experiment were as follows:

1) Photoshop software was used to draw the road network diagrams. The experiment designed five road network diagrams. The structures of each diagram were the same and were composed of six districts (District A to F) and nine roads (Road 1–9), as shown in Fig. 6 a). The destinations in the five diagrams were different: straight proximal, straight remote, left-turn proximal, left-turn remote and left-front position. The district names and road names of the five road network diagrams were also different. The straight proximal position and straight remote position diagrams shown in Fig. 6 b) and c) are examples.
2) AutoCAD software was used to draw the blank signs.
3) The road and district information notes of the road network diagram were then made.

3.3.2. Procedures

3.3.2.1. Become familiar with the road network. First, the subject was asked to become familiar with the structure and the destination of five diagrams.

3.3.2.2. Suppose the situation. Second, taking Fig. 6 b) and c) as examples, the subject was told that he was driving through the intersection of the road network, and his destinations are a straight proximal destination and a straight remote destination, respectively.

3.3.2.3. Select the information. Third, the subject needed to select the road and district information notes according to driving destination and habits.

3.3.2.4. Design guide signs. Finally, the subject needed to put the information notes on the blank sign, as shown in Fig. 6 d). The sign designed by the subject is shown in Fig. 6 e).

3.3.3. Results

Define the information demand degree (to measure the degree of drivers' demand for the road or district information at the intersection) as the letter *D*. After the experiment, the information put on the blank sign was collected and filled into Table 1, taking the demand degree of the straight proximal destination (D_1) as an example. When subject *i* selects information *j*, the D_{ij} value is 1; otherwise, the value is 0.

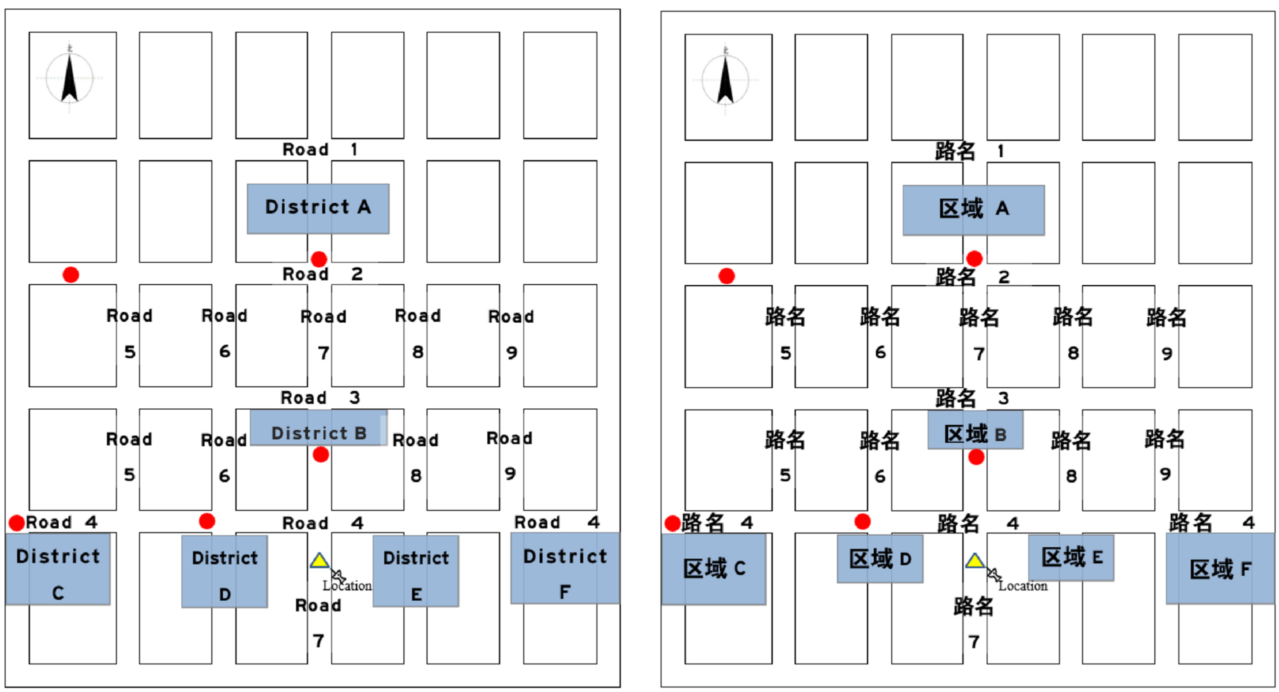
The last column (total column for the straight proximal destination) of Table 1 is listed in Table 2. Similarly, the other four diagrams are shown as follows. Then, by calculating the mean values of the five columns, the overall demand degree (*D*) was calculated, as shown in the last column in Table 2. The data will be used in Step 3.

3.4. Step 2: Sign understanding experiment

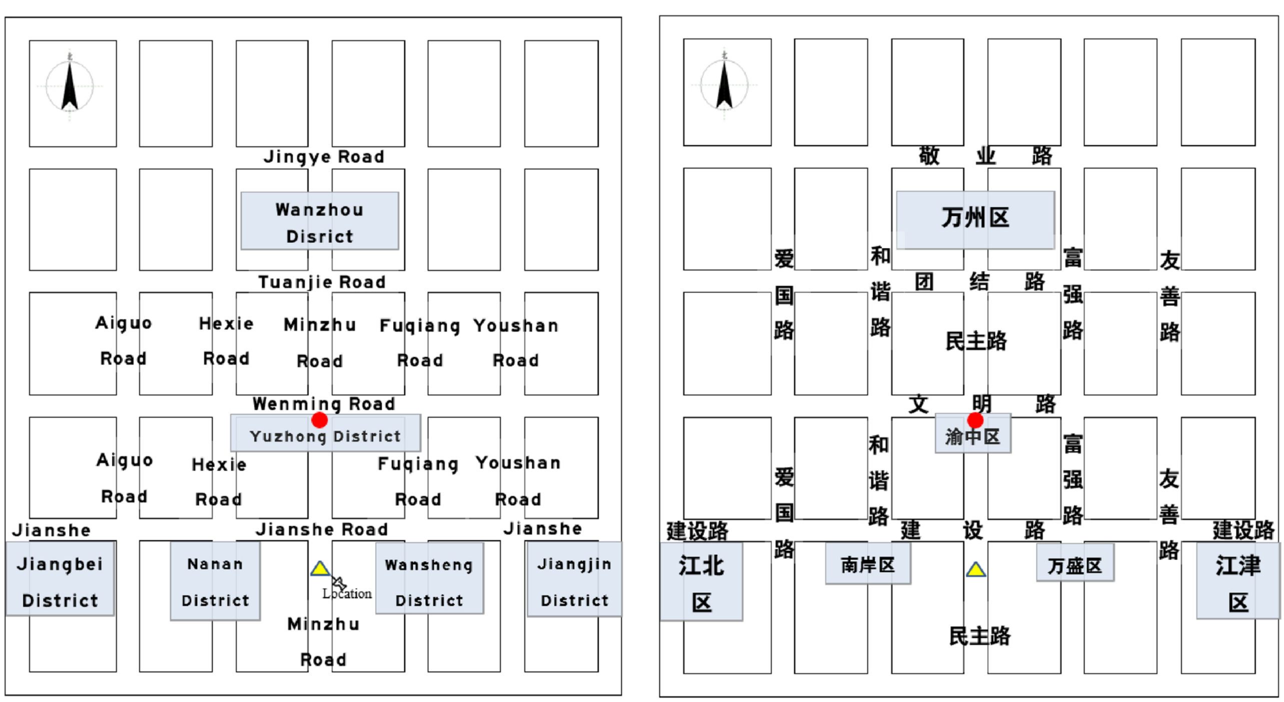
3.4.1. Apparatus

The materials required for the experiment are as follows:

1) AutoCAD software was used to draw the traffic guide signs.
2) Photoshop software was used to draw a blank road network diagram.
3) The road and district information notes for the traffic guide signs were then made.

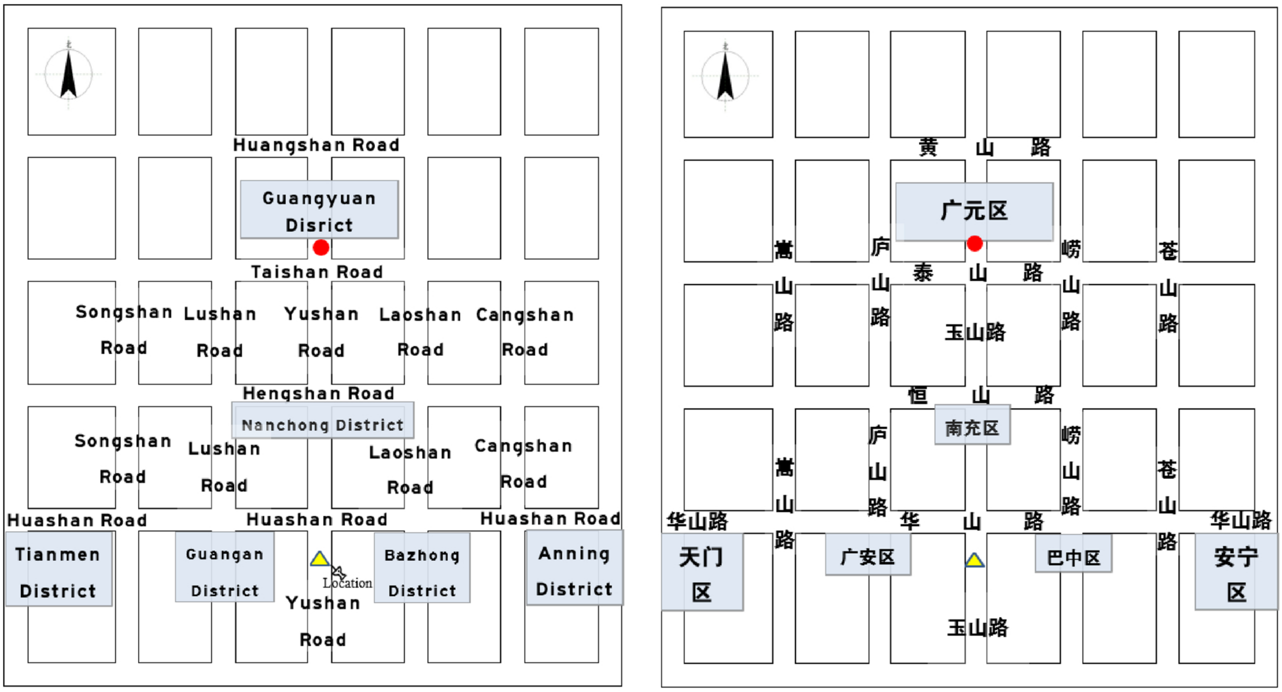


a) Road network (in English and Chinese)

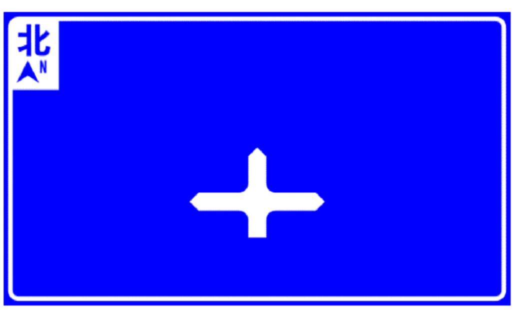


b) The straight proximal destination as an example (in English and Chinese)

Fig. 6. Information demand experiment.



c) The straight remote destination as an example (in English and Chinese)



d) Template of the blank sign

e) Sign diagram designed by the subject

Fig. 6. (*continued*)

Table 1
Selection of road or district information (straight proximal destination).

Road or district information *j*		Subject *i*								Total
		A_1	A_2	A_3	…	A_i	…	A_{31}	A_{32}	
1	Jingye Road	0	0	0	…	…	…	0	0	**2**
2	Tuanjie Road	0	0	0	…	…	…	0	0	**4**
3	Wenming Road	0	0	1	…	…	…	0	1	**11**
4	Jianshe Road	0	1	1	…	…	…	1	0	**29**
5	Aiguo Road	0	0	0	…	…	…	0	0	**2**
6	Hexie Road	1	0	1	…	…	…	0	1	**10**
7	Minzhu Road	1	1	1	…	…	…	1	1	**27**
8	Fuqiang Road	1	0	1	…	…	…	0	1	**10**
9	Youshan Road	0	0	0	…	…	…	0	0	**3**
10	Wanzhou District	0	0	0	…	…	…	0	0	**13**
11	Yuzhong District	1	0	1	…	…	…	1	1	**16**
12	Jiangbei District	1	0	0	…	…	…	0	0	**10**
13	Nanan District	1	1	1	…	…	…	1	0	**18**
14	Wansheng District	1	1	1	…	…	…	1	0	**18**
15	Jiangjin District	1	0	0	…	…	…	0	0	**9**
	j	D_{1j}	D_{2j}	D_{3j}	…	…	…	D_{31j}	D_{32j}	$\boldsymbol{D_1}$

3.4.2. Procedures

3.4.2.1. Suppose the situation. First, the subject was told that he was driving through the intersection of the road network, as shown in Fig. 7 a). The point represents the intersection where the subject is located. The sign shown is the one that the subject can see at the intersection.

3.4.2.2. Show the signs. Second, the experimental signs were displayed on the screen using Microsoft PowerPoint. The subject sat 2 m away from the screen.

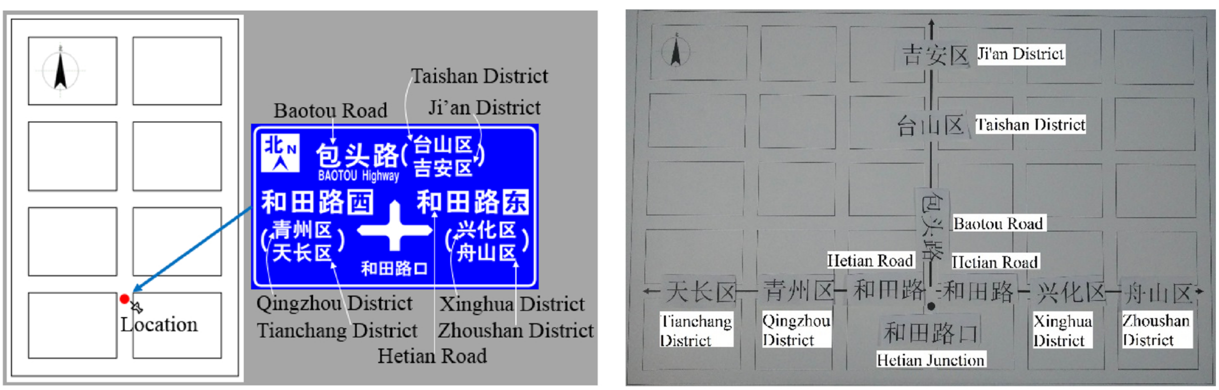
3.4.2.3. Include sign notes. Finally, the subject put the sign information notes on the corresponding positions in the blank road network diagram. The road network placed by the subject is shown in Fig. 7 b).

3.4.3. Results

Define the sign understanding degree (to measure whether the information on the sign is correctly understood) as the letter *C*. All the road or district information that were correctly understood by subjects were collected and placed in Table 3, taking scheme 1 as an example. As shown in Fig. 2, scheme 1 selected only district information and did not select road information. When subject *i* correctly understood information *j*, the C_{ij} value was 1; otherwise, the value was 0. Then, the

Table 2
Total selection for road or district information.

Road or district information *j*		Five Road Network						
		Straight proximal	Straight remote	Left turn proximal	Left turn remote	Left front	Mean	
1	Road 1	2	2	0	0	2	**1.2**	$D_{Road\ 1}$
2	Road 2	4	4	2	3	11	**4.8**	$D_{Road\ 2}$
3	Road 3	11	7	8	8	5	**7.8**	$D_{Road\ 3}$
4	Road 4	29	29	29	26	31	**28.8**	$D_{Road\ 4}$
5	Road 5	2	5	5	6	7	**5**	$D_{Road\ 5}$
6	Road 6	10	9	14	10	9	**10.4**	$D_{Road\ 6}$
7	Road 7	27	27	25	26	26	**26.2**	$D_{Road\ 7}$
8	Road 8	10	12	17	10	11	**12**	$D_{Road\ 8}$
9	Road 9	3	3	3	4	5	**3.6**	$D_{Road\ 9}$
10	District A	13	20	5	9	15	**12.4**	$D_{District\ A}$
11	District B	16	19	19	21	17	**18.4**	$D_{District\ B}$
12	District C	10	5	5	18	10	**9.6**	$D_{District\ C}$
13	District D	18	16	23	16	15	**17.6**	$D_{District\ D}$
14	District E	18	14	23	19	16	**18**	$D_{District\ E}$
15	District F	9	5	5	13	9	**8.2**	$D_{District\ F}$
		D_1	D_2	D_3	D_4	D_5	D	



a) Exhibition diagram b) Road network diagram as understood by subjects

Fig. 7. Sign understanding experiment.

understanding degree (*C*) of each type of information was calculated, see the last column (Total) in Table 3. The data will be used in Step 3.

3.5. Step 3: DCI ergonomic model

Take scheme 1 as an example. As shown in Fig. 2, there are 6 information points in scheme 1, so $I_1 = 6$, as is also shown in Equation (1). The optimal information volume is generally 7, so I = 7, which is also shown in Eq. (3). Because 32 subjects were selected in the experiment, n = 32. Therefore,

$$\text{DCI1} = \frac{\sum_{j=1}^{I_k} \sum_{i=1}^{n} C_{ijk} \sum_{i=1}^{n} D_{ijk}}{I \cdot n^2}$$

$$= \frac{C_{District\ A} \times D_{District\ A} + C_{District\ B} \times D_{District\ B} + C_{District\ C} \times D_{District\ C} + .+C_{District\ F} \times D_{District\ F}}{7 \times 32^2}$$

$$= \frac{21.5 \times 12.4 + 29.5 \times 18.\ 4 + 19.5 \times 9.6 + 27 \times 17.6 + 28.5 \times 18 + 21 \times 8.2}{7 \times 32^2} = 0.301$$

Similarly, after the calculation, $DCI_2 = 0.380$, $DCI_3 = 0.509$, and $DCI_4 = 0.410$ were obtained. Therefore, scheme 3 had the highest score, followed by scheme 4 and scheme 2, and scheme 1 had the lowest score. At the drivers' subjective level, scheme 3 has the best ergonomics and is easiest to understand. However, the DCI ergonomic model cannot reflect a drivers' objective behavioral data. Thus, it is necessary

Table 3
Road or district information correctly understood from scheme 1.

Road or district information *j*		Subject *i*										Total	
		A_1	A_2	A_3	A_4	A_5	…	A_i	…	A_{31}	A_{32}		
scheme 1	District A	0	1	1	0	1	…	…	…	1	1	***21.5***	$C_{District\ A}$
	District B	1	1	1	1	1	…	…	…	1	1	***29.5***	$C_{District\ B}$
	District C	0	0	1	1	0	…	…	…	0	1	***19.5***	$C_{District\ C}$
	District D	1	0	1	1	1	…	…	…	0	1	***27***	$C_{District\ D}$
	District E	1	1	1	1	1	…	…	…	0	1	***28.5***	$C_{District\ E}$
	District F	0	1	1	1	0	…	…	…	0	1	***21***	$C_{District\ F}$
		C_{1j}	C_{2j}	C_{3j}	C_{4j}	C_{5j}	…	C_{ij}	…	C_{31j}	C_{32j}	***C***	

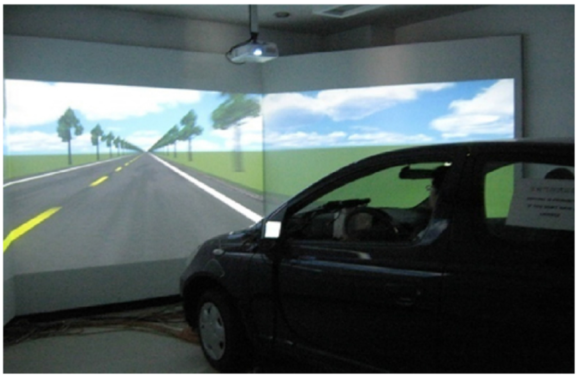


Fig. 8. Driving simulator at Beijing University of Technology.

to carry out driving simulation experiments.

3.6. Step 4: Driving simulation experiment

3.6.1. Apparatus

A fixed-base driving simulator was used in this paper (see Fig. 8). The virtual scenario was projected onto three large screens, providing a 130° field of view. The driving simulator is able to generate various sensory effects for participants, including visual, auditory and tactile effects. Moreover, real-time data were collected, including vehicle trajectory parameters and operating performance data (e.g., speed, acceleration, deceleration and steering). The data acquisition frequency is 30 Hz.

Moreover, the validity of this simulator has been determined in previous studies (e.g., Zhang et al., 2014; Guan et al., 2014). Over 200 drivers have evaluated the validity of this driving simulator through questionnaires. The evaluated items include characteristics such as the realistic feel of the accelerator, brakes, and speed perception. The ratings results are shown in Table 4 (1- not real at all to 10-very real). Because previous studies (Ding et al., 2014) have shown that driving simulator performance is highly similar to real road environment performance, this simulator appears to be a valuable research tool for driving behavior studies.

3.6.2. Scenarios and design

The experiment consists of 16 scenarios, each of which is approximately 7 km long. There are three routes in the scenarios, as shown in Fig. 9. Among them, scenarios 1–4 and 9–12 use Route 1, scenario 5–8 use Route 2, and scenarios 13–16 use Route 3.

According to the destination, 16 scenarios were divided into straight remote, straight proximal, left-turn proximal and left-turn remote positions, as shown in Table 5. For example, in scenario 1, the traffic guide sign uses scheme 1, the destination of the subject is a straight remote position, and the travel route is Route 1.

The experimental scenario picture is shown in Fig. 10.

3.6.3. Procedures

The experiment was divided into three sections, and the specific process is as follows.

3.6.3.1. Before the formal experiment.

Table 4
Ratings of the subjective evaluation of the driving simulator.

	Steering wheel	Accelerator	Brake	Clutch	Gear	Speed perception
Mean	7.9	7.9	7.5	8.2	7.5	7.7
SD	1.25	1.20	1.50	1.20	1.46	1.39

1) The subject filled out the basic information form, which included name, age, gender, driving experience, and occupation.
2) Then, the subject was given a tutorial on how to use the driving simulator and was required to perform a test drive for 5 min to create familiarity with the equipment.
3) After the test drive, the subject started the formal experiment.

3.6.3.2. During the formal experiment.

1) The order of the 16 scenarios was randomly arranged by the experimenter.
2) The subject was required to drive all scenarios, taking a rest after four scenarios.

3.6.3.3. After the formal experiment.

1) The subject was required to fill out the simulator evaluation table after driving.
2) The subject checked personal information and was compensated.

3.6.4. Results

Repeated measures analysis of variance (rANOVA) was applied to compare the impacts of the four traffic sign schemes on the driving behavior. Generally, $p < 0.1$ is defined as significant. The rANOVA results showed significant differences among the SDs of the speed, average acceleration and throttle power. However, the four schemes had no significant impacts on the average speed, SD of acceleration, travel time or braking frequency, as shown in Fig. 11. The horizontal axis denotes the different schemes. The vertical axis denotes the seven indexes of the different schemes. The SD of speed in scheme 4 was significantly greater than those of the other schemes, while that of scheme 2 was the lowest. Overall, a lower SD of speed indicates a better effect. Therefore, scheme 2 had a greater impact on the SD of speed. The average acceleration of scheme 4 was significantly greater than those of the other schemes. Overall, a greater average acceleration indicates a better effect. Therefore, scheme 4 had the best impact. The throttle powers of scheme 2 and scheme 3 were significantly higher than those of scheme 1 and scheme 4. A higher throttle power indicates a better effect. Therefore, scheme 2 had the best impact. It can be seen that the four schemes had different effects on drivers. Overall, scheme 2 had a better impact on the drivers' behavioral data.

In the driving simulation experiment, drivers' objective behavioral data were obtained. The results showed that the effects of the different guide sign schemes were diverse and reasonable. Thus, according to the subjective DCI index obtained in Step 3 and the objective indexes obtained in Step 4, the Grey relational analysis was carried out to explore the relationship between the subjective and objective data.

3.7. Step 5: Grey relational analysis

In this paper, the quantized attribute values of the 4 scheme indexes are shown in Table 6.

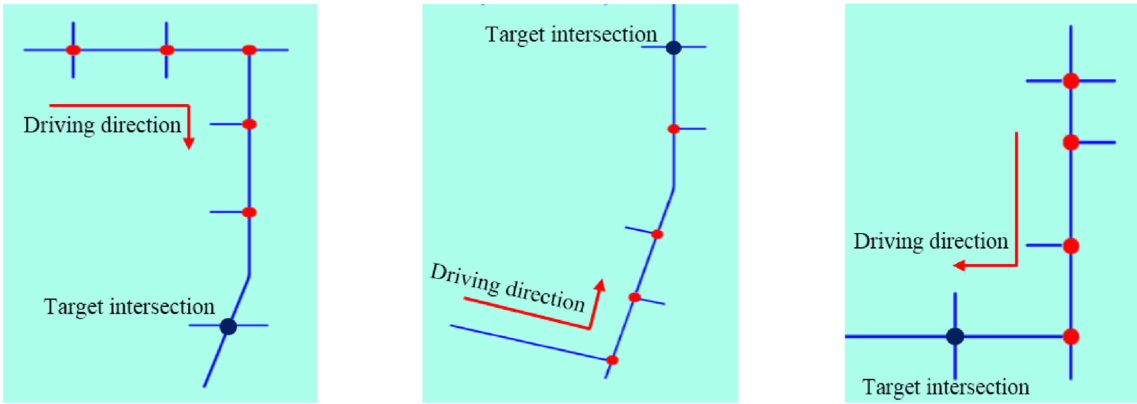
According to Eq. (6), the matrix was normalized. The normalized matrix is shown in Table 7.

The indexes C_1 C_3 C_7 C_8 are known as the benefit types, and C_2 C_4 C_5 C_6 are the cost types. Therefore, the ideal scheme set was defined as Y_{0j} = (1,0,1,0,0,0,1,1).

According to Equation (7), after the Grey relational analysis with Y_{0j}, the matrix Z_{ij} is shown in Table 8.

The correlation coefficient the matrix was obtained according to Eq. (8). The matrix is shown in Table 9.

Finally, the correlation coefficients of the four schemes in Table 9 were averaged according to Eq. (9) so that the correlation degrees could be obtained, as shown in Fig. 12. It can be seen that scheme 2 had the greatest value (0.703), which means that it was closest to the ideal scheme. It was followed by scheme 4 (0.692) and scheme 3 (0.683).



a) Route 1 b) Route 2 c) Route 3

Fig. 9. The three routes of the scenarios.

Table 5
The description of 16 scenarios.

destination	alternatives			
	scheme 1	scheme 2	scheme 3	scheme 4
straight remote position	scenario 1	scenario 2	scenario 3	scenario 4
straight proximal position	scenario 5	scenario 6	scenario 7	scenario 8
left-turn proximal position	scenario 9	scenario 10	scenario 11	scenario 12
left-turn remote position	scenario 13	scenario 14	scenario 15	scenario 16

Fig. 10. The experimental scenario.

Scheme 1 was the lowest (0.668).

4. Discussion

The paper proposed a general evaluation method (TGSEM) for traffic guide signs. In addition, an example of Beijing traffic guide signs was verified. Moreover, the influence of sign information on driver physiology and psychology has been studied. The research was conducted through three experiments: an information demand experiment, a sign understanding experiment and a driving simulation experiment. Through these experiments, the relationship between drivers and guide signs was studied. The desktop simulation experiments can better reflect the drivers' cognition of the traffic guide information. The driving simulation experiment can better reflect drivers' objective driving behavior data. Therefore, the three experiments were complementary to each other.

According to the previous conclusion, a driver's demand for information is related to their characteristics, such as age, driving experience and driving style (Zhang, 2015). Future studies will consider driver characteristics. In this paper, elderly subjects accounted for 13% of the total sample size. Concerning preferences between aged and young subjects, an interesting inference was obtained. This paper found that older drivers are inclined to prefer a sign that has directional information during the driving process and that there is a positive correlation between age and directional information preference ($R = 0.332$, $p < 0.05$). This preference might be related to the slower reaction time that accompanies increased age. If there is no directional information on a sign, the driver is required to think and judge. Thus, it might be more appropriate to provide directional information directly. Young drivers prefer signs with proximal district information during the driving process. This preference might relate to their driving experience. The young drivers have not yet formed a regular driving habit and depend more on the traffic guide signs. Therefore, they prefer more specific information on the sign.

Subjectively, the results showed that scheme 3 was optimal, followed by scheme 4, scheme 2 and scheme 1. Scheme 3 was the most popular of the four schemes. The reason for this distinction might be that scheme 3 is similar to the current urban road signs. Thus, it is easier to understand and has a distinct layer. However, due to the lack of proximal district information, scheme 3 was most likely to cause drivers to take a wrong turn. Scheme 1 was the least popular of the four schemes. The reason for this distinction is that scheme 1 does not present road information. The questionnaires showed that road information is vitally important to drivers. Objectively, under the guidance of scheme 2, drivers will be able to drive faster and more smoothly, with less rapid acceleration and deceleration. In other words, scheme 2 has a better impact on drivers' behavioral data. The reason for this difference might be that scheme 2 provides sufficient information for drivers to successfully find their destinations. From the subjective and objective findings, it can be seen that the effectiveness ratings of the schemes are inconsistent. Therefore, the subjective and objective aspects must be combined to form a general evaluation method to assess traffic guide signs. To this end, the paper applied Grey relational analysis to consider the relevance of each evaluation index. The use of this analysis led to the conclusion that scheme 2 has the greatest correlation degree. Therefore, scheme 2 can be recommended to the traffic management department. In addition, scheme 4 slightly lower than scheme 2. The main reason for this similarity is that both schemes contain the same information, and the only difference exists in their structures.

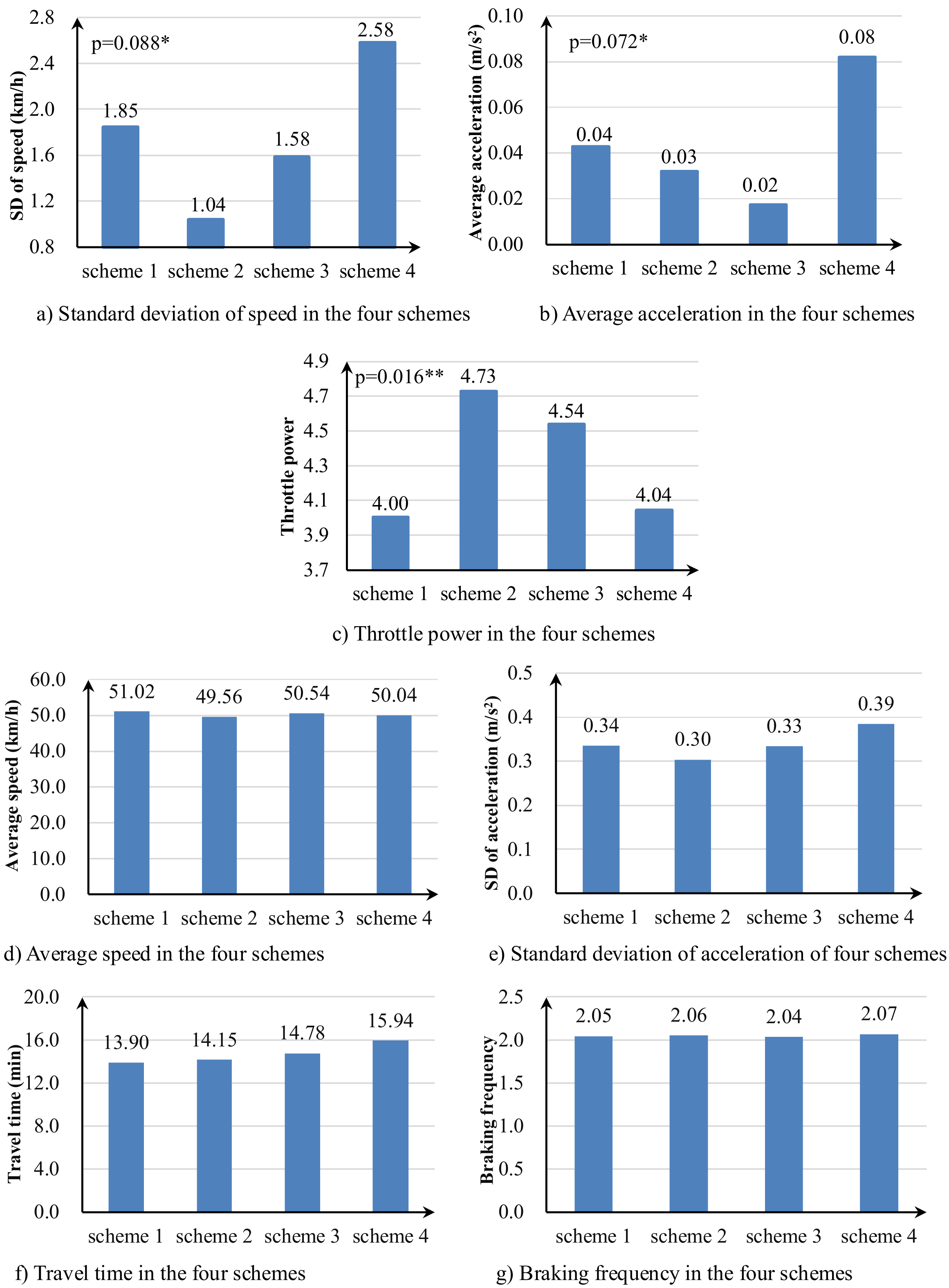


Fig. 11. The indexes of the four schemes.

To fully explore the relationships between the three experiments, this paper used Pearson correlation analysis to test the relationships between the indexes mentioned above, as shown in Table 10. The correlation coefficient of the DCI model index and average speed is 0.65. This result shows that there is a positive correlation. The participants' speeds will be higher when the traffic signs have better ergonomics. This result agrees with general common sense. Similarly, the higher the DCI model index, the smaller is the SD of acceleration, which shows that if the traffic sign ergonomics are better, the speed change is more uniform, and rapid acceleration and deceleration seldom occur. The higher the DCI model index, the lower is the braking frequency, and the higher is the throttle power, which also agrees with general common sense.

The limitation of this study is that the participants' range was

Table 6
Index attribute values of the four schemes.

Scheme	Index							
	Average Speed (C_1)	SD of speed (C_2)	Average acceleration (C_3)	SD of Acceleration (C_4)	Travel Time (C_5)	Braking Frequency (C_6)	Throttle Power (C_7)	DCI (C_8)
Scheme1	51.015	1.845	0.043	0.335	13.902	2.047	4.003	0.301
Scheme2	49.557	1.041	0.032	0.304	14.151	2.055	4.729	0.380
Scheme3	50.544	1.582	0.017	0.334	14.775	2.039	4.539	0.509
Scheme4	50.038	2.580	0.072	0.385	15.935	2.070	4.041	0.410

Table 7
The normalized matrix *Y*.

Scheme	Index							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Scheme1	0.5072	0.4995	0.4676	0.4916	0.4725	0.4986	0.4613	0.3699
Scheme2	0.4927	0.2817	0.3503	0.4461	0.4809	0.5005	0.5449	0.4670
Scheme3	0.5025	0.4282	0.1883	0.4901	0.5021	0.4966	0.5230	0.6255
Scheme4	0.4975	0.6985	0.7894	0.5649	0.5416	0.5042	0.4657	0.5038

Table 8
The matrix $Z_{ij.}$

Scheme	Index							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Scheme1	0.4928	0.4995	0.5324	0.4916	0.4725	0.4986	0.5387	0.6301
Scheme2	0.5073	0.2817	0.6497	0.4461	0.4809	0.5005	0.4551	0.5330
Scheme3	0.4975	0.4282	0.8117	0.4901	0.5021	0.4966	0.4770	0.3745
Scheme4	0.5025	0.6985	0.2106	0.5649	0.5416	0.5042	0.5343	0.4962

Table 9
The correlation coefficient matrix.

Scheme	Index							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Scheme1	0.6860	0.6809	0.6570	0.6869	0.7019	0.6816	0.6526	0.5951
Scheme2	0.6751	0.8966	0.5840	0.7236	0.6952	0.6801	0.7160	0.6566
Scheme3	0.6824	0.7391	0.5063	0.6880	0.6789	0.6831	0.6982	0.7900
Scheme4	0.6786	0.5582	1.0000	0.6350	0.6507	0.6774	0.6557	0.6834

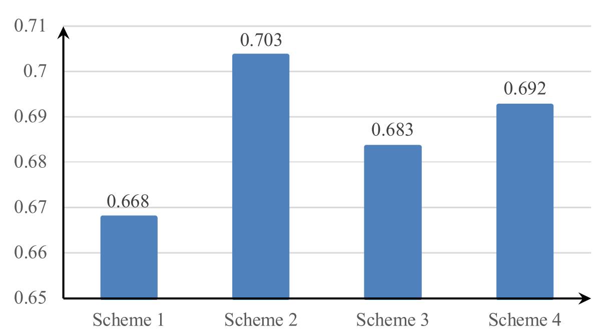


Fig. 12. The correlation degree of the four schemes.

Table 10
Pearson correlation.

Subjective experiments index	Driving simulation experiment indexes	r
DCI model index	Average speed	0.65
	Standard deviation of acceleration	−0.93
	Braking frequency	−0.95
	Throttle power	0.76

relatively singular. The young drivers were mostly students, and the old drivers were mostly professional drivers. Future studies can work to diversify the sample. The driving behavior data in this paper were collected using driving simulators based on virtual scenarios; however, the influence of traffic guide signs on drivers in the real world should be tested. A validation of the driving simulator results should be performed in future research through field tests. As shown in Table 4, the subjective ratings showed that the majority of subjects thought that the simulator was effective. In addition, the paper considered vehicle operation, driver control and safety when selecting the indicators. The indicators of the criterion SAE J2944 will be taken into account in the future to form a comprehensive indicators system.

5. Conclusion

Based on subjective and driving simulator experiments, a generic approach, TGSEM, was developed to examine and assess the effectiveness of traffic guide signs. In addition, the example of the Beijing traffic guide signs was studied. This paper's outline is as follows. First, questionnaires were conducted. This work concluded that the current highway traffic guide signs in Beijing are insufficient and need to be rectified. Then, three simulation experiments were conducted. The information demand experiment studied participants' demand for road information and district information. The sign understanding experiment studied participants' understanding of traffic guide sign information. The driving simulation experiment studied drivers' performances under different guide sign schemes.

By analyzing the data collected, the following conclusions can be reached. After the subjective questionnaires, it was clear that road information is of vital importance to road users. Drivers of different ages have different preferences for traffic sign information. In subjective experiments, the DCI ergonomics model was obtained. These experiments showed that scheme 3 is the most popular of the four schemes. After the driving simulation experiment, the objective indexes showed that scheme 2 has a greater impact on drivers' behavioral data. The Grey relational analysis showed that according to the highest degree of correlation, scheme 2 is the best solution and can be recommended to the traffic management department.

This paper can provide a theoretical basis for the optimization of highway traffic signs in Beijing. Moreover, this work can help unify highway traffic signs and urban road traffic signs. These findings provide a good guideline for engineers and guide sign designers. They also provide helpful results for use by traffic management departments.

Acknowledgements

This research was supported by the Beijing Municipal Science and Technology Project Major Projects (Research and Application of Multi-Function Collaborative Design Evaluation System for Expressway. Project No. D171100004017003; and the Collaborative Design of Facilities and Lighting for Expressway and the Demonstration Application in Tunnel and Service Area. Project No. D171100004017001).

References

Arup, D., Carpenter, R., Noyce, D., 2014. Drivers' understanding of overhead freeway exit guide signs. Transp. Res. Rec. 2014, 102–109.
Beijing highway traffic sign system setting guidebook, 2010. Beijing Municipal Commission of Transport. Beijing. .
Cao, W., Zhang, Y., Zhao, M., 2008. Study on interval relative fuzzy optimization method to determine support schemes for foundation pits. Chin. J. Geotech. Eng. 30 (1), 66–71.
Darja, T., Areh, I., Cvahte, T., 2016. Examination of driver detection of roadside traffic signs and advertisements using eye tracking. Transp. Res. Part F 43, 212–224.
Ding, H., Zhao, X., Rong, J., 2014. Experimental Research on the Validation of the Driving simulator in Beijing University of Technology. Research Report in College of Metropolitan Transportation in Beijing University of Technology.
Ding, H., Zhao, X., Rong, J., Ma, J., 2015. Experimental research on the effectiveness and adaptability of speed reduction markings in downhill sections on urban roads: a driving simulation study. Accid. Anal. Prevent. 75, 119–127.
Ding, H., Guo, F., Zheng, X., 2017. Traffic guidance–perimeter control coupled method for the congestion in a macro network. Transp. Res. Part C 81, 300–316.
Du, Z., 2008. Relationship between information quantity and visual cognition of traffic guide sign. J. Traffic Transport. Eng. 8 (1), 118–122.
Federal Highway Administration, 2009. Manual on Uniform Traffic Control Devices for Streets and Highways (2009 Edition). U.S. Department of Transportation.
Guan, W., Zhao, X., Qin, L., Rong, J., 2014. An explanation of how the placement of traffic signs affects driver' deceleration on curves. Saf. Sci. 68, 243–249.
Hashim, A., Janahi, A., 2002. Assessment of drivers' comprehension of traffic signs based on their traffic, personal and social characteristics. Transport. Res. Part F 5, 63–76.
Huang, L., 2017. Optimal setting methods of complex diagrammatic guide signs on urban expressway. China J. High. Transp. 31 (4), 139–146.
Juan, Z., 2005. Study on driver traffic signs comprehension based on cognitive psychology. China Saf. Sci. J. 15 (8), 8–11.
Liu, X., Zhang, W., 2015. Evaluation and optimization of traffic Guide sign layout. J. Beijing Univ. Technol. 41 (1), 95–102.
Mansoureh, J., NarooieNezhad, S., Kelarestaghi, K., 2017. Integration of a driving simulator and a traffic simulator case study: exploring drivers' behavior in response to variable message signs. IATSS Res.
Mei, N., Luo, X., Jiang, N., 2013. Establishment and application of grey multi-objective decision-making optimization model for foundation pit supporting schemes. J. Cent. South Univ. (Sci. Technol.) 44 (5), 1982–1987.
National Motor Vehicles and Drivers Maintained High Growth, 2017. The Ministry of Public Security of the People's Republic of China. Accessed 15 February. http://www.mps.gov.cn/n2254098/n4904352/c5976651/content.html.
Neill, Justin M., Hurwitz, D.S., Olsen, M.J., 2016. Alternative information signs: evaluation of driver comprehension and visual attention. J. Transp. Eng. 142, 1–12.
Pline, J.L., 1992. Traffic engineering handbook. Institute of Transportation Engineers, 4th ed). Prentice-Hall, Englewood Cliffs, NJ.
Standardization Administration of the People's Republic of China, 2009. Road Traffic Signs and Markings (GB 5768-2009). Beijing. .
Standardization Administration of the People's Republic of China, 2015. Code for Layout of Urban Road Traffic Signs and Markings (GB 51038-2015). Beijing. .
Tamar, B., Shinar, D., 2015. The effect of context and drivers' age on highway traffic signs comprehension. Transp. Res. Part F 33, 117–127.
Xu, W., Zhao, X., Chen, Y., Bian, Y., li, H., 2018. Research on the relationship between dynamic message sign control strategies and driving safety in freeway work zones. J. Adv. Transp.
Yu, A.H., Zhao, C., 2012. Evaluation on the highway asphalt pavement runoff with the gray correlation model. The 18th Biennial Conference of International Society for Ecological Modelling. Procedia Environmental Sciences. pp. 1827–1835.
Zhang, Y., Qi, C., Zhu, S., 2011. Eye tracker based on urban road traffic signs on the visual impact of the driver. J. Inner Mongolia Agric. Univ. 32 (3), 260–262.
Zhang, X., Du, H., Ma, J., Rong, J., 2014. Effect of different breath alcohol concentrations on driving performance in horizontal curves. Accid. Anal. Prev. 72, 401–410.
Zhao, X., Ding, H., Wu, Y., Ma, J., Zhong, L., 2015. Experimental research on safety impacts of the inside shoulder based on driving simulation. Accid. Anal. Prev. 76, 6–14.