

# Research on Pedestrian Wayfinding Behavior in Large Public Space Utilizing Non-immersive VR Platform

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**Abstract** In this study, we conducted experiments to investigate pedestrian wayfinding behavior using a non-immersive virtual reality platform. We developed a route choice model that combines environmental factors and individual pedestrian attributes, employing a hybrid Logit model. The dataset for pedestrian route choices is collected from participants' walking trajectories within the Tianjin West Railway Station scenario. The results of our experiments demonstrate that the model effectively represents pedestrians' route choices within the environment and exhibits strong predictive capabilities for wayfinding.

**Keywords** Virtual reality · wayfinding behavior · utility model

## 1 Introduction

Understanding how pedestrians make decisions as they move from one location to another is essential for analyzing pedestrian dynamics. By examining the decisions pedestrians make when choosing their paths, we can uncover the distribution of pedestrians along viable routes. This knowledge enables precise predictions of pedestrian density, flow patterns, and crowd dynamics within infrastructure.

Previous research has identified a range of factors that influence pedestrian decisions regarding their chosen routes [1]. These factors fall into two main categories: personal attributes [2–4], which include age, gender, neighborhood behavior, and social interactions, and environmental conditions [5–8], which encompass factors like route length, obstacles,

and route directness. Currently, there is a dearth of models that comprehensively consider the combined effects of both these sets of factors on pedestrian behavior. Furthermore, many experimental scenarios do not accurately replicate real-world situations.

Two primary methodologies for studying pedestrian wayfinding behavior are field observation [9] and controlled experiments. However, both these approaches have limitations, including issues related to result accuracy and cost. The advent of virtual reality has introduced an innovative means of collecting data on pedestrian behavior. This technology allows researchers to create virtual scenarios that closely mimic real physical spaces [10]. Previous studies have illustrated the efficacy of virtual reality in examining pedestrian behavior across various contexts. In comparison to field observation experiments, virtual reality-based experiments offer several advantages, such as shorter experimental durations, reduced economic and labor costs, and higher levels of data precision [11–14].

In this work, based on a non-immersive virtual reality platform, we construct a pedestrian route choice model that integrates environmental factors and pedestrian individual attribute factors to study the pedestrian wayfinding behavior in large public spaces. By recording the data of participants' walking trajectories in the scenario of Tianjin West Transportation Hub, a hybrid Logit model is developed and the utility functions corresponding to different routes are obtained. Based on this low-cost experimental approach, comparing to previous behavioral research models focusing on the physical information of paths, we newly added destination visibility time, type of marking information, and pedestrian heterogeneity factors to the model and verified the validity of the presence of the first two factors, and the non necessity of the heterogeneity.

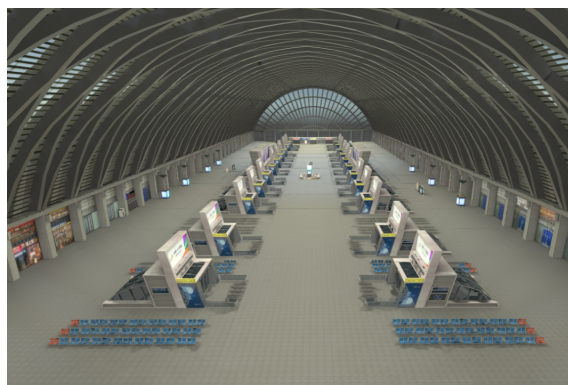
The paper is structured as follows: in Sec. 2.2 we introduce the behavioral experimentation set up based on the VR platform and the wayfinding model. In Sec. 3 we provide the calibration and statistical results of behavioral data. The paper ends with Sec. 3.3 summarizing our results and drawing possible future directions.

## 2 Methods

### 2.1 Experimental setup

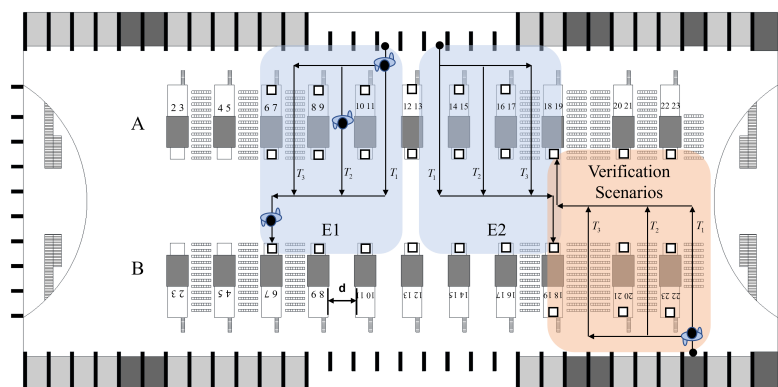
The study takes the elevated level of Tianjin West High-speed Railway Hub (see Fig. 1) as the experimental scene of pedestrian wayfinding, and imports the 3D model of the station constructed by Maya into Unity3D, and realizes the human-computer interaction function of the desktop experimental platform by combining with Visual Studio 2019 programming.

The pedestrian controlled by the participant is initialized to the starting point before the experiment. Imagining traveling through a transit station, the participant is informed of the end point marker that he/she needed to reach. In the absence of a scene layout, participants are required to choose a route to the destination based on the route information acquired in their own field of view. Three sets of experiments are conducted for each participant, two of which are used to calibrate the parameters of the wayfinding model (scenario E1 and E2), and the third set of data serves as a validation dataset (Red area) for



**Figure 1** Top view of the virtual reality experiment scenario.

validating the predictive effectiveness of the model, as show in Fig. 2. Immediately after the experiments. The coordinates of the pedestrian’s current position are synchronized and recorded during the experiment.



**Figure 2** Plan view of the virtual reality scene of Tianjin West Station constructed by the study.

A total of 28 participants joined the experiment in the study, in which the male to female ratio of the participating population is 44.4% and 55.5% respectively, with an age range of 20-28 years old, and 84.21% of the participants had postgraduate education or above. In order to verify the reasonableness of the sample size used in the experiment and to ensure that the experiment has sufficient statistical efficacy, we examined the results and obtained the results of the reliability analysis with a Cronbach’s coefficient of 0.512 and the validity analysis with a KMO coefficient of 0.659, which illustrates the statistical efficacy of the experimental data.

A total of eight factors including route length, width, and age are recorded during the experiment, and the meaning of each factor and its quantification method are as follows:

1. Route length. The length of the pedestrian’s trajectory from the starting point to the destination.

2. Number of route decision points. Total number of locations where direction decisions need to be made during pedestrian wayfinding.
3. Duration of time the destination is visible in the field of view. The study proposes the ratio of target visual duration to total route walking duration to quantify the impact of the duration of the destination in view on pedestrian walking, which is calculated as follows

$$c_i = \frac{t'_i}{t_i} (t'_i < t_i), \quad (1)$$

where  $t'_i$  is the period of time during which the target place can be clearly seen in the  $i$  th path, obtaining  $c_i$  as the ratio of the two lengths of the route. By surveying participants on the visualization of the platform (The statistics show that, at a distance of 25 m 94.74 % of the participants were able to see the distant sign completely, while at a distance of more than 30 m, the result was less than 50% ), the visual radius of the pedestrian's field of view is set to 25 m.

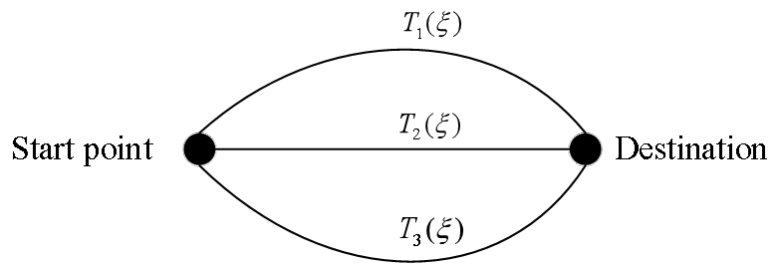
4. Signage information. The signages within the virtual scenario is shown in Fig. 3, including numeric and character information. Record changes in the two types of signage information for route direction as binary variables.
5. Route width. Width of walkable distance between obstacles (see parameter  $d$  in Fig. 2)
6. Pedestrian heterogeneity factors included both gender and scenario familiarity.



**Figure 3** Signage information types in a virtual scenario.

## 2.2 Wayfinding model

The study reduces the pedestrian wayfinding scenario to an undirected graph  $U$  consisting of two nodes, the start and the destination point, as shown in Fig. 4. It is assumed that pedestrians choose the route with the greatest utility  $T_i(\xi)$  based on their own attributes and route information.



**Figure 4** Pedestrian walking network map.

Formally, we use binary variables  $x_i$  to represent the pedestrian's choice of route  $i$  to take in the network.

$$x_i = \begin{cases} 1, & \text{if } T_i > T_j \quad \forall j \neq i \\ 0, & \text{otherwise.} \end{cases} \quad (2)$$

For the choice of route  $i$ , the utility  $T_i$  can be expressed in the following format

$$T_i = \sum_{j=1}^n \beta_{ij} \cdot X_{ij} + \varepsilon, \quad (3)$$

where  $X_j$  is the programmatic characteristic of the  $j$  th explanatory variable,  $\beta_j$  is the regression coefficient for the explanatory variable and  $\varepsilon$  is constant term. In this study, the values of  $j$  and  $U$  are 8 and 3. (1: Route length, 2: Decision point, 3: Duration of time, 4: Character signage information, 5: Numeric signage information, 6: Route width, 7: Gender, 8: Scenario familiarity).

## 3 Results

### 3.1 Model calibration

The calibration of the hybrid Logit model is achieved by analyzing the route and pedestrian training set data using Python 3.8 calling Biogeme. Based on the coefficients corresponding to the resulting explanatory variables, the fixed utility corresponding to each wayfinding scheme  $T_i$  can be found, as shown in the table Tab. 1 below

The results show that decision points, the presence of numerical signs and an increase in width have a positive effect on the pedestrian's choice of one route. Whereas path length and time-related factors have an inverse effect on path selection. Gender and familiarity do not correlate significantly with route choice outcomes (Sig.>0.05). We therefore remove these two explanatory variables from the model. For the performance of the calibrated model on the validation dataset, it is able to predict 100% of the pedestrian wayfinding results, which proves the effectiveness of our proposed pedestrian wayfinding model.

Parameter	Data type	Correlation	Sig.	Route1	Route2	Route3
Route length	Real number	-0.784**	2.4274E-12	-0.01800	-0.01723	0.00771
Decision_point	Real number	1**	.000	-4.70197	1.05727	3.64471
Time	Real number	-0.787**	1.6523E-12	-0.06158	0.35110	-0.28952
Sign_p	Binary variables	-0.782**	.000	-2.54119	12.71797	-10.17678
Sign_n	Binary variables	0.884**	.000	-0.01372	0.01640	-0.00268
Width	Real number	0.805**	2.0662E-13	2.1822	-2.30495	0.12275
Gender (Leave out)	Binary variables	0.187	0.176	-	-	-
Familiar (Leave out)	Binary variables	-0.047	0.735	-	-	-

**Table 1** Pedestrian wayfinding model calibration results.

### 3.2 Ablation experiment

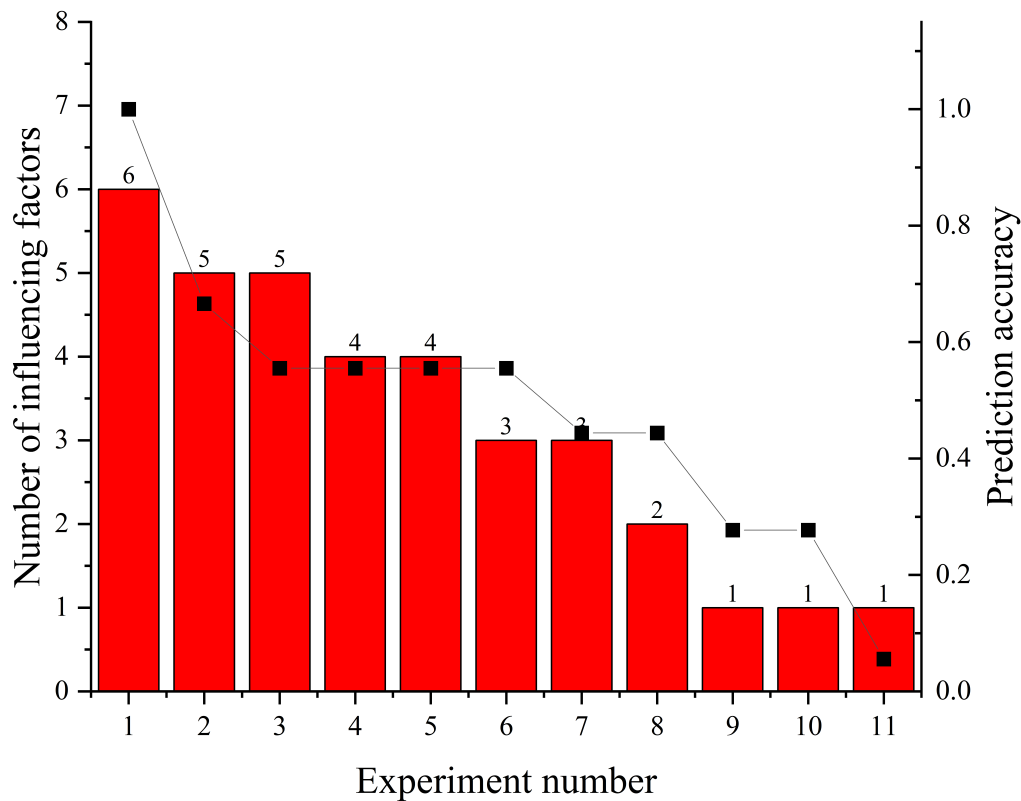
To investigate the effect of the proposed influencing factors on the pedestrian wayfinding process, ablation experiments are conducted to recalibrate the model by removing some of the influencing factors from the original dataset and compare the predictive effects with the original model. We remove the parameters in the order in which they are listed in Tab. 1 in turn. And the results are as shown in Fig. 5. As the influencing factors used to calibrate the model are reduced, the accuracy of the model is generally decreasing.

Further, AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion) based metrics are used to verify the goodness of fit of the model considering different combinations of influencing factors. The fit of the model with different combinations is shown in Fig. 6. This indicates that the analysis of pedestrian path behavior considering a single factor is unreliable and in some cases the increase in the number of factors considered does not lead to an improvement in the model's goodness of fit.

### 3.3 Behavioral analysis

Based on the correlation results, it is evident that pedestrians tend to opt for routes that are shorter in length, provide a longer line of sight to their destination, and offer a wider walkable area. Regarding the impact of signage information on pedestrian wayfinding behavior, the survey findings reveal that over 88% of the participants believe that the signs in the environment effectively assist them in navigating. Furthermore, the model calibration results indicate that pedestrians assign greater utility to numerical signage information than character-based information when selecting routes to their destinations. This preference may be due to the fact that numerical information can provide pedestrians with a more clear displacement direction.

Although we removed gender from the model, we still counted and compared the differences in the data for the different genders choosing the route scenarios. Tab. 2 shows the calculated path average attribute data from the route scenarios chosen by people of different genders to select their choices.



**Figure 5** Prediction accuracy of wayfinding models on validation dataset under different experimental scenarios. The red bar indicates the total number of factors considered and the black line indicates the prediction accuracy.

The average length and width of paths chosen by women are slightly higher than those chosen by men, but the number of route decision points is slightly lower than that of men. There is no significant difference between the male and female pedestrians in terms of the length of time that the destination signage is visibility.

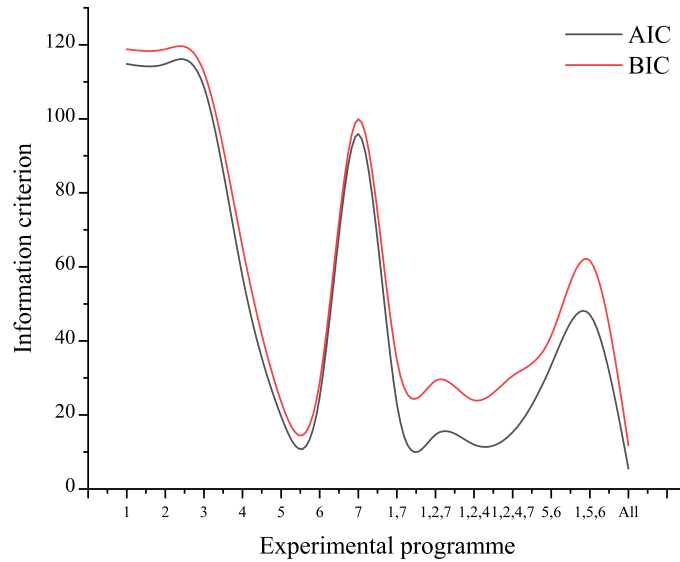
## 4 Conclusion

In this work, we constructed a virtual reality scenario of a large public space and collected pedestrian route choice data through the desktop, portrayed pedestrian wayfinding behavior with the help of a hybrid Logit model, and proved the validity of the model by applying it on a validation dataset.

Based on the results of the above experimental analysis, suggestions can be given as follows:

(1) Pedestrians' comprehension of the spatial layout effectively improve their walking efficiency, so it is necessary to provide pedestrians with spatial plans in public spaces to facilitate wayfinding decisions, which will also alleviate crowd congestion and improve the efficiency of spatial turnover to a certain extent.

(2) It is found that pedestrians pay more attention to numerical signage information,



**Figure 6** Plot of model fit goodness-of-fit considering different influencing factors.

	length	decision_point	width	time
Male	118.1	1.71	6.48	0.33
Female	120.4	1.6	7.33	0.33

**Table 2** Statistical table of pedestrian route choice data under gender differences.

so in the process of signage design, numerical information should be more prominent, improve its clarity, brightness or increase the font size, which will also be conducive to pedestrians' decision-making on their own walking programs.

In terms of the study's limitations, it is important to note that the heterogeneity among pedestrians should be more thoroughly examined. This involves considering the variations in wayfinding behaviors resulting from factors such as age, weight, and the influence of peers. This approach would enable a more comprehensive exploration of pedestrian wayfinding behavior.

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**Author Contributions** Zhicheng Dai: Writing and Investigation – Original draft preparation / Dewei Li: Conceptualization, Revise.



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