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Optimal Layout of Static Guidance Information in Comprehensive Transportation Hubs Based on Passenger Pathfinding Behavior

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Abstract: Passenger orientation (pathfinding) is an important factor in designing the layout of comprehensive transportation hubs, especially for static guidance sign systems. In essence, static guidance signs within the hub should be designed according to passengers' pathfinding demand, that is, to provide passengers with accurate information at the appropriate location. Therefore, from the perspective of passenger information demand, this study aims to determine the appropriate location and density of static guidance information. Two types of passenger information demand in the pathfinding process are defined in this study: one is generated at the path decision point, where multiple path options exist; the other is at the points between decision points, where pathfinders need to confirm that they are still on the correct path. According to the interaction of pathfinding behavior and guidance information, the abstract relationship model is established between macro-behavioral characteristics and the micro-psychological state. Moreover, based on walking speed analysis, the judgment criterion of passenger psychology in pathfinding is proposed to determine the spatial location and density of guidance information. The analysis results of Shanghai Hongqiao International Airport show that, under the threshold of the speed drop section given in the study, 80% of passenger information demand is satisfied when guidance information spacing is 47 m, and 60% of information demand is satisfied when the spacing is 56 m. The findings presented in this paper can provide a reference for the optimal design of static guidance information in comprehensive transportation hubs.

Keywords: behavioral decision-making; comprehensive transportation hub; pathfinding behavior; passenger information demand; information demand density

1. Introduction

With the intercity transportation modes in comprehensive transportation hubs, most passengers arrive for the first time and are not familiar with the hub. Timely and effective information services are essential for smooth and quick movement [1,2], and a well-designed information release system is an important foundation to ensure the efficient operation of the hub [3].

Passenger information demand is the starting point for information release [4], whose benefits can be maximized by accurate demand analysis [5,6]. In the field of library and information science, information demand represents the insufficient cognitive state of those who demand information and the cognitive mechanisms on which they depend [7,8]. Due to the dynamics and uncertainty of information demand, there are different passenger demands at different times and locations within the hub [9,10]. Only when appropriate information is released at the appropriate times and locations can we meet the demands of passengers and improve the effects of information release [11,12].

Static guidance information has the highest demand intensity within the hub, and the information demand runs through the entire transfer streamline [13]. As the main carrier of guidance information, the static guidance sign is a means of organizing internal passenger flow and a powerful guarantee for the smooth transfer of passengers [14,15]. It is necessary to set reasonable guidance signs at the appropriate locations, so that passengers can follow the designed streamline [16,17]. At the same time, the setting of guidance signs should be appropriately dense; that is, too little information cannot provide passengers with continuous guidance, and too much information will bring confusion.

Scholars often analyze the layout of guidance signs using the mathematical method of multi-objective optimization modeling [18–21]. Whether to set a sign at a decision point is regarded as the 0–1 planning problem. Cao [18] put forward an optimization model based on the genetic algorithm to determine the locations of signs, which was improved by Han [19] based on a simulated annealing genetic algorithm. Tam [20] proposed a binary linear program for better allocation of guidance signs. Lin [21] established a multi-objective model for the layout of guidance signs using improved genetic algorithms.

Additionally, the layout design of guidance signs rarely considers passengers' demand for enhanced information [22–26]. So, for points of enhanced information, the setting of guidance signs usually takes the designers' subjective experience and conceptual framework as the design basis, and the influence of passengers' behavioral factors are considered less, which often leads to an unreasonable and discontinuous design of guidance signs. In terms of setting the spacing of static guidance signs, there are no unified standards in various countries and regions. The *German Signage Planning Manual* (2004) states that a sign should be set at a decision point, and if the path is long, it is necessary to set more signs at intervals of 25–100 m to ensure passengers' certainty of the path. In Japan [27], the spacing of guidance signs is generally 40–50 m when they are continuously set. When the spacing is 20–40 m, attached guidance signs are added. The *Provisions on the establishment of signs for rail transit operation service in Shanghai, China* (2005) state that guidance signs should be set every 80 m on a transfer passageway to indicate the route and direction. The *Public signs and marking standards for rail transit in Beijing, China* (2010) stipulate that corresponding guidance signs should be added when the length of the passageway is greater than 30 m, that is, existing studies of guidance sign layout are limited to qualitative analysis of passenger flow and passenger lines within the hub. And guidance signs are laid out in key locations according to the standards, but an optimal quantitative layout method has not yet been created.

The existing guidance signs within urban comprehensive transportation hubs are more or less deployed rigidly, which cannot fully consider the relationship between the sign layout and the information demand for passenger decision-making. Therefore, the influence of guidance signs on pathfinding behavior and path decision-making is explored. Pathfinding as a concept of space legibility originated in 1960 [28] and has grown into a large body of research for navigation around libraries [29], hospitals [30,31], shopping centers [32], airports [33–36], and transit centers [37]. Arthur and Passini [38] made guidance sign a design objective, comprehensively taking into account the integration of passengers, architecture, and guidance signs using the pathfinding method to determine the key design elements of guidance signs. Li and Xu [15] studied the impact of guidance signs on pedestrians making decisions using a simulation technique. Fang [39] proposed that the certainty of passengers' behavior fluctuated within a certain range. Judging from the existing research results, the layout of static guidance signs obviously affects the pathfinding behavior of passengers within hubs, which further affects the operation efficiency of the hubs.

To sum up, the mathematical method of multi-objective optimization modeling is often used to analyze the layout of the guidance signs, which is theoretical, and the applicability to the actual guidance sign system needs to be verified. Moreover, there are no uniform standards for the sign layout spacing in various countries and regions, which will have a relatively poor guiding effect on the design of the actual guidance sign system. In particular, existing models and standards fail to quantitatively describe the behavioral and psychological characteristics of passenger flow, and

rarely consider passengers' demand for enhanced information. Therefore, sophisticated guidance sign location models that respond to passenger decision-making and behavioral characteristics will be an interesting trend in the optimal layout of future comprehensive transportation hubs.

To reduce the gap between the service level of signs and the actual demand of passengers, it is critical to design the layout of static guidance signs based on passengers' information demand. The objective of this study is to propose an optimal quantitative layout method, from the perspective of passenger information demand, to determine the appropriate location and density of static guidance information, and to explain the layout law of guidance information from the perspective of cognitive psychology. Therefore, the Shanghai Hongqiao Comprehensive Transportation Hub is investigated as a research object. The decision points of guidance information within the hub are identified with a combination of theoretical analysis and field measurement. Then, an on-site survey is performed to investigate passengers' behavior and psychology to determine the points of enhanced information between decision points.

2. Methodology

2.1. Definition of Information Demand

Based on pathfinding behavior, passengers within a hub will generate two types of information demand. When there are multiple path selections, the passenger needs to select a suitable path, which generates the first type of information demand. After selecting the correct path, the passenger may deviate from the given direction due to psychological discontinuity. To reduce the uncertainty, the second type of information demand is generated, and the passenger can confirm that he or she is still on the correct path. Therefore, two types of passenger information demand in the pathfinding process are defined in this study.

(1)   Information demand for path selection

In the process of pathfinding, the location where the passenger needs to select a path is called the decision point, which is where the information demand for path selection is generated. That is, it is necessary to provide sufficient guidance signs at corresponding decision points to help passengers make pathfinding decisions.

(2)   Information demand for enhanced certainty

After the passenger enters the correct path, the location where the information demand for enhanced certainty is generated between decision points is called the information enhancement point. It is necessary to add appropriate guidance signs between decision points to ensure continuity of the passenger's psychology.

Figure 1 displays the relationship between the locations of two information demand points.
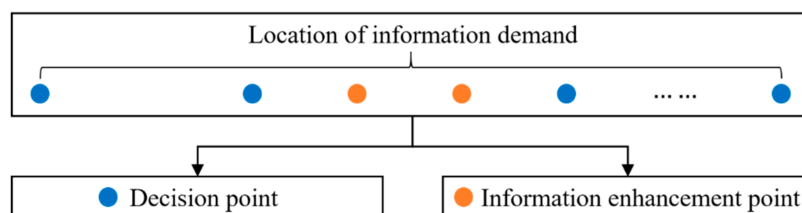

Figure 1. Relationship between the locations of two information demand points.

The method adopted in this study is mainly divided into two steps. Based on theoretical research and field investigation, the decision points in the process of pathfinding, that is, the spatial locations of information demand, are identified. Then, combined with the knowledge of cognitive psychology

and behavior analysis, field questionnaires and path tracking are used to determine the density of information demand between decision points, that is, the locations of information enhancement points.

2.2. Determination of Decision Points for Information Demand

Providing efficient and rapid information is a basic requirement for the operation of the hub, and the shortest walking paths help passengers save transfer time and physical exertion [3,40]. Frequently, passengers also prefer the shortest path [41]. For passengers who are not familiar with the hub, signs are the main means of path guidance and should be set along the shortest path based on a comprehensive consideration of multiple streamlines within the hub. In this study, a network topology relationship of the hub spatial structure is built abstractly, and the shortest paths between origination–destination (OD) pairs are calculated. According to the selection principles, the decision points on the path are determined as spatial locations of the demand for guidance information. A flowchart for determining decision points for information demand is shown in Figure 2.
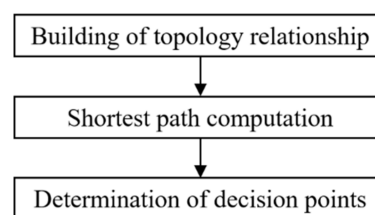
Figure 2. Flowchart for determining decision points.

2.2.1. Building of Topology Relationship

There are some key locations in building interiors, such as corridor intersections, corridor corners, and hall exits. At these locations, the passengers must choose between more than two directions to determine the direction in which to proceed [42]. The topology network formed by key locations and their connection paths in the building plane is called a reasonable route of addressing.

The oriented graph theory is introduced in this study, which abstracts hub spaces into nodes and edges. Nodes are the activity and decision points within the hub, which do not take up space. Edges are passageways connecting two nodes, called an arc if the passageway has a direction, and the weight of the edge (arc) is the impedance function of the segment on the passageway. To simplify the method, travel time is selected as the impedance function of the segment. After determining the topology relationship and its weight, the hub space can be abstracted to a weighted oriented graph, and the decision points of information demand are ultimately determined by calculating the number of nodes along the shortest path between specific OD pairs.

2.2.2. Shortest Path Computation

Dijkstra's algorithm is used to calculate the shortest path and the shortest distance. The basic idea of Dijkstra's algorithm is that each node is supposed to have a pair of labels (d_j, p_j), where d_j is the length of the shortest path from initial node s to node j (the shortest path from the vertex to itself is zero without arc, which length is zero), and p_j is the previous node of j along the shortest path from s to j. Now we can find the shortest path from initial node s to node j by the following steps of Dijkstra's algorithm.

Step 1: Initialization

Set the initial node to $d_s = 0$, in which p_s is empty. Then the initial node is marked as $k = s$, and all other nodes are set as unmarked.

Step 2: Distance verification

Verify the distance from all marked nodes k to their directly connected unmarked nodes j and set as follows:

$$d_j = \min\left[d, jd_k + l_{kj}\right]$$

where l_{kj} is the directly connected distance from node k to node j.

Step 3: Selection of next node

Select the lowest node of d_j from all unmarked nodes:

$$d_i = \min\left[d_j, \text{ all unmarked nodes } j\right]$$

Then node i is selected as a node in the shortest path, which is marked.

Step 4: Determination of previous node of i

Find node j^* directly connected to node i and define it as the previous one, which is set as $i = j^*$.

Step 5: Algorithm exit

If all nodes are marked, the algorithm exits completely. Otherwise, set $k = i$ and repeat steps 2–5.

2.2.3. Determination of Decision Points

Interconnection density (ICD) can be used to analyze the topological complexity of a building plane [42], where the ICD value of the node is the number of other nodes connected to it.

If ICD ≥ 3 and the connected node does not conclude a one-way exit, the node on the path is selected as the candidate for the decision point of information demand. According to the principle of information simplification, too much information makes passengers annoyed. Based on that, when the distance between two candidate points is shorter than the visual distance between signs, the candidate points can be merged selectively. The selection criteria for merging are as follows:

(1)　Priority of high ICD

　　The path selection of nodes with higher ICD is more complicated, so nodes with higher ICD are given top priority to reserve.

(2)　Priority of interfloor connection nodes

　　Nodes near elevators or escalators are more important than those on other passageways, because passengers need to decide whether to move between floors. Therefore, interfloor connection nodes are preferred to reserve when merging.

(3)　Merger of nodes with spacing shorter than the visual distance of signs

　　According to the formula for calculating the visual distance of different character heights under different visual conditions, as shown in Equation (1) [43], nodes of the same type with spacing shorter than the visual distance are merged.

$$D = 678.55 \times h \times \frac{A}{c} \tag{1}$$

　　where D is the visual distance, h is the character height, A is the absolute vision, and c is the conversion coefficient between characters and visual symbols, $c = 3.0735$.

2.3. Determination of Information Enhancement Points between Decision Points

Based on a combination of follow-ups and interviews, the pathfinding process of passengers was investigated and the microscopic behavioral characteristics of the guidance information environment were obtained. Following that, the information enhancement points between decision points for passengers on the passageway were determined by analyzing the relationship between passenger walking speed and guidance sign spacing.

2.3.1. Experimental Design

Experimental preparation: The typical scenario is selected for the experiment, and the mean speed of a path segment is approximated as the speed at the midpoint of the segment to obtain the passengers' walking speed on the passageway. Passengers are randomly selected.

Experimental process: The following methods are adopted to investigate the microscopic behavioral characteristics of passengers in the pathfinding process.

(1)   Follow-up survey

Taking two researchers as a group, a follow-up survey of pathfinding is conducted. One records the time when the passenger passes each marker point, and the other records the key behavior of the passenger in the pathfinding process. For each experimental scenario, a round-trip follow-up survey is conducted. After completing a one-way follow-up survey, the researcher waits in the place and selects the appropriate passenger to return from the original path for the next survey.

(2)   Passenger attribute record

Based on observation and inquiry, the researcher records the passengers' gender, estimated age, baggage quantity, and destination.

(3)   Passenger pathfinding survey

The passenger's familiarity with the experimental scenario and whether the guidance sign was viewed during the pathfinding process are obtained by filling out the questionnaire.

2.3.2. Analysis of Passenger Information Behavior

According to the definition of pathfinding, the process can be divided into three stages: spatial cognition, pathfinding decision, and pathfinding execution [38]. The three stages are related to each other, and occur alternately in cycles until the pathfinding process is completed.

On this basis, this study establishes an information processing model for passengers looking at guidance signs between decision points. During the pathfinding process, passengers mainly rely on visualization to obtain information, then analyze the collected information and decide to move. Consequently, pathfinding behavior can be a combination of discovering a sign, confirming the sign, executing an action, and experiencing confusion. The information processing behavior is divided into the recognition stage, action stage, and confusion stage.

(1)   Recognition stage

A passenger can clearly see the content of the sign, identify the information, and understand the displayed information.

(2)   Action stage

After understanding the content of the displayed information, the passenger determines the direction of travel and begins to walk until the current path becomes uncertain.

(3)   Confusion stage

In the confusion stage, the passenger is slightly to completely uncertain about the current path. The confusion ends when the passenger discovers the next sign or asking point.

Passengers who are unfamiliar with the hub can improve the certainty of their pathfinding behavior by interpreting the sign information. After obtaining the information, their certainty in the walking path increases, and as time goes on, their certainty decreases. Therefore, it is necessary to provide passengers with information within sufficient time so that certainty is maintained at a certain level. The ideal certainty level of passengers at each stage is shown in Figure 3.
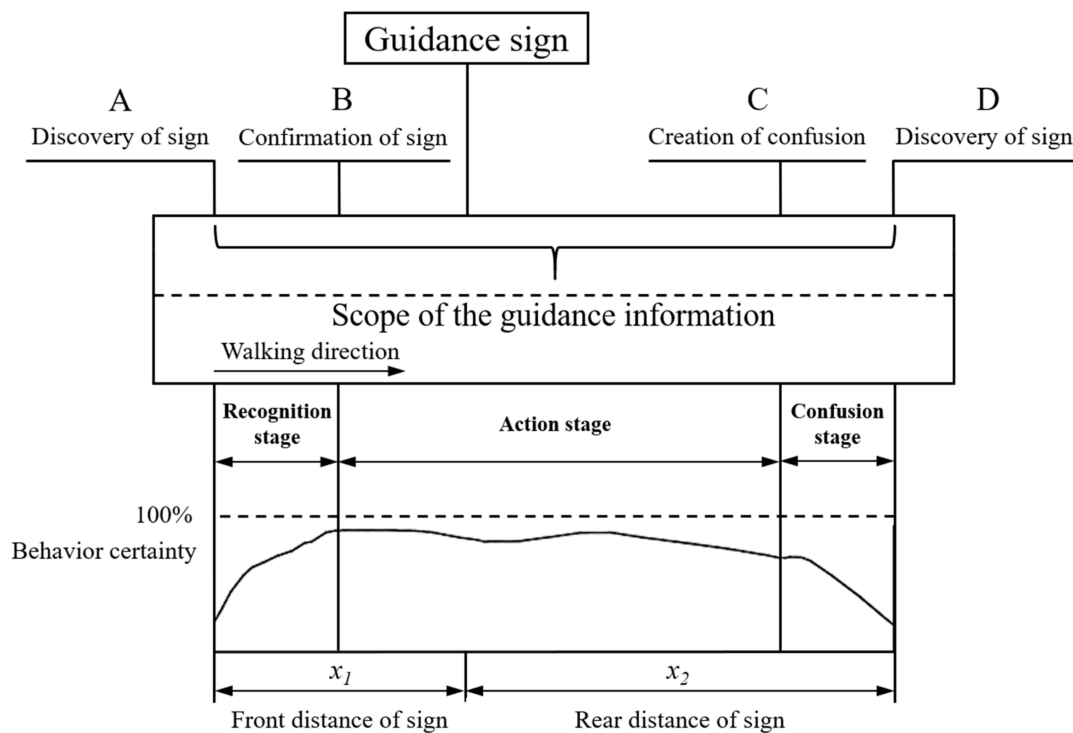
Figure 3. Passenger information behavior stages.

Based on cognitive psychology, passengers process and make decisions through the perceptual and cognitive systems, and feed their decision information back to the environment through the motor system (speed, acceleration, etc.). Generally, walking speed fluctuates within a certain range, increasing and decreasing. When a passenger's certainty is lower than the threshold, there is a sudden drop in speed [44–46].

Accordingly, the scope of the guidance sign is divided into a front distance and a rear distance. Their concepts are interpreted graphically, as shown in Figure 4.
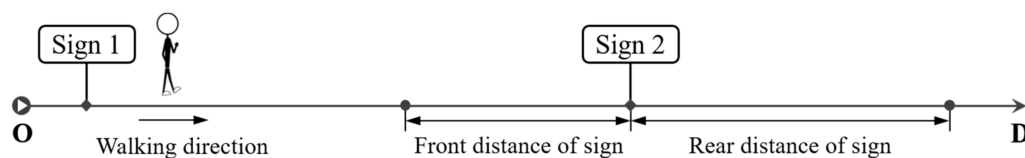

Figure 4. Scope of guidance information.

(i)   Front distance of sign

Passengers move in continuous space and time, and the cognitive discontinuity makes them hesitate or suspend, which further leads to the generation of information demand. Also, passengers will be psychologically certain when they can clearly see what is on the guidance sign ahead. Therefore, the visual distance to recognize the sign is defined as the front distance of the sign.

(ii)   Rear distance of sign

Passengers move on after they arrive from the previous sign and memorize its contents, and will experience a process of ambiguity or decline in psychological certainty before the next sign arrives. Therefore, the rear distance of the sign is the range from the previous sign to the point where certainty is lower than the threshold. A detailed explanation of the rear distance of the

sign is determined by calculating the distance between the rear point of the speed drop section and the previous sign. The steps to determine the speed drop section are as follows:

Step 1: Speed standardization

Due to individual differences among passengers, it is necessary to standardize the walking speed, and the ratio of speed to average speed is used as the standardized speed.

$$V_C = \frac{V}{\overline{V}} \times 100 \tag{2}$$

where V is walking speed and $\overline{V}$ is an individual's average speed.

Step 2: Analysis of speed drop section

The speed drop section consists of the front point and the rear point. The distance from the front point to the starting point is X_1, with a standardized speed of V_{C1}, and the distance from the rear point to the starting point is X_2, with a standardized speed of V_{C2}. Accordingly, (X_1, V_{C1}) represents the point where the standardized speed is greater than 100 and a downward trend appears, and (X_2, V_{C2}) represents the point where the standardized speed is lower than 100 for the first time.

Step 3: Determination of speed drop section

Indeed, not all speed drops are due to passenger uncertainty, and there is speed fluctuation due to motion characteristics. The speed drops significantly, which is caused by uncertainty; when the speed drops slowly, it is the speed fluctuation due to individual motion characteristics; otherwise, it is necessary to judge the degree of drop by analyzing the individual's overall speed drop behavior, thereby distinguishing between speed drop due to uncertainty and speed fluctuation. The purpose of this step is to identify the speed drop sections due to passenger uncertainty.

First, for an individual, the rate of speed drop per unit distance of each section is calculated. And the rate of speed drop per unit distance is as follows:

$$\Delta_X = \frac{V_{C1} - V_{C2}}{X_2 - X_1} \tag{3}$$

Second, the percentage of the speed drop rate is judged: if the percentage is greater than a certain value, it is judged as the speed drop due to uncertainty; if the percentage is less than a certain value, it is the speed fluctuation due to individual motion characteristics. When the percentage is between these two values, the percentage is sorted in descending order, and the cumulative percentage of the speed drop rate is calculated and judged. If the cumulative percentage is within a certain range and the percentage exceeds the threshold of the speed fluctuation, it is the speed drop due to uncertainty.

Therefore, the decision process of the speed drop sections is shown in Figure 5.

a_{X1i} is the percentage of the speed drop rate, and b_{X1i} is the cumulative percentage of the speed drop rate. a and c are the percentage thresholds of the speed drop rate for judging the speed drop due to uncertainty and the speed fluctuation due to motion characteristics, respectively. For the percentage between a and c, the former and latter percentages corresponding to the maximum percentage reduction are found, as shown by a_{X1i} and $a_{X1(i+1)}$ in Figure 6. The sum of a_{X1i} and its previous percentages is the lower limit of the cumulative percentage, the sum of $a_{X1(i+1)}$ and its previous percentages is the upper limit of the cumulative percentage, and the value of b is in the range between the upper and lower limits determined by the speed drop behavior of all passengers.
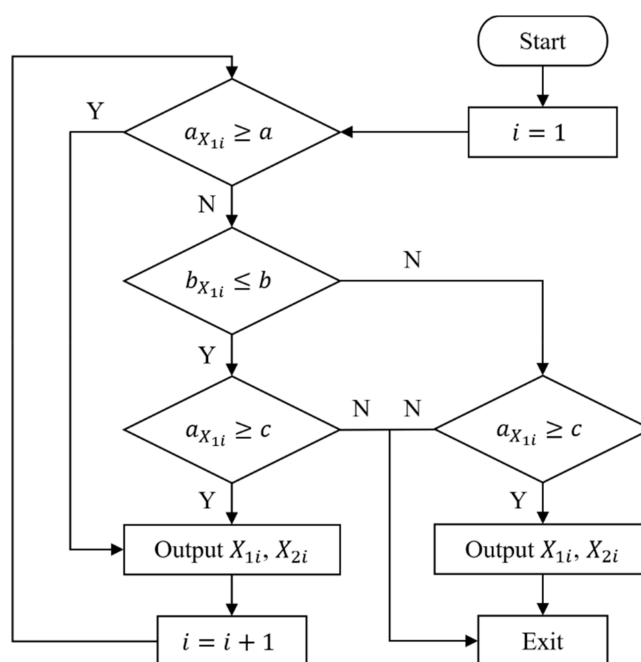
Figure 5. Decision flowchart for speed drop sections.
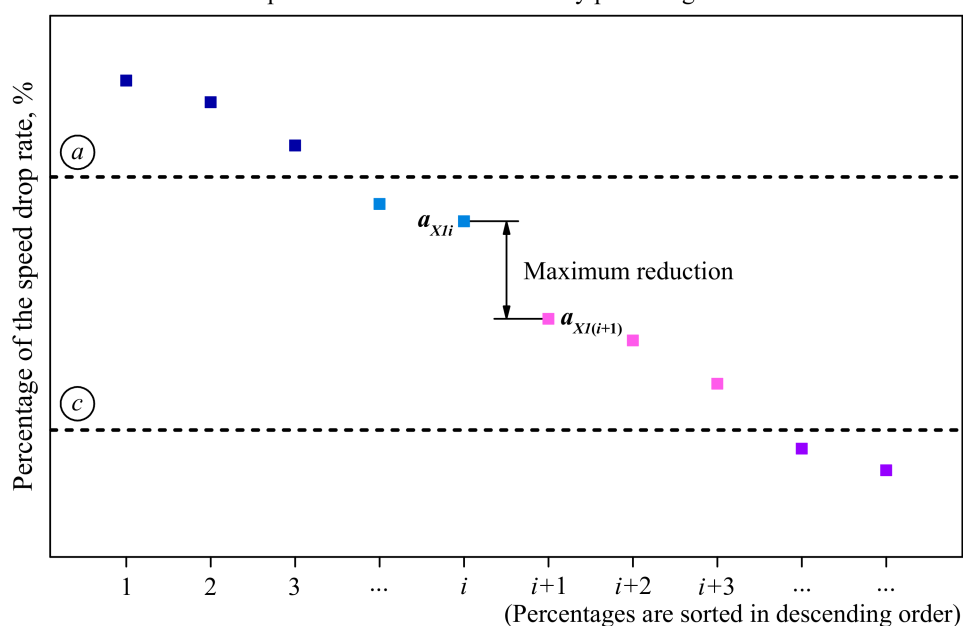

Figure 6. Analysis of individual speed drop behavior.

The specific decision process is as follows. Each speed drop section is sequentially judged in descending order. First, the percentage of the speed drop rate is judged: if a_{X1i} exceeds a, section i is taken as the speed drop section. Otherwise, the cumulative percentage is judged: if b_{X1i} does not reach b and a_{X1i} exceeds c, section i is the speed drop section. According to the field survey data, the values of a, b, and c are determined.

Based on this circular judgment, all speed drop sections can be extracted. Following that, the distance between the rear point of the speed drop section and the previous sign is calculated to determine the rear distance of the sign. Combined with the front distance, the layout density of guidance information demand between decision points is determined.

3. Case Study

3.1. Study Objective

To verify the model and method proposed in this study, we take Shanghai Hongqiao Comprehensive Transportation Hub as the study object. The internal environment of the hub is complex and the passenger flow composition is diverse. From east to west, Shanghai Hongqiao Hub consists of the Hongqiao Airport West Terminal, East Transportation Center, Maglev Station, High-speed Rail Station, and West Transportation Center. Only six modes of transportation are considered (train, plane, subway, taxi, bus, and private car), and 22 effective transfer lines are formed. It is necessary to optimize the layout of guidance signs within the hub to meet the information demand of passengers for smooth transfer.

3.2. Data Preparation

The main area plan of Shanghai Hongqiao Hub is collected, and the spatial topology relationship is built in combination with field measurements. The nodes within the hub are designated by letter + number, and segments are represented by node numbers at both ends; in addition, parameters such as segment length, segment attributes, and travel time are measured in the field. For larger areas without nodes, virtual nodes are used to represent their centers.

Taking the third floor of Hongqiao Airport West Terminal (departure floor) as an example, the field plan and network topology relationship are shown in Figure 7 and Table 1.
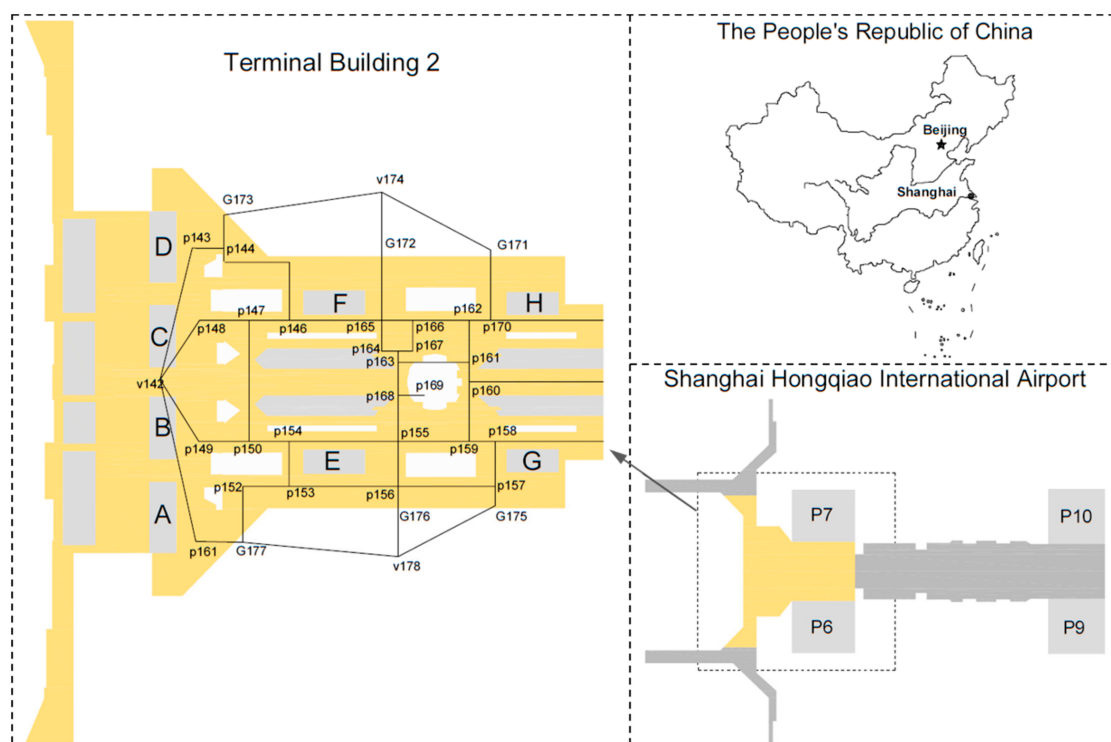

Figure 7. Airport departure floor (F3).

Table 1. Network topology relationship of airport departure floor.

Starting Point	Ending Point	Travel Time, s	Segment Attribute	Segment Length, m
L169	P168	20.97	Passageway	30
P168	P163	27.97	Passageway	40
P163	P167	31.46	Passageway	45
P163	P164	31.46	Passageway	45
P164	P165	34.96	Passageway	50
P167	P166	34.96	Passageway	50
P166	P162	48.95	Passageway	70
P162	P170	17.48	Passageway	25
P162	P161	48.95	Passageway	70
P161	P160	17.48	Passageway	25
P165	G172	62.93	Passageway	90
P170	G171	62.93	Passageway	90
P168	P155	48.95	Passageway	70
P160	P159	48.95	Passageway	70
P155	P159	62.93	Passageway	90
P159	P158	24.47	Passageway	35
P156	P157	87.41	Passageway	125
P155	P156	34.96	Passageway	50
P158	P157	34.96	Passageway	50
P156	G176	13.98	Passageway	20
P157	G175	13.98	Passageway	20
P156	P153	83.91	Passageway	120
P155	P154	83.91	Passageway	120
P154	P153	34.96	Passageway	50
P153	P152	34.96	Passageway	50
P154	P150	34.96	Passageway	50
P152	G177	48.95	Passageway	70
G177	P151	45.45	Passageway	65
P150	P149	34.96	Passageway	50
P147	P148	34.96	Passageway	50
P144	P143	24.47	Passageway	35
P147	P150	104.89	Passageway	150
P147	P146	31.46	Passageway	45
P146	P165	69.93	Passageway	100
P146	P145	41.95	Passageway	60
P145	P144	62.93	Passageway	90
P144	G173	27.97	Passageway	40
P143	V142		Virtual path	
P148	V142		Virtual path	
P149	V142		Virtual path	
P151	V142		Virtual path	
G173	V174		Virtual path	
G172	V174		Virtual path	
G171	V174		Virtual path	
G177	V178		Virtual path	
G176	V178		Virtual path	
G175	V178		Virtual path	
P165	P166	27.97	Passageway	40
P163	P161	62.93	Passageway	90
P160	E197	524.47	Large span Passageway	750
P170	E198	524.47	Large span Passageway	750
P158	E197	524.47	Large span Passageway	750

Note: G-gate, P-passageway, E-escalator, L-lift, V-virtual node.

In this study, five OD pairs within the Shanghai Hongqiao Hub are selected. According to the topology relationship within the hub, we can calculate the shortest path between the five selected OD pairs by Dijkstra's algorithm and determine the nodes that the shortest path passes.

(1) From the subway station (Hongqiao railway station) to the high-speed rail departure floor

The passing nodes are in turn: V76-G74-P71-P44-P43-P42-P41-P40-P39-P202-P38-P37-P36-P35-P34-P203-P33-P32-P29-E30-E198.

(2) From the bus station (1st floor of the East transportation center) to the high-speed rail departure floor

The passing nodes are in turn: V126-G124-P117-E116-E130-E167-P166-P162-P170-E198.

(3) From the subway station (Terminal 2) to the airport departure floor

The passing nodes are in turn: G10-P5-P6-P16-L180-L181-L169-P168-P155-P154-P150-P149-V142.

(4) From the high-speed rail arrival floor (B1) to the airport departure floor

The passing nodes are in turn: G111-P48-P47-P46-P45-P44-P43-P42-P41-P40-P39-P202-P38-P37-P36-P35-P34-P203-P33-P32-P29-P30-E198-P170-P162-P166-P165-P146-P147-P148-V142.

(5) From the P7 parking garage to the airport departure floor

The passing nodes are in turn: V20-P12-P4-P7-P17-L180-L181-L169-P168-P155-P154-P150-P149-V142.

According to the selection criteria for node merging, nodes of the same type whose spacing is shorter than the visual distance are merged. Referring to the visual distance of signs under different visibilities and character heights in Equation (1), we can select when the visibility is 1.0 and the character height is 20 cm, the visual distance is 44.74 m. Therefore, the decision points of guidance information demand are determined, and the optimization results for the five OD pairs are shown in Table 2.

Table 2. Optimal results of decision points on five OD pairs.

No.	OD Pairs	Decision Points of Guidance Signs
1	Subway station (Hongqiao railway station) to high-speed rail departure floor	P71 P44 P41 P40 P202 P36 P203 P32 P29 E30
2	Bus station (1st floor of East Transportation Center) to high-speed rail departure floor	P117 E116 E130 E167 E166 P162
3	Subway station (Terminal 2) to airport departure floor	P5 P6 L16 L180 L181 L169 P168 P155 P154 P150
4	High-speed rail arrival floor (B1) to airport departure floor	P44 P41 P40 P202 P36 P203 P32 P29 E30 P162 P165 P146 P147
5	P7 Parking garage to airport departure floor	P4 L17 L180 L181 L169 P155 P154 P150

3.3. Field Experiment

In the field experiment, two typical scenarios in the Shanghai Hongqiao Hub are investigated to determine the information demand density between decision points, and the sign layouts are shown in Figure 8a,b.

(1) Scenario 1

The connected passageway on the basement 1st floor (B1) connects the terminal and high-speed rail areas. The length of the survey area is 255 m, and sign layout spacing is shown in Figure 8a.

(2) Scenario 2

The connected passageway on the third floor (F3) connects the airport departure and high-speed rail departure floors. The length of the survey area is 248 m, and sign layout spacing is shown in Figure 8b.
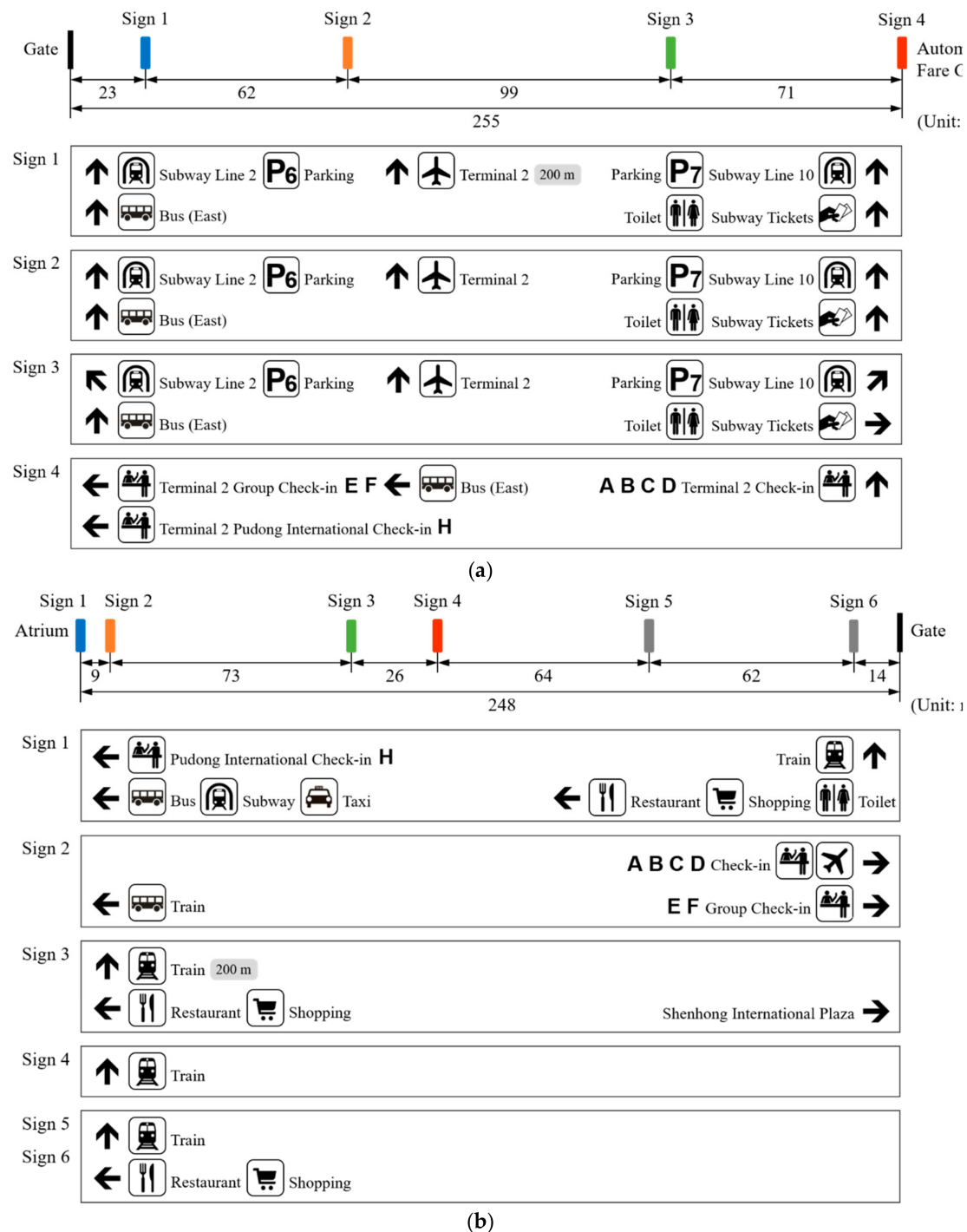

(a)

(b)

Figure 8. (**a**) Sign spacing of B1 connected passageway. (**b**) Sign spacing of F3 connected passageway.

In the above two scenarios, follow-up and questionnaire surveys were used to investigate the micro-behavioral characteristics of passengers; 74 passengers were randomly investigated, 55 men and 19 women. The field survey was conducted from 12:00 to 17:00 on March 31, 2015. The investigators were members of the research team and received effective investigation training.

A questionnaire survey was conducted to determine whether passengers often take this path; passengers who take this path often are classified as "familiar" passengers, those who occasionally take this path or are taking it for the first time are classified as "unfamiliar" passengers. Based on the follow-up survey, whether passengers view the sign during the pathfinding process is recorded. The basic data of surveyed passengers are shown in Figure 9.
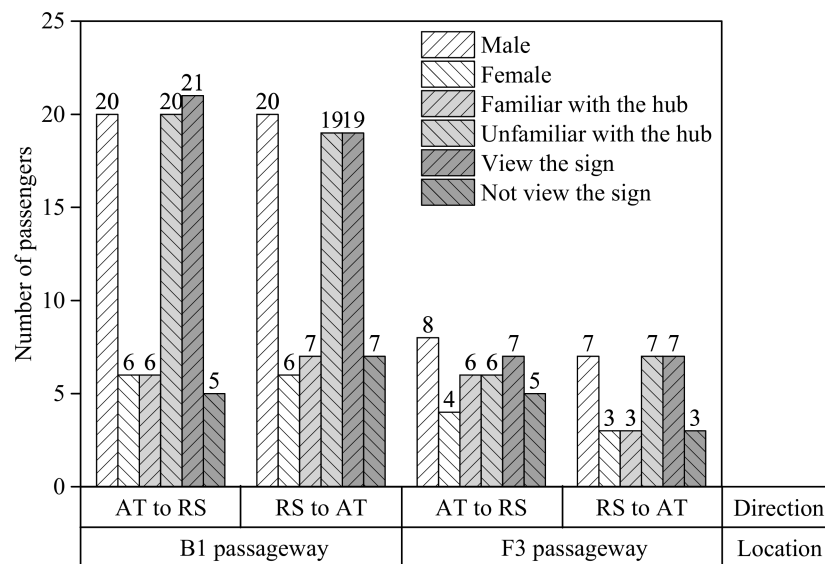

Figure 9. Basic data of surveyed passengers. Note: AT-airport terminal, RS-railway station.

As shown in Figure 9, on the B1 passageway, unfamiliar passengers account for 75%, and 77% of passengers viewed the guidance signs during the pathfinding process. It can be concluded that unfamiliar passengers account for the majority, and they rely heavily on the guidance signs, with a greater demand for guidance information. On the F3 passageway, passenger flow is relatively low, and the proportion of familiar passengers is higher than on the B1 floor. Besides, most passengers choose to view the guidance signs.

3.4. Results and Analysis

Based on the previous interpretation of passenger information behavior, unfamiliar passengers improve the certainty of their pathfinding behavior by viewing guidance signs. The investigators measured the distance of the markers inside the hub in advance and recorded the time when the respondents passed the markers in the follow-up survey to calculate their walking speed. It was indeed found that, when the certainty of passengers is lower than the threshold, there is a sudden drop in their speed.

Passengers who were unfamiliar with the scenario and viewed the guidance signs on the two passageways were selected for further research, and their demand for guidance information in the pathfinding behavior is discussed. In order to determine passengers' speed drop sections, we discussed the values of, *b*, and *c* by analyzing the information behavior of passengers who are unfamiliar with the hub. Figure 10a shows the percentage distribution of the speed drop rate for all passengers, and there are two inflection points on the curve. If the percentage of the speed drop rate is greater than 30%, it is the speed drop due to uncertainty; if the percentage of the speed drop rate is less than 10%, it is judged to be the speed fluctuation due to motion characteristics. Therefore, we initialized a = 30%, and c = 10%. Figure 10b indicates the corresponding upper and lower limits of the cumulative percentage of the speed drop rate when the speed drop rate of each passenger is reduced the most. Then, we assumed b = 60%, which is between 53% and 71%.
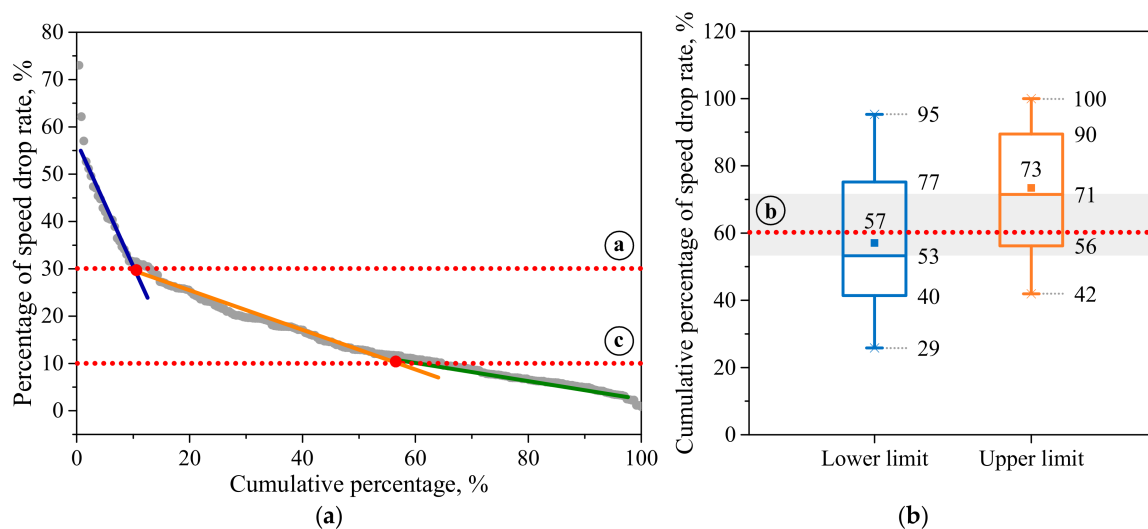
Figure 10. (**a**) Percentage distribution of the speed drop rate; (**b**) Cumulative percentage distribution of the speed drop rate.

According to the circular judgment process for speed drop sections in Figure 5, all the speed drop sections are extracted. Taking a passenger on the B1 connected passageway as an example, individual speed drop behavior is analyzed, as shown in Figure 11.
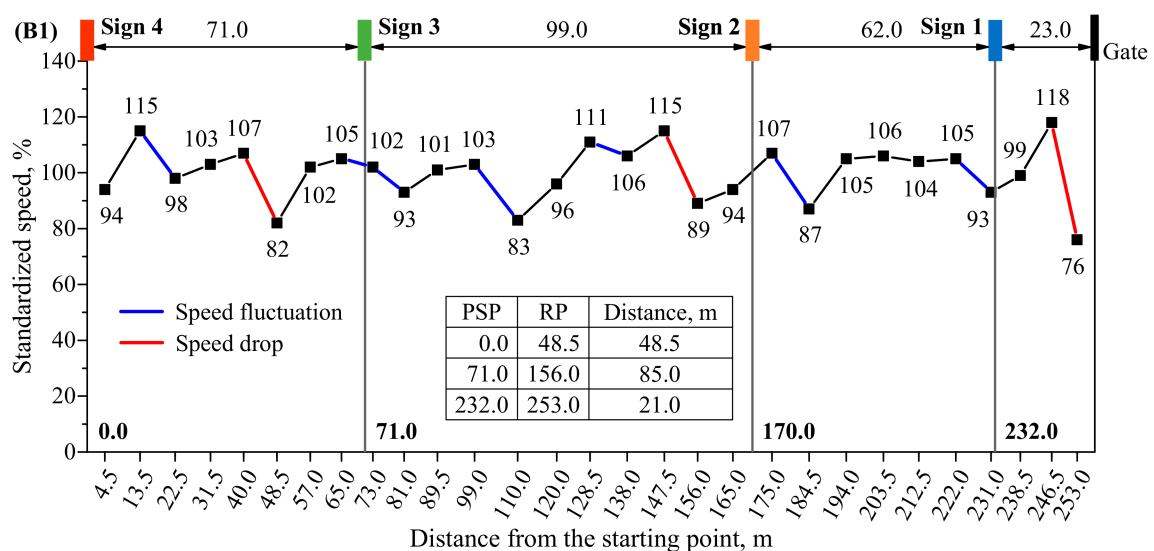

Figure 11. Individual speed drop behavior. Note: PSP-previous sign point, RP-rear point of the speed drop section.

As shown in Figure 11, the blue line represents the speed fluctuation, and the red line represents the judged speed drop. When the rear points of the speed drop sections are located at 48.5 m, 156.0 m, and 253.0 m, the corresponding positions of the previous sign points are 0.0 m, 71.0 m, and 232.0 m, respectively, and the distance between the two is 48.5 m, 85.0 m, and 21.0 m, respectively, which is also the rear distance of the sign.

The speed drop behavior of all passengers for each passageway is analyzed. The rear distance of the sign was calculated, and the cumulative percentage is plotted as shown in Figure 12.
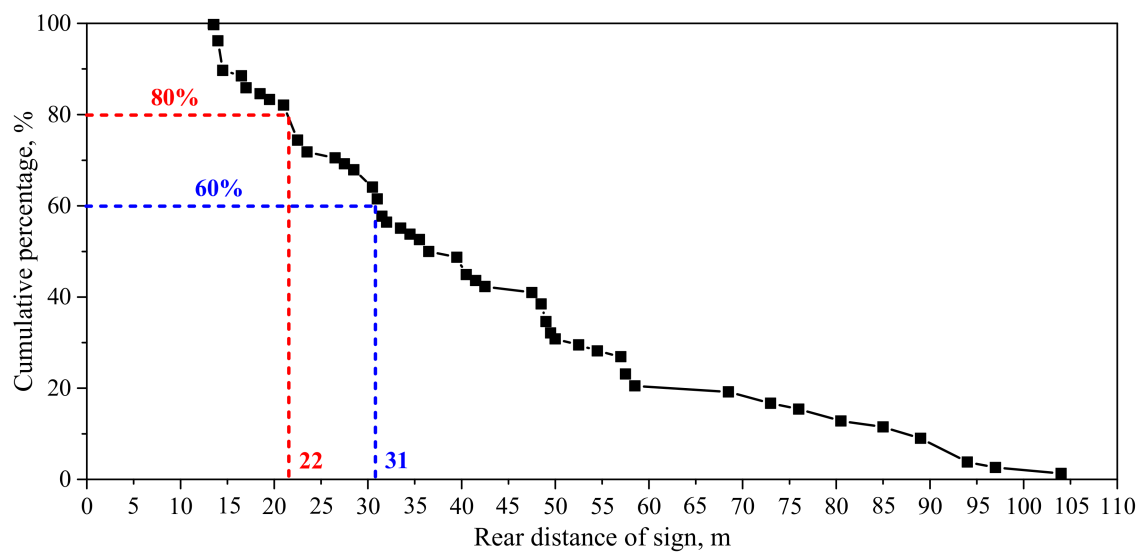
Figure 12. Cumulative percentage of the rear distance of sign.

As is clearly shown above, under the discriminant threshold of speed drop given in this study, 80% of passengers had a rear distance of the sign greater than 22 m, and 60% of passengers had a rear distance greater than 31 m.

For the front distance of the sign, referring to the analysis of visual distance in the existing research [47], the visual distance of confirmation for characters is 25 m, that is, the front distance of the sign is 25 m. Sign spacing consists of the front and rear distance of the sign. Accordingly, it can be considered that 80% of passenger demand is satisfied when the sign spacing is 47 m, and 60% is satisfied when the sign spacing is 56 m. It is necessary to increase the information density or set up reasonable inquiries to enhance the certainty of passengers in the transfer passageway.

4. Discussion

(1) About the method of determining the decision points

In the method of determining the decision points for information demand, this study establishes the spatial network topology relationship within the hub and assumes that passengers select the shortest path in the pathfinding process. According to the selection criteria for point merging, the decision points of information demand on the path are finally determined.

The path selection behavior of passengers is an influencing factor in the method. In the existing research [48–50], many path selection models have been proposed to reveal a realistic path selection process by analyzing the factors affecting passenger path selection from various aspects. These path selection models can be introduced into the method to determine the decision points, and the decision points are still obtained. This does not affect the determination of the decision points and the density of guidance information between them, and therefore the method itself does not have deviation due to different path selection models.

(2) About the layout density of guidance information between decision points

Combined with the knowledge of cognitive psychology and behavior analysis, field questionnaires and path tracking are used in this study to determine the layout density of guidance information between decision points, and the layout law of guidance information is explained. The results of the case study show that 80% of passenger information demand is satisfied when the layout density is 47 m, and 60% is satisfied when the layout density is 56 m.

The results on the layout density of guidance information given in the case study are compared with the standards of some countries and regions, as shown in Table 3.

Table 3. Comparison of layout density of guidance information.

	Object of Comparison	Layout Density of Guidance Information
Standards	Germany	25–100 m
	Japan	40–50 m
	Shanghai, China	80 m
	Results of this study	56 m (60% of information demand is satisfied)
		47 m (80% of information demand is satisfied)

As shown in Table 3, the standards of Germany and Japan provide a range of layout density rather than a specific density value, which is not convenient for designers when trying to design the guidance information system for a specific transportation hub, so a general method for determining the layout density will be helpful for them under this situation. Based on passenger information demand, the method proposed in this paper gives a reasonable and definite layout density of guidance information. This method can also provide a reference for the optimal design of guidance information systems in comprehensive transportation hubs. In addition, the standard in Shanghai, China, stipulates that the layout density of the guidance information is 80 m. According to the analysis results of Figure 12, only 13% of passenger information demand is satisfied.

(3) About the analysis of passenger behavior certainty

During the pathfinding process, passengers experience the process of discovering the guidance information, understanding and confirming the collected information, and then deciding to move. Based on the analysis of macroscopic behavioral characteristics, this study discusses the fluctuation of passenger behavior certainty with the distance from guidance information, and analyzes passenger behavior in the information environment, as shown in Figure 3.

Fang [39] proposed that passengers' certainty of their behavior fluctuates within a certain threshold range, but will not exceed the upper and lower limits. Figure 13a shows the fluctuation of passenger behavior certainty with distance in the case of reasonable layout of guidance information. When the passenger receives the guidance information, his certainty increases rapidly. However, if the next guidance information is not provided, the passenger's certainty will be reduced during the movement, so the guidance information should be provided in time before the certainty has not dropped to the lower limit. Therefore, the behavior certainty constantly fluctuates between the upper and lower limits, and passengers can always have sufficient information to smoothly reach the destination.
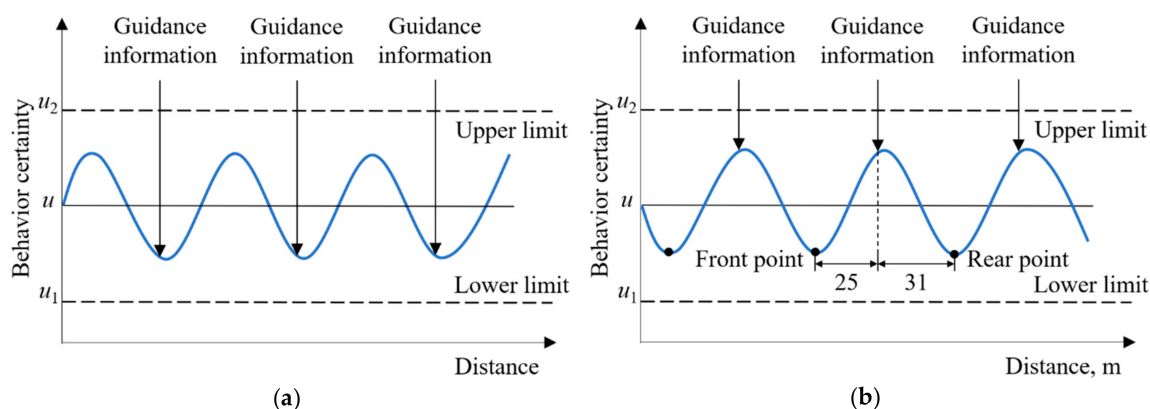

Figure 13. (**a**) Fluctuation of behavior certainty under the reasonable layout of guidance information (from Fang [39]); (**b**) Fluctuation of behavior certainty after improving and quantifying the layout spacing of guidance information.

Considering the human visual characteristics, passenger behavior certainty continues to increase during the process of discovering and confirming the guidance information, and reaches the maximum when arriving at the location of the guidance information. On this basis, this study confirms the fluctuation law of passenger behavior certainty, and improves and quantifies the layout of guidance information from the perspective of passenger information demand. As shown in Figure 13b, when the front and rear distances of the sign are 24 m and 31 m, respectively, 60% of passenger information demand can be satisfied. Therefore, Figure 13a indicates the schematic layout requirements of the guidance information; Figure 13b shows the actual layout rules, and provides an evaluation method for the guidance information system of the transportation hub.

In particular, the field investigation in this study is carried out in an actual transportation hub, which is a rare breakthrough. However, due to the limited survey data, the analysis results need to be further verified and improved. It is necessary to increase the survey sample to make the field survey data more convincing and scientific. At the same time, the fault-tolerant design of decision point selection needs to be considered.

In general, the findings presented in this study can provide a reference for the layout design of guidance sign systems for other comprehensive transportation hubs.

5. Conclusions

This study proposes an optimal layout method to determine the location and density of static guidance information in comprehensive transportation hubs, which considers the behavioral and psychological factors of passengers. The main conclusions of this study are listed below.

First, based on the characteristics of passenger pathfinding behavior, two types of information demand are defined to better explain the pathfinding process from the perspective of passenger perception. One is the information demand for path selection; the other is the information demand for enhanced certainty.

Second, according to the combination of theoretical analysis and field investigation, a method to determine the decision points of guidance information demand is proposed. Based on the analysis of microscopic behavioral characteristics, the information behavior of passengers between decision points is modeled, and the speed drop sections are proposed to characterize passenger certainty. In addition, the locations of information enhancement points are further determined, and the layout law of guidance information is explained from the perspective of cognitive psychology.

Finally, the spatial location and density of static guidance information are determined to fully characterize the function of the comprehensive transportation hub and provide a reference for its optimal layout design. As shown in the case analysis, 80% of passenger information demand is satisfied when the sign spacing is 47 m, and 60% is satisfied when the sign spacing is 56 m.

Therefore, this study provides a complete and effective design method and process for the optimal layout of guidance information systems from the perspective of passenger information demand.

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