A Method of Designing Outdoor Safety Way Guidance Sign Layout Information Based on Human Factors Engineering

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Abstract. Outdoor safety way guidance sign's guidance function benefits from its reasonable layout information design. In order to get an effective design method, a series of analyses were done as follows. Based on the theory of human factors engineering, an interactive mode between individual and sign was proposed, dividing the interaction process into four stages: Capturing Sign, Reading Information, Making Decision, and Taking Action. Based on Shannon information theory, a method on how to measure a sign's information and its loss caused by obstacles was put forward, and 305.2 bit was pointed out to be the allowed information maximum value when designing a sign under the consideration of human's ability to deal with information. Signs were classified to be 11 kinds according to corresponding evacuation environment and psychological needs, and what information should each kind show on layout was analyzed with several typical design examples following. A simulation model was created by 3dsmax to verify obstacle's influence on information transferring from signs to individuals, and to analyze improved design methods. The research results were expected to be useful to instruct designers in designing outdoor safety way guidance signs and to improve evacuation efficiency.

Keywords: Human factors engineering · Layout information · Outdoor safety way guidance sign · Information amount · Emergency evacuation

1 Introduction

In recent years, various disasters occurred more and more frequently, leading to huge losses in people's lives and property. It appears to be particularly important to carry out effective evacuation in sudden disasters. Safety way guidance signs are designed for emergency evacuation, aiming to guide the public to safe areas in a safe and quick way.

Currently, a series of relevant standards have been promulgated internationally. ISO 16069 [1], newly issued in 2017, is mainly for the setting standards of indoor environmental safety way guidance signs. ISO 7010 [2], a standard dedicated to graphical symbols, gives a large number of safety symbols that can be used in safety signs. ISO 20712-1 [3], a standard dedicated to water safety signs and beach safety flags, gives design methods for water-related signs. However, existing standards are

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mainly for indoor or some other specific environmental evacuation, and none is for general outdoor environmental evacuation. In the other words, based on existing standards, the public can be guided just from a building's inside to its exit, but how to get to emergency shelters then, is still a problem.

Layout information of a safety way guidance sign plays a great role in achieving the sign's guidance function. Reasonable layout information design contributes to the interactive effect between individuals and signs. Therefore the evacuation efficiency can be greatly improved.

In order to improve the standardization construction of safety way guidance system, a design method for layout information of outdoor safety way guidance sign (OSWGS) was analyzed, aiming to be helpful in establishing OSWGS design standards.

2 Design Principles

To ensure the design effect, design principles for OSWGS layout information were analyzed first of all as follows.

Information Correctness. Wrong information causes erroneous decisions and wrong actions. Information correctness is the basic requirement of OSWGS design.

Information Clarity. Clearly defined layout information helps the public speed up their understanding, and reduce the probability of misunderstanding.

Information Amount. Too little information leads to the public not fully understanding, while too much information leads to the public a slower understanding. In order to get a balance, the minimum and maximum values of information should be determined by some methods.

3 Interactive Mode

3.1 Interaction Model

Base on Jun Liang's research [4] on evacuation behavior of people in building fires, and according to the interaction mode between driver and traffic sign, an interaction model between public and OSWGS has been proposed, dividing the interaction process into four stages: Capturing Sign, Reading Information, Making Decision, and Taking Action. The interaction model is shown in Fig. 1.

Capturing Sign. Capturing sign stage refers to the process that evacuators evacuate from the capturing point A to the reading point B. The capturing point is the position where the evacuators notice the sign for the first time and complete the first interaction with the sign. The reading point is the position where the evacuators start reading the information on the sign and complete the first interaction with the guidance information. The meaning of this stage for evacuators is finding and noticing the sign, and achieving their psychological verification that the direction they have selected is right,

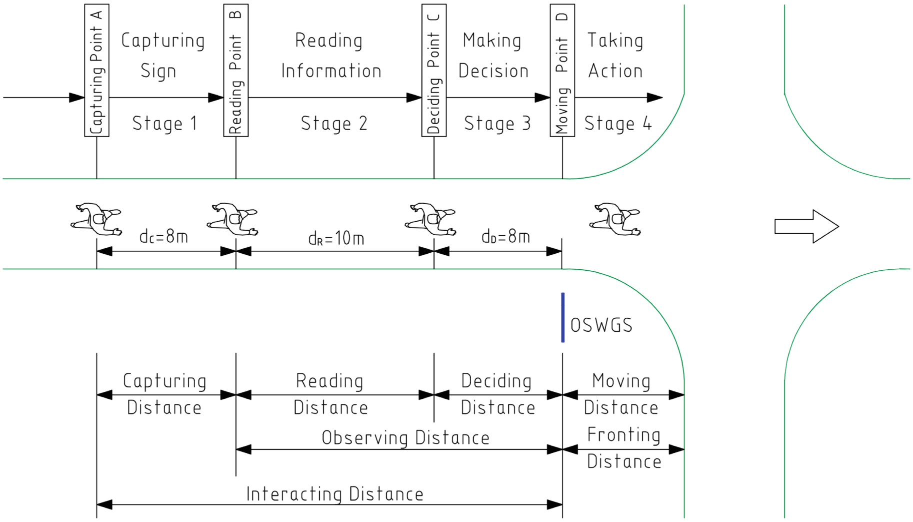

Fig. 1. OSWGS interaction model

so that they should make some physiological and psychological preparation for the stage of reading information.

Reading Information. Reading information stage refers to the process that the evacuators evacuate from the reading point B to the deciding point C. The deciding point is the position where the evacuators finish their reading information and start thinking about the meaning of the guidance information and considering how to make decisions next for themselves. The meaning of this stage for evacuators is getting the guidance information from OSWGS. As a much important stage of the interaction process, this stage can be regarded as the information input stage of evacuators' cognitive process.

Making Decision. Making decision stage refers to the process that the evacuators evacuate from the deciding point C to the moving point D. The moving point is the position where the evacuators finish their making evacuation decisions and start taking action as the instruction of the guidance information. Different from driving behavior, emergency evacuation doesn't have to consider the distance between moving point and sign position point for walking's low speed, so the two positions overlap in the interaction model. The meaning of this stage for evacuators is understanding information and making decisions, and it can be regarded as the information processing stage of evacuators' cognitive process.

Taking Action. Taking action stage refers to the process after the moving point D. Based on the information comprehension and evacuation decision, the evacuators take specific action in this stage, and it can be regarded as the information output stage of evacuators' cognitive process.

3.2 Interaction Distance

Interaction distance refers to the evacuation distance of each interaction stage in the OSWGS interaction model. The values of interaction distance should be determined based on the actual statistics, including the evacuators' statistical features (such as age, gender, education level, physical condition, response capability, and so on) and the environment's statistical features (such as path width, crossing amount, road condition, lighting situation, and so on).

Take a certain case as an example to illustrate the interaction distance values' calculation methods. Assume that statistical analysis has been carried out on the characteristics of the public in the area of China and the evacuation velocity υ value can be determined as 3.5 m/s.

Deciding Distance. Deciding time t_D can be divided into two parts: thinking time t_t and reaction time t_r. According to the measured data, thinking time can be determined from 1.0 s to 1.5 s, while reaction time may be roughly determined as 1.0 s. The method of calculating deciding distance d_D is as follow.

$$d_D = \upsilon \times (t_t + t_r) \tag{1}$$

Approximate the result of the calculation as an integer: $d_D = 8\,\text{m}$.

Reading Distance. According to Posner [5], the average reading speed of regular English article is 330 words/min. According to Liao and Zhang [6], the average reading speed of regular Chinese article is 309 words/min. Having considered an OSWGS's information amount and the corresponding relationship between other information elements (such as Arabic numeral, graphic, symbol, and so on) and words, the reading time t_R may be roughly determined as 3.0 s. The method of calculating reading distance d_R is as follow.

$$d_R = \upsilon \times t_R \tag{2}$$

Approximate the result of the calculation as an integer: $d_R = 10\,\text{m}$.

Capturing Distance. Capturing time is similar to deciding time, so t_C may be roughly determined as 2.25 s. The method of calculating deciding distance d_C is as follow.

$$d_C = \upsilon \times t_C \tag{3}$$

Approximate the result of the calculation as an integer: $d_C = 8\,\text{m}$.

4 Information Amount

4.1 Shannon Information Theory

Shannon [7], the founder of information theory, gave a method for information measurement from the perspective of probability.

Consider that there's a discrete random variable X, whose possible output is x_i, $i = 1, 2, \ldots, n$. The information amount of $X = x_i$ is as follow.

$$I(x_i) = -logP(x_i) \tag{4}$$

When the base is 2, the unit is bit.

4.2 Information Amount Calculation

OSWGS mainly includes 7 types of information: English, Local Language, Arabic numeral, Color, Shape, Direction Arrow, and Graphic Symbol. Particularly, Local Language varies from country to country, aiming to be better understood by the locals. In this paper, Local Language takes Chinese as an example.

Calculate each type of information separately. Take the calculation of English as an example. There are a total of 26 English letters, and in order to simplify the calculation, assume that each letter appears to be independent of each other. In the other words, the probability of each letter appearing is 1/26 when there's some English Language on an OSWGS. The information amount of a single English letter is calculated as follow.

$$\begin{aligned} I(x_1) &= -\,log_2^{P(x_1)} \\ &= -\,log_2^{\frac{1}{26}} \\ &= 4.7\,bit \end{aligned} \tag{5}$$

Similarly, the calculation results of all unit information amounts are shown in Table 1.

Table 1. OSWGS unit information amount summary table

x_i	x_1	x_2	x_3	x_4	x_5	x_6	x_7
Information type	English	Chinese	Arabic numeral	Color	Shape	Direction arrow	Graphic symbol
Amount/bit	4.7	11.3	3.3	3.0	3.3	4.6	5.9

In order to calculate an OSWGS's information amount, count its unit number of each information type separately, and record it as n_i. Take Color as an example. Assume that an OSWGS contains several types of information. Having observed it carefully, we find that it contains three kinds of colors altogether: blue, green, and white, and we can point out that n_4 equals 3. The method of calculating the amount of an OSWGS's layout information is as follow.

$$I_{OSWGS} = \sum\nolimits_{i=1}^{7} n_i \cdot I(x_i) \tag{6}$$

4.3 Allowed Maximum Information Amount

Too much information extends evacuators' reading and understanding time. Due to human's limited ability to process information and the importance of evacuation time in emergency escape, it is necessary to get a reasonable value of an OSWGS's allowed maximum information amount.

Considering that an OSWGS may contain uncertain types and quantities information units, in order to simplify the calculation, we may unify all types of information into one type, such as language information. Due to the familiarity with English differing from country to country, local language may be the best choice. In this paper, assume that an OSWGS includes only Chinese character information.

According to the reading speed of Chinese (309 words/min) and the OSWGS's interaction model, the allowed information process time during evacuation is the sum of reading time and decision time (3.0 s + 2.25 s = 5.25 s). The allowed maximum number of Chinese character may be determined as 27 (309 ÷ 60 × 5.25 ≈ 27). The allowed maximum information amount I_{max} is as follow.

$$\begin{aligned} I_{max} &= \sum\nolimits_{i=1}^{7} n_{imax} \cdot I(x_i) \\ &= n_2 \times I(x_2) \\ &= 305.2\,bit \end{aligned} \tag{7}$$

It is recommended to control the amount of information within 305.2 bit when designing an OSWGS.

4.4 Occlusion Information Loss Amount

Considering the impact of occlusion on the information transfer effect during the information input stage, it is necessary to analyze the information loss amount caused by occlusion. The method of calculating occlusion information loss amount I_{loss} is as follow.

$$I_{loss} = \sum\nolimits_{k}^{n} \frac{I_k \cdot d_k}{d_R} \tag{8}$$

In the equation above, k refers to the kth occluded information unit, and I_k refers to the kth unit's information amount, and d_k refers to the kth unit's obscured distance, and n refers to the number of obscured units in the reading information stage, and d_R refers to the reading distance.

Occlusion information loss amount can be used to measure the information transmission loss caused by occlusion and evaluate the occlusion disposal methods.

5 Information Design

5.1 OSWGS Classification

OSWGSs in different positions provide different guidance functions and meet evacuators' different psychological needs. As shown in Table 2, OSWGSs are classified into 11 kinds based on different evacuation environments.

Table 2. OSWGS classification

Main procedure	Evacuation environment	OSWGS
Starting point	Disaster area	Disaster Type Sign
	Risk area	Evacuation Plan Sign
		Description Sign
En route	Straight road	Midway Indication Sign
	Curved road	
	Vertical multilayer	Vertical Indication Sign
	General intersection	Intersection Indication Sign
	Optional intersection	Optional Route Sign
	No entry	No Entry Sign
	Dangerous section	Danger Warning Sign
	Safe area	Temporary Area Sign
Terminal point	Refuge place	Emergency Shelter Sign

5.2 Necessary Information Element

Disaster Type Sign. Compared with other areas, disaster areas are much more dangerous, so it is necessary to set Disaster Type Signs at these locations to alert the public to caution. The disasters mainly include fires, floods, landslides, typhoons and mudslides.

The main function of Disaster Type Sign is to quickly attract the public's attention. Their layout information should be as simple as possible and their features should be much prominent. Therefore, besides color and shape, only the Disaster Type Symbol element should be selected when designing its layout information.

To be more acceptable, the symbols prefer the corresponding symbols in the current standards. Fires Symbol selects W021 in ISO7010, and Floods Symbol selects WSW014 in ISO20712-1. Symbols not found in current standards need to be designed based on the principle of simple and vivid.

Disaster Type Symbols are shown in Fig. 2. From left to right, there are Fires, Floods, Landslides, Typhoons, and Mudslides.

Color and shape play an important role in attracting public's attention. As shown in Yuchang Han's eye movement experiments [8], yellow and triangle are easier to be found first. Disaster Type Signs corresponding to the Disaster Type Symbols are designed as shown in Fig. 3.

Fig. 2. Disaster Type Symbols

Fig. 3. Disaster Type Signs (Color figure online)

Evacuation Plan Sign. Sudden disasters cause public bad mood such as panic and anxiety, leading to a decline in cognitive ability. Evacuation Plan Sign can increase the public's awareness of the surroundings and help them adjust their mood. Evacuation Plan Sign should provide real and streamlined information within the evacuation scope and highlight the information that is important for evacuation.

Road Network Information. According to this information, evacuators can familiarize themselves with the surrounding road network in advance, and reduce their strangeness during the evacuation.

Current Location Information and Emergency Shelter Location Information. According to this information, evacuators can specify the relative location of the emergency shelter and quickly determine the best evacuation route.

Best Evacuation Route Information. Generally speaking, a short and good road conditions path can contribute to evacuation. Marking the best evacuation route on the evacuation plan can help evacuators make their best choices in complex road networks.

Distance Information. Distance information shows the distance from the current location to the emergency shelter. It can help evacuators get certain expectations for evacuation intensity in advance.

Relative Safe Areas Information. According to this information, evacuators can know the location of temporary rest areas on the way to the emergency shelter, and they can decide whether to have a short rest at the right point during their evacuation.

Other Potential Disaster Information, Dangerous Areas Information, and No Entry Information Within the Evacuation Scope. They can remind evacuators to be vigilant about unsafe environments and bypass them in advance.

Other Information. Other information such as scale information and compass information should also be contained. Since the Evacuation Plan Sign is mainly used before the disaster, its information should be as detailed as possible and not subject to the allowed maximum information amount.

Evacuation Plan Sign is designed as shown in Fig. 4.

Fig. 4. Evacuation Plan Sign

Description Sign. In general, the Description Sign is designed to match the Evacuation Plan Sign. It can deepen the public's understanding of the evacuation environment.

The Description Sign should contain the following information: Emergency Shelter Symbol, Disaster Type Symbols, and other precautions. Emergency Shelter Symbol and Disaster Type Symbols indicate that the Description Sign is applicable to emergency evacuation situations in the event of such types of disaster.

Description Sign is designed as shown in Fig. 5.

Fig. 5. Description Sign

The setting effect of Evacuation Plan Sign and Description Sign in a scene is shown in Fig. 6.

Midway Indication Sign and Vertical Indication Sign. Setting Midway Indication Signs and Vertical Indication Signs at appropriate locations helps evacuators

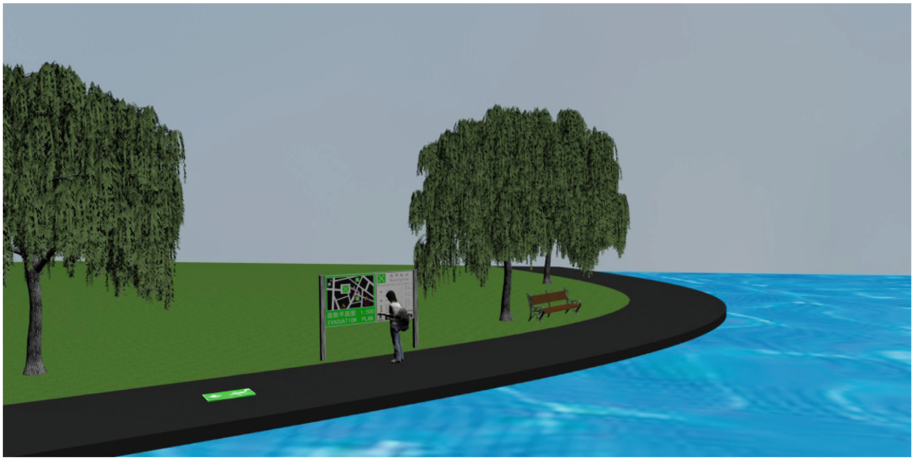

Fig. 6. The setting effect of Evacuation Plan Sign and Description Sign

continuously obtain guidance information during their evacuation process and achieve the psychological verification of their evacuation direction's correctness.

According to their functions, the Midway Indication Sign and the Vertical Indication Sign should be designed as simple as possible. They should contain only Emergency Shelter Symbol information and Direction Arrow information. The Emergency Shelter Symbol indicates that the sign is suitable for emergency evacuation and the Direction Arrow indicates that the direction indicated by the arrow is the correct evacuation direction.

They are designed as shown in Fig. 7. Midway Indication Sign is the left one, and it means going straight in the direction of the arrow. Vertical Indication Sign is the right one, and it means going up in the direction of the arrow.

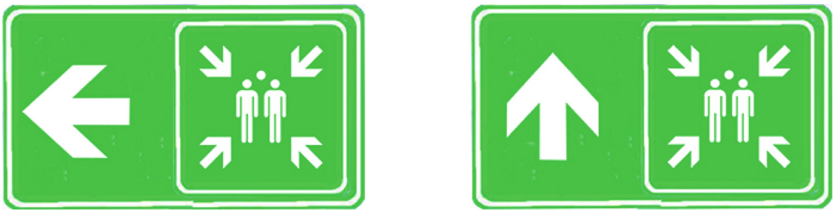

Fig. 7. Midway Indication Sign and Vertical Indication Sign

The setting effect of Midway Indication Sign and Vertical Indication Sign in a scene is shown in Fig. 8.

Intersection Indication Sign. The intersection is one of the most confusing locations for evacuators due to its multiple selectivity. Intersection Indication Sign's function is to guide the evacuators to correctly select their evacuation route. It should contain the

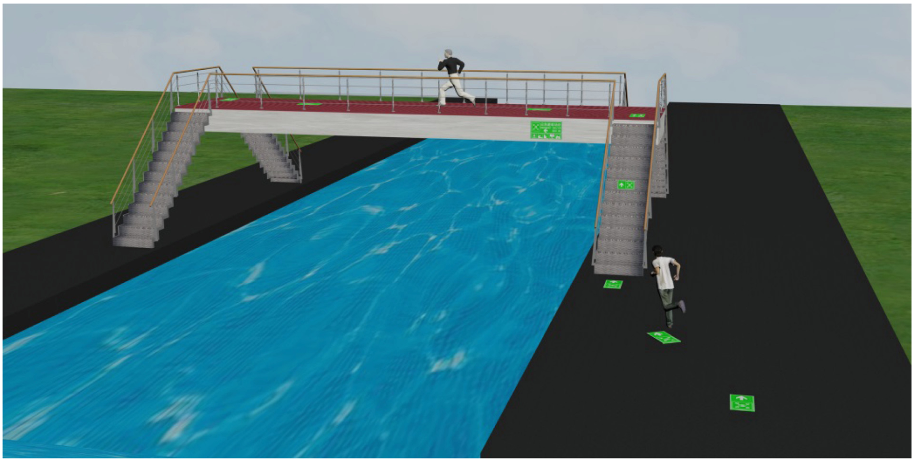

Fig. 8. The setting effect of Midway Indication Sign and Vertical Indication Sign

following information: Direction Arrow, Distance, Text, Emergency Shelter Symbol, and Disaster Type Symbols.

Direction Arrow Information. According to this information, evacuators can select a right evacuation route at the intersection. It improves the accuracy of the public's evacuation direction selection.

Distance Information. In order to avoid the homing behaviors of the evacuators, it is necessary to provide distance information on the sign. Distance information also contributes to adjusting evacuators' anxiety during their evacuation.

Text Information. As an auxiliary function, text information can further clarify the meaning of the sign.

Symbol Information. Symbol information of the Intersection Indication Sign includes Emergency Shelter Symbol and Disaster Type Symbols, indicating that the sign is suitable for emergency evacuation of such disasters.

Intersection Indication Sign is designed as shown in Fig. 9.

Fig. 9. Intersection Indication Sign

The setting effect of Intersection Indication Sign in a scene is shown in Fig. 10.

Fig. 10. The setting effect of Intersection Indication Sign

Optional Route Sign. The density of personnel during evacuation has a certain impact on evacuation efficiency. Diverted evacuation helps relieve congestion. When there are routes similar to the best evacuation route's length, they can also be used for evacuation. To illustrate this situation, it is necessary to set an Optional Route Sign at the selection point.

Optional Route Sign should include the information of Emergency Shelter Symbol, Disaster Type Symbols, Text, and Optional Route Sketch. Optional Route Sketch should fully reflect the start point and the terminal point, and clearly mark the optional routes.

Optional Route Sign is designed as shown in Fig. 11.

Fig. 11. Optional Route Sign

The setting effect of Optional Route Sign in a scene is shown in Fig. 12.

Fig. 12. The setting effect of Optional Route Sign

No Entry Sign and Danger Warning Sign. In order to indicate the no entry road sections and the dangerous locations caused by the disaster around the evacuation route, it is necessary to set No Entry signs and Danger Warning Signs at the corresponding locations.

No Entry Sign/Danger Warning Sign should include the information of Emergency Shelter Symbol, Disaster Type Symbols, No Entry Symbol/Danger Warning Symbol. No Entry Symbol and Danger Warning Symbol are each selected from P004 and W001 in ISO 7010.

They are designed as shown in Fig. 13. No Entry Sign is the left one, and Danger Warning Sign is the right one.

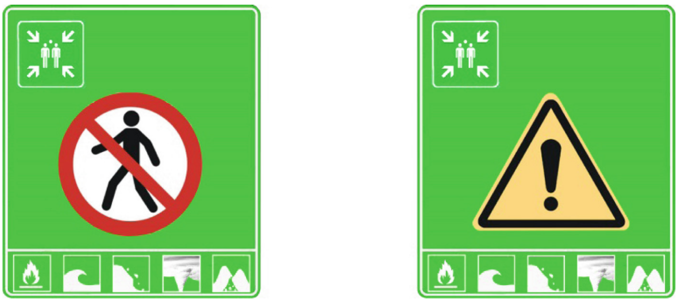

Fig. 13. No Entry Sign and Danger Warning Sign

Temporary Area Sign. When the evacuation distance is a little far, it is necessary to set Temporary Area Signs in relatively safe positions to prompt the needy evacuators to take a short break there.

Temporary Area Sign should include the information of Text, Temporary Area Symbol, and Disaster Type Symbols. Temporary Area Symbol is selected from 1–1 in DB12/330 [9].

Temporary Area Sign is designed as shown in Fig. 14.

Fig. 14. Temporary Area Sign

Emergency Shelter Sign. Emergency Shelter is the evacuation terminal point. In order to clarify to the evacuators that they can gather here, it is necessary to set up an Emergency Shelter Sign in the corresponding position.

Emergency Shelter Sign should include the information of Text, Emergency Shelter Symbol, and Disaster Type Symbols. It states that the emergency shelter is suitable for such disasters.

Emergency Shelter Sign is designed as shown in Fig. 15.

Fig. 15. Emergency Shelter Sign

5.3 Information Amount Verification

In order to verify whether the designed information meets the requirement of allowed maximum information amount, the information amount of each sign is calculated and compared with 305.2 bit. Particularly, considering the function and application conditions of Evacuation Plan Sign and Description Sign, their information amount does not participate in this verification.

Take Fires Sign as an example. It includes only 2 kinds of colors (yellow and black), and a symbol (Fires Symbol), and a shape (triangle). According to Table 1, the information amount of Fires Sign is calculated as follow.

$$\begin{aligned} I_{FiresSign} &= \sum\nolimits_{i=1}^{7} n_i \cdot I(x_i) \\ &= 2 \times 3.0 + 1 \times 3.3 + 1 \times 5.9 \\ &= 15.2\,bit \end{aligned} \tag{9}$$

Compared with 305.2 bit, the information of designed Fires Sign meets the requirement of allowed maximum information amount. The information of other designed signs can be calculated in the same way, and the results are shown in Table 3.

Table 3. Designed OSWGSs' information amount verification

Sign name	Information amount/bit	Meet(Y) or Not(N)
Disaster Type Sign	15.2	Y
Midway Indication Sign	23.1	Y
Vertical Indication Sign	23.1	Y
Intersection Indication Sign	230.0	Y
Optional Route Sign	305.2	Y
No Entry Sign	83.0	Y
Danger Warning Sign	83.0	Y
Temporary Area Sign	196.7	Y
Emergency Shelter Sign	210.8	Y

5.4 Information Occlusion Disposal

Effective transmission of information should also be considered in information design. Occlusion is one of the most important reasons that affect OSWGS's information transmission.

Simulation Model. A simulation model was created by 3dsmax software to simulate the effect of occlusion on information. The model is shown in Fig. 16.

In the simulation model, an OSWGS and two obstacles were created, and a camera 1.6 m above the ground was used to simulate the human eyes. Observe the occlusion of the OSWGS information by the obstacles when the camera is gradually moved from the distance to the OSWGS.

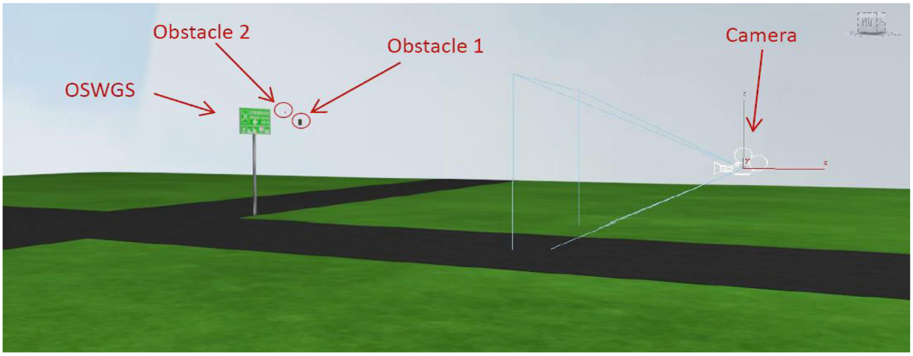

Fig. 16. The simulation model of information occlusion

Table 4. The information occlusion by obstacle 1

Occlusion element	Occlusion start position (m)	Occlusion end position (m)	Occlusion distance (m)
m	18.00	10.09	7.91
T	18.00	11.42	6.58
E	18.00	8.85	9.15
R	18.00	8.00	10.00
所	15.17	8.00	7.17

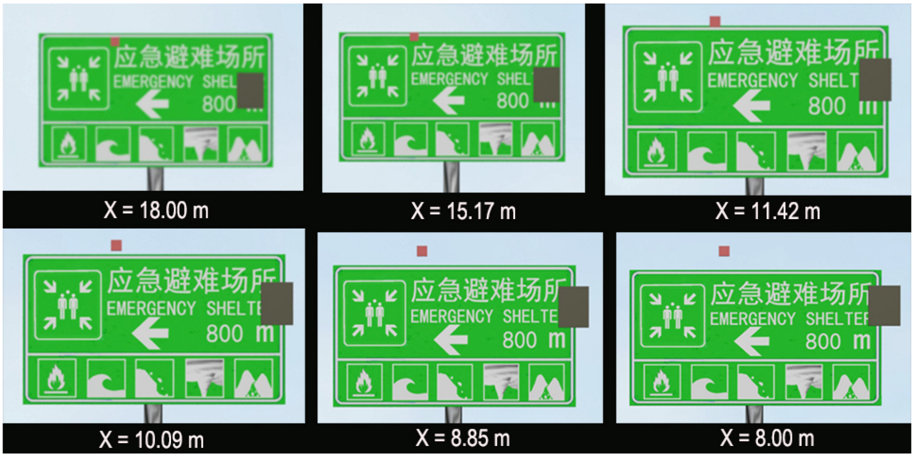

Fig. 17. Vision screenshots of key positions

While the camera moving in the entire stage of Reading Information, the obstacle 2 obscures the sign for a period of time, but it has no effect on the information at all, because there is no information in the area it blocks.

The occlusion of the information by obstacle 1 is shown in Table 4.

Several vision screenshots of key positions during the camera's movement are shown in Fig. 17.

The OSWGS's occlusion information loss can be calculated based on the Eq. (8) in this paper as follow.

$$
\begin{aligned}
I_{loss} &= \sum\nolimits_{k}^{n} \frac{I_k \cdot d_k}{d_R} \\
&= \frac{4.7 \times (7.91 + 6.58 + 9.15 + 10.00) + 11.3 \times 7.17}{10.00} \\
&= 23.91 \text{ bit}
\end{aligned}
$$

Obstacles Disposal. Since the obstacle 2 has no effect on the information transmission, it is judged that no treatment is required. In order to reduce occlusion information loss caused by obstacle 1, several solutions are as follows.

Remove Obstacle 1. If obstacle 1 is easy to remove, direct removal can reduce the occlusion loss to zero.

Move OSWGS. If obstacle 1 is not easy to remove, moving the OSWGS's design position to the left a little bit can also reduce the occlusion loss to zero, but be careful not to create new occlusions due to this operation.

Adjust Layout. If obstacle 1 and OSWGS's position are not easy to change, moving the Text information and the Distance information on the layout to the left a little bit can perfectly reduce the occlusion loss to zero.

6 Conclusion

In this paper, we have analyzed the design principles and a design method of OSWGS's layout information based on human factors engineering and psychology.

Through the analysis of the interaction mode between evacuator and OSWGS, the interaction process is divided into four stages, and we have gotten the conclusion that the main research stage of information transmission should be the stage of Reading Information, and the range is about 8 ~ 18 m away from the front of OSWGS.

Based on Shannon information theory, a method of calculating an OSWGS's information amount and its loss caused by occlusion has been proposed, and 305.2 bit has been pointed out to be the recommendation value of the allowed maximum information amount, which can be used to evaluate an OSWGS's design rationality.

OSWGSs have been divided into 11 categories. What necessary information elements should each kind of OSWGS provide has been analyzed, and typical design examples and setting effects in some scenes have been given in this paper to explain the application of the analysis results.

Particularly, focusing on the influence of occlusion on information transmission, the application of occlusion information loss calculation method in occlusion effect evaluation and occlusion disposal has been given by simulation. It shows that the occlusion information loss calculation method helps to guide the OSWGS's information design to the occlusion problem.

The method of designing an OSWGS's layout information proposed from the perspective of Interactive mode and information quantification can be used to guide OSWGS's design and it is of great significance to improve evacuation efficiency. Further statistical analysis of the basic characteristics of personnel in different countries and regions will help to improve the accuracy of the method and expand its application scope.

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