

1 **MODELING PEDESTRIAN BEHAVIOR IN METRO STATIONS WITH COMMERCIAL**  
2 **FACILITIES: AN ATTRACTIVENESS-BASED APPROACH**

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**1 ABSTRACT**

2 This study focuses on understanding and optimizing pedestrian behaviors in metro stations with  
3 commercial facilities. Recognizing that both transit and commercial interests influence pedestrian  
4 behavior in these stations, we developed an improved attractiveness-based route choice model.  
5 This model incorporates subjective perceptions of distance and waiting time, alongside the utility  
6 of facilities, to more accurately predict pedestrian behavior and passenger flow. We implemented  
7 the model in AnyLogic using the Social Force Model for simulation. Our findings show that incor-  
8 porating subjective perceptions enhances the predictive accuracy of pedestrian behavior in metro  
9 stations with commercial facilities. We validated the model using benchmarking methods against  
10 real-world data from Shanghai's Jing'an Temple station. The simulation results highlighted how  
11 strategic placement and configuration of transit and commercial facilities can optimize operational  
12 performance and enhance passenger experience. We applied the model to various scenarios, reveal-  
13 ing critical insights for spatial design, such as the benefits of repositioning gates, adding barriers  
14 near escalators, and adjusting escalator speeds. The study provides actionable recommendations  
15 for station layout optimization to improve transportation efficiency and commercial viability. Fu-  
16 ture research should expand sample sizes, incorporate more diverse commercial types, and utilize  
17 advanced tools like virtual reality for data collection to further refine pedestrian behavior models  
18 in complex environments.

19

20 *Keywords:* metro station, pedestrian commercial behavior, route choice modeling, pedestrian sim-  
21 ulation

## 1 INTRODUCTION

2 In response to growing demands for enhanced service quality, enriched passenger experience, and  
3 diversified revenue sources, numerous metro stations have integrated commercial facilities within  
4 their station space (1). These stations combine transit functions with amenities such as vending  
5 machines, retail stores, and restaurants. Unlike typical metro stations, they serve both traffic and  
6 commercial functions, attracting transit users and increasing urban rail transit revenue (2, 3). The  
7 behaviors of pedestrians with commercial intentions differ significantly from those who merely  
8 commute, influencing passenger flow distribution, transportation efficiency, and business benefits  
9 within metro stations (4). Therefore, understanding and modeling pedestrian commercial behav-  
10 ior is crucial for optimizing spatial design and passenger flow in metro stations with commercial  
11 facilities.

12 Numerous studies have explored pedestrian behavior within metro stations, focusing on  
13 safety and evacuation modeling (5), route choice modeling (4, 6), and pedestrian dynamics (7).  
14 However, research specifically on commercial behavior within metro stations is lacking. Unlike  
15 regular metro stations where passengers are primarily focused on transit, users of stations with  
16 commercial facilities often have additional commercial interests that affect their route choices and  
17 temporary destinations.

18 Existing studies on pedestrian route choice in metro stations with commercial facilities  
19 consider factors such as individual characteristics (8), the influence of commercial facilities (9),  
20 and spatial design (10). However, pedestrians in metro stations are particularly sensitive to distance  
21 and time due to limited space and the urgency of their travel purposes. Thus, it is essential to  
22 consider subjective distance and waiting time in route choice modeling for these stations.

23 Another challenge lies in the microsimulation of pedestrian behavior within these stations.  
24 While existing simulation studies often use cellular automata models (11, 12), social force models  
25 (13), and queueing theory models (14, 15), the focus of metro station evaluation is on spatial  
26 design and passenger flow organization. Therefore, this paper uses the social force model as the  
27 foundation for our simulation.

28 In this context, our paper makes several key contributions. First, we propose a novel pedes-  
29 trian route choice model that incorporates attractiveness between pedestrians and station facilities,  
30 enhanced by factors such as individual distance perception and waiting time perception. Second,  
31 we implement this model using AnyLogic software to build a pedestrian simulation based on the  
32 social force model. Third, we validate our model and simulation by applying them to the analysis  
33 of a metro station with commercial facilities. Finally, we provide practical recommendations for  
34 optimizing the spatial layout and passenger flow organization within such stations.

## 35 STATE-OF-THE-ART

### 36 Pedestrian Route Choice Modeling

37 Understanding how pedestrians choose their routes in complex environments has been a focal  
38 point in many studies. Researchers have explored various factors and methodologies to analyze  
39 pedestrian decision-making processes.

40 Previous studies on pedestrian route choice can be divided into those focusing on individual  
41 preferences and those examining external influences. For example, Cheung and Lam (16) investi-  
42 gated preferences between escalators and stairways in metro stations during peak hours, highlight-  
43 ing the importance of individual choice in facility planning. Kurose et al. (17) classified pedestrian  
44 shopping behaviors in shopping centers using temporal and spatial choice heuristics, emphasiz-

1 ing individual decision-making patterns. Lue and Miller (18) used GPS data from smartphones to  
2 analyze pedestrian route choices in Toronto, exploring explicit preferences in urban environments.

3 On the other hand, Werberich et al. (19) developed a friction force-based model to study  
4 the impact of crowd impedance on route choices, focusing on pedestrian dynamics in congested  
5 areas. Oyama and Hato (20) proposed a method to estimate route choice parameters in urban  
6 pedestrian networks by accounting for GPS measurement error, thereby investigating the influence  
7 of external environmental factors. Filomena et al. (21) explored the impact of urban subdivisions  
8 and separating elements on pedestrian movement, highlighting how city design can interfere with  
9 pedestrian route choice.

10 The methodologies used in these studies are diverse and can be categorized primarily into  
11 field observations, simulation modeling, and travel trajectory data analysis. Cheung and Lam (16)  
12 and Kurose et al. (17) gathered data through direct observation and surveys, providing empirical  
13 insights into pedestrian choices. In contrast, Werberich et al. (19) used simulation models, specif-  
14 ically a friction force model, to simulate pedestrian behavior and calibrate their model with real  
15 data, offering a theoretical approach to understanding pedestrian dynamics.

16 Oyama and Hato (20) used data analysis techniques, using road condition variables and  
17 GPS data to examine route choice. Lue and Miller (18) analyzed revealed preference data from  
18 smartphone-based GPS tracking to study pedestrian route choice in an urban context, demon-  
19 strating the potential of modern data collection technologies in pedestrian studies. This range of  
20 methods highlights the complexity of factors influencing pedestrian route choices and the diverse  
21 approaches used to understand them.

## 22 **Pedestrian Simulation Models and Software**

### 23 *Three Main Pedestrian Simulation Models*

24 Pedestrian route choice in metro station spaces is highly individualistic and complex. Microscopic  
25 models, which describe individual human behavior, are more suitable for simulating metro station  
26 environments. Pedestrian simulation models can be divided into discrete and continuous types:

- 27 1. *Cellular Automata Models*: The Cellular Automaton Model is a discrete dynamic model  
28 that considers each cell in a grid as the smallest unit. Each cell updates its state based on  
29 specific rules. For pedestrian simulation, the walking area is divided into a grid of cells,  
30 where each pedestrian occupies a cell. Depending on specific rules, a cell can move to  
31 one of the eight neighboring cells in the next time step Zhou et al. (22). Advantages  
32 include fast computation speed and feasibility, but the model has drawbacks such as  
33 coarse descriptions of individual behaviors and limited interaction considerations.
- 34 2. *Social Force Model*: Helbing and Molnár (23) proposed the Social Force Model that  
35 simulates pedestrian behavior through force analysis, considering self-driven force, in-  
36 teraction force between pedestrians, and interaction force between pedestrians and the  
37 environment. This model is well-suited for simulating diverse pedestrian flows in com-  
38 plex environments like metro stations, though it does not prevent pedestrian overlap.
- 39 3. *Magnetic Field Force Model*: The magnetic field force model (24) assigns magnetic at-  
40 tributes to pedestrians and obstacles, simulating attraction to destinations and repulsion  
41 from obstacles. It is simple and intuitive but lacks standardized parameter calibration,  
42 making it less suitable for complex scenarios.

43 Each model has its suitable scenarios. In metro stations with commercial facilities, pedes-  
44 trian behavior is complex and influenced by diverse objectives and attractions. The Social Force

1 Model, with its self-driven force component, aligns better with the complex pedestrian dynam-  
2 ics in these stations, making it the preferred choice for simulating and evaluating pedestrian flow  
3 capacity.

#### 4 **Simulation Software Based on Social Force Models**

5 Given the selection of the Social Force Model for pedestrian simulation, several mainstream soft-  
6 ware options are available, including SimWalk, AnyLogic, and Vissim.

- 7 1. *SimWalk*: SimWalk is a pedestrian simulation software aimed at transportation and ur-  
8 ban planning applications. It uses a potential field algorithm based on the Social Force  
9 Model. However, it does not support secondary development, limiting its ability to in-  
10 corporate special pedestrian behaviors.
- 11 2. *AnyLogic*: AnyLogic is versatile system simulation software applicable to pedestrian  
12 traffic, logistics, aerospace, and service systems. It supports secondary development  
13 and offers flexible settings for individual behaviors, making it ideal for complex envi-  
14 ronments like stations with commercial facilities.
- 15 3. *Vissim*: Vissim is a microscopic traffic simulation software that includes pedestrian sim-  
16 ulation based on the Social Force Model. It is mainly used in traffic engineering and  
17 urban planning but is less suitable for purely pedestrian environments like subway sta-  
18 tions.

19 Given the focus on individual pedestrian behavior and commercial settings, AnyLogic is  
20 selected as the preferred simulation software for this study.

21 In summary, while extensive research exists on pedestrian route choice behavior, stud-  
22 ies specifically focusing on subway stations with commercial spaces are relatively rare. This is  
23 noteworthy given the rapid development of metro rail in China. Moreover, existing studies often  
24 overlook subjective perceptions of distance and time, critical factors in environments like subway  
25 stations, where pedestrians are more sensitive to these aspects. This study aims to fill that gap by  
26 integrating these subjective perceptions into the modeling and simulation of pedestrian behavior in  
27 these metro stations.

#### 28 **ATTRACTIVENESS-BASED ROUTE CHOICE MODEL**

29 To better understand and predict pedestrian behaviors in stations with commercial facilities, we  
30 develop an attractiveness-based route choice model. This model defines an attractiveness coeffi-  
31 cient between pedestrians and facilities within the station, evaluating the likelihood of a pedestrian  
32 choosing a particular facility as their next destination. Our model improves upon existing at-  
33 tractiveness models by incorporating individual distance perception and waiting time perception  
34 factors, in addition to the utility satisfaction of the facilities.

#### 35 **Attractiveness Coefficient Model**

##### 36 *Definition of Attractiveness Coefficient*

37 Pedestrian behavior in stations with integrated commercial amenities differs significantly from  
38 that in regular metro stations. Pedestrians may be temporarily drawn to commercial services,  
39 resulting in changes in their walking trajectories and speeds. The attractiveness of various facilities  
40 to pedestrians is influenced by these behavior changes.

41 The attractiveness coefficient model, as proposed by W.L. Wang, considers the matching  
42 degree between attraction points and individual needs, distance, and visibility. Additionally, Ma

1 Jie's model in evacuation scenarios incorporates a judgment coefficient to dynamically compare  
 2 subjective walking time and waiting time for exit selection. The attractiveness coefficient calcula-  
 3 tion formula is:

$$4 \quad A_{ij} = a_{ij} \times \left[ E_{ij} \times d_{ij} + F_{ij} \times \left( \frac{c_j^{t_n}}{N_j} + T_j \right) \right] + C \quad (1)$$

5 where  $A_{ij}$  is the comprehensive attractiveness coefficient of facility  $j$  for pedestrian  $i$ ,  $a_{ij}$  is the  
 6 utility of facility  $j$  in meeting pedestrian  $i$ 's needs,  $E_{ij}$  and  $F_{ij}$  are judgment coefficients reflecting  
 7 pedestrian  $i$ 's subjective perception of distance and waiting time for different types of facilities  $j$ ,  
 8  $d_{ij}$  is the straight-line distance between pedestrian  $i$  and facility  $j$ ,  $c_j^{t_n}$  is the number of pedestrians  
 9 waiting for service at facility  $j$  at time  $t_n$ ,  $N_j$  is the service capacity of facility  $j$ ,  $T_j$  is the average  
 10 service duration of facility  $j$ , and  $C$  is a random variable for other influencing factors.

### 11 *Parameter Identification*

12 1. The utility of facilities in meeting pedestrian Demand ( $a_{ij}$ ). Pedestrians exhibit attri-  
 13 butes of "perception-decision-action". Different pedestrians have varying needs for  
 14 traffic and consumption events, different sensitivities to various commercial services,  
 15 and may make different decisions even when perceiving the same service facilities. For  
 16 example, when pedestrian  $i$  is in a hurry and encounters commercial service facility  $j$ ,  
 17 pedestrian  $i$  is likely to pass by quickly to expedite boarding and alighting because the  
 18 facility only minimally meets their needs, indicating a small  $a_{ij}$  value. In contrast, if a  
 19 passage facility  $j$  (such as an escalator) is within their field of vision, the  $a_{ij}$  value is  
 20 large, increasing the likelihood that the pedestrian will choose this facility. The variable  
 21  $a_{ij}$  represents how well different facilities meet the needs of various pedestrians, thus  
 22 reflecting the attractiveness of the facilities to pedestrians.

23 The utility of facilities meeting pedestrian needs is related to the following factors: the  
 24 nature of the facilities themselves, the basic attributes of pedestrians, and their subjective  
 25 preferences. Facilities include passage facilities (entrance/exit gates, stairs, escalators,  
 26 and elevators) and commercial service facilities (shops, vending machines, etc.). For ex-  
 27 ample, both stairs and escalators serve as vertical transport facilities in stations, but their  
 28 utility in meeting pedestrian needs differs. When the elevation is low, the number of pas-  
 29 sengers choosing to walk up the stairs and those taking the escalator is similar; however,  
 30 as the elevation increases, the number of pedestrians choosing to walk decreases signifi-  
 31 cantly, creating a large difference in the utility of stairs and escalators. Additionally, for  
 32 some disabled individuals, elevators may be the only option for vertical transportation,  
 33 making their utility significantly higher than other facilities.

34 2. Pedestrians' subjective distance perception of service facilities affects the attractiveness  
 35 of those facilities. The shorter the perceived distance, the shorter the time required to  
 36 reach the target at an expected speed. For two facilities with the same attractiveness and  
 37 function, pedestrians tend to choose the one they perceive as closer. Subjective distance  
 38 perception involves two factors, i.e., the subjective perception  $E_{ij}$  and the actual distance  
 39  $d_{ij}$ .

40 Pedestrians have limited subjective perception abilities and cannot precisely describe  
 41 distances. Subjective perceptions vary by gender, personality, preferences, and facility  
 42 type. Closer facilities are more attractive, making the correlation between  $E_{ij}$  and the

1 attractiveness coefficient negative. As passage facilities are necessary, their distance  
 2 perception coefficients are set to the same negative value, while commercial facilities  
 3 are more sensitive to distance.

4 3. Pedestrian subjective time Perception ( $F_{ij}$ ). Pedestrians' subjective time perception af-  
 5 fects the attractiveness of facilities, including waiting and service time. Longer per-  
 6 ceived times decrease attractiveness. Time perception involves subjective perception  
 7  $F_{ij}$ , actual waiting time  $\frac{c_j^n}{N_j}$ , and average service time  $T_j$ ,  $F_{ij}$  is negative as shorter times  
 8 increase attractiveness.  $\frac{c_j^n}{N_j}$  represents the actual waiting time, calculated as the queue  
 9 length divided by service capacity, and  $T_j$  is the average service time. Combined,  $\frac{c_j^n}{N_j} + T_j$   
 10 represents the total time to complete the service. For subway stations, this includes wait-  
 11 ing and service time for commercial facilities.

## 12 **Setting Parameters for the Attractiveness Model**

### 13 *Data Collection*

14 To accurately determine the parameters for the attractiveness model of facilities, we conducted  
 15 extensive field research and a questionnaire survey at Shanghai's Jing'an Temple metro station,  
 16 a high-capacity **underground** urban transit hub with substantial passenger volume and integrated  
 17 commercial facilities. For the "objective" parameters, i.e.,  $d_{ij}$ ,  $c_j^n$ ,  $N_j$ , and  $T_j$ , we conducted field  
 18 research, gathering real-time data on the usage of different facilities, including transit facility ca-  
 19 pacity, transit service duration, commercial facility queue lengths, and commercial shopping du-  
 20 rations. For the "subjective parameters, i.e.,  $a_{ij}$ ,  $E_{ij}$ , and  $F_{ij}$ , we collected data by observing  
 21 pedestrian behaviors and conducting questionnaire surveys. The survey included questions on de-  
 22 mographic information, pedestrian-facility utility, subjective distance perception, and subjective  
 23 time perception. The survey was conducted using wjx.cn and administered online through so-  
 24 cial media, with 37 valid responses from participants aged 18 to 60. As one of the first studies  
 25 investigating the interactions between transit and commercial activity-related movements within  
 26 metro stations, a smaller sample size was considered sufficient to capture preliminary insights into  
 27 pedestrians' route choice patterns. The sample includes diverse demographic profiles, ensuring  
 28 representation across all groups to provide a foundational understanding for subsequent research.  
 29 The data collected serves as the foundation for setting the model parameters. Table 1 shows the  
 30 participants' demographic profiles based on collected data.

### 31 *Outcomes related to Parameters Settings*

32 Based on our survey data and field research, we quantified pedestrian utility, subjective perception  
 33 of distance and waiting time, and facility attributes. We calculated the pedestrian demand levels  
 34 for different facilities, considering factors like gender and travel purpose. The results are presented  
 35 in Table 2.

36 Based on the perceived distance survey and waiting time survey, we calculated the per-  
 37 ceived distance coefficients ( $E_{ij}$ ) and perceived time coefficients for different facilities ( $F_{ij}$ ), con-  
 38 sidering the travel purpose as the main influencing factor. The results are presented in Tables 3 and  
 39 4.

40 Based on field research in Jin Ansi metro station in Shanghai, we measured service capacity  
 41 and queue lengths of facilities. The results are presented in Table 5, where  $H$  represents the height

**TABLE 1 Demographic Information of Questionnaire Participants**

Variable	Category	Frequency (N)	Percentage (%)
Gender	Male	22	59.46
	Female	15	40.54
Age Group	18-25	30	81.08
	26-60	7	18.82
Purpose of Travel	Commuting	20	54.05
	Business	8	21.62
	Leisure	25	67.57
	Personal Errands	18	48.65

**TABLE 2 Parameter Settings of  $a_{ij}$** 

Trip Purpose	Gender	Transit Facility			Commercial Facility				
		Escalator	Stair	Elevator	Retail Store	Bakery Shops	Dine-in Restaurants	Food/Beverage VM	Entert. VM
Commuting	Male	5.00	3.64	3.64	5.73	4.18	4.27	5.73	4.09
	Female	4.50	3.63	4.25	6.63	4.13	4.50	6.63	4.25
Business	Male	4.67	3.50	3.83	6.33	4.33	4.33	6.17	5.00
	Female	5.00	5.00	5.00	6.50	4.00	3.50	6.00	5.00
Leisure	Male	4.85	4.00	3.15	5.54	3.92	3.77	5.46	4.31
	Female	4.67	3.17	3.92	6.33	4.17	4.17	6.33	4.33
Personal Errands	Male	4.89	4.44	3.89	5.56	4.44	3.78	5.33	4.44
	Female	4.50	2.88	5.25	6.38	4.13	4.13	6.13	4.00

**TABLE 3 Parameter Settings of  $E_{ij}$** 

Trip Purpose	Transit Facility	Commercial Facility within Paid Area	Commercial Facility outside Paid Area
Commuting	-1	-1.89	-2.63
Business	-1	-2.13	-3.38
Leisure	-1	-1.36	-2.32
Personal Errands	-1	-1.59	-2.06

**TABLE 4 Parameter Settings of  $F_{ij}$** 

Trip Purpose	Stair	Escalator	Elevator	Commercial store	Vending Machine
Commuting	-2.35	-3.52	-4.89	-4.71	-5.21
Business	-2.50	-2.25	-2.50	-2.69	-1.63
Leisure	-8.93	-5.24	-7.64	-6.26	-7.24
Personal Errands	-5.50	-3.41	-5.25	-4.15	-4.65

1 between the hall level and platform level, i.e., the vertical height of the escalator.

**TABLE 5 Parameter Settings of  $N_j$  and  $T_j$** 

Facility Type		$N_j$ (Person/s)	$T_j$ (s)	
Transit Facility	Downstream Transit	Stair	11	$H/1$
		Escalator	1.7	$H/0.75$
		Elevator	1.25	$H/1.5$
	Upstream Transit	Stair	10	$H/0.8$
		Escalator	1.7	$H/0.75$
		Elevator	1.25	$H/1.5$
Commercial Facility	Commercial Store	Retail Store	6	3
		Bakery Shops	3	2.5
		Dine-in Restaurants	6	15
	Vending Machine	Food/Beverage	2	0.5
		Entertainment	0.67	1.5

### 1 Development of Attractiveness-Based Route Choice Model

2 Pedestrians in subway station commercial spaces exhibit varying levels of attraction to commercial  
3 facilities, leading to changes in their route choice and overall trajectory. This attraction manifests  
4 in two primary scenarios:

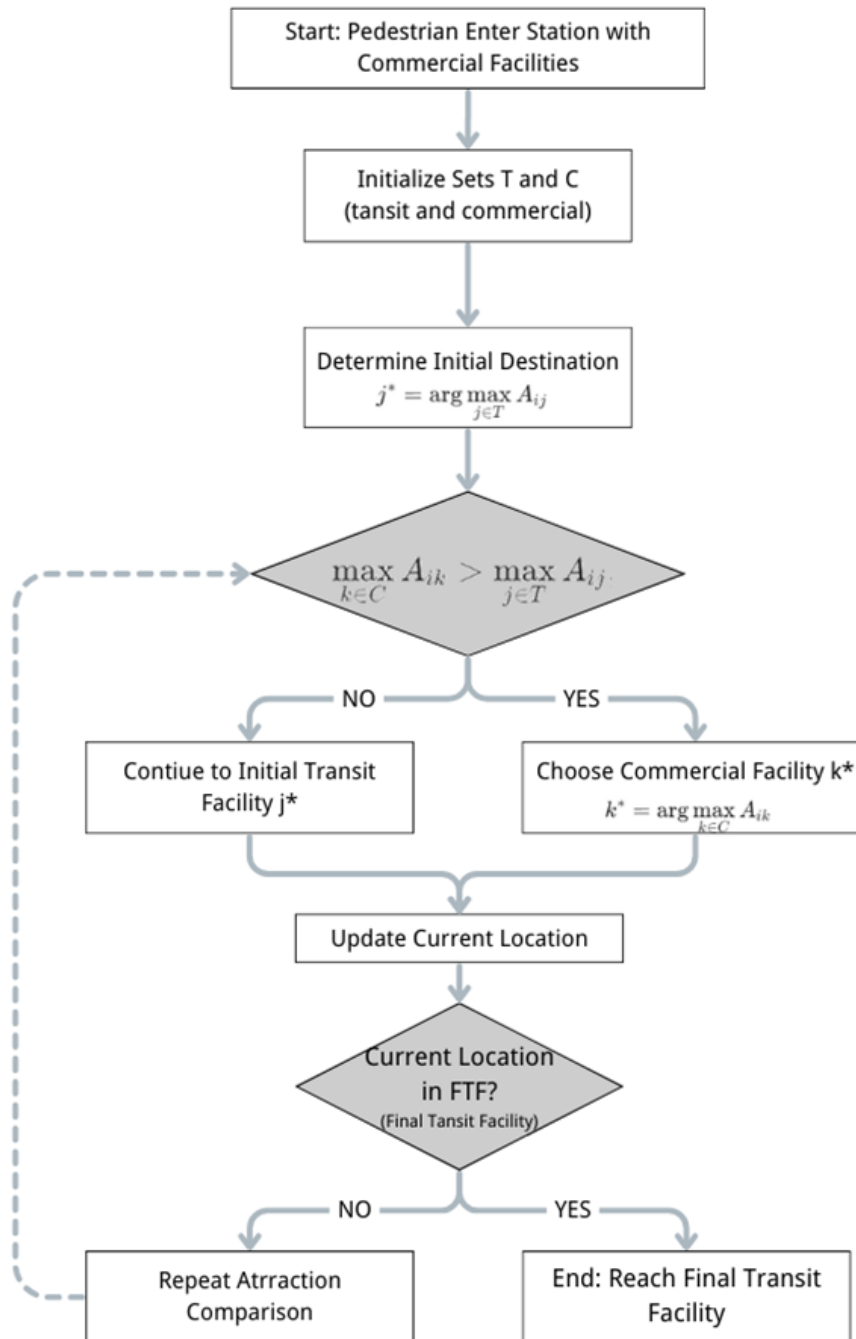
- 5 1. *High Attraction to Commercial Facilities*: Pedestrians highly attracted to commercial  
6 facilities completely alter their trajectory to walk towards these commercial spaces. In  
7 this case, they may either leave without engaging in commercial activities or enter the  
8 space to consume, but their route choice changes are similar in both scenarios.
- 9 2. *Low Attraction to Commercial Facilities*: Pedestrians experience a lower level of at-  
10 traction to commercial facilities, continuing along their original route with only minor  
11 directional changes.

12 We outline the conceptual model used to determine pedestrian route choice decisions based  
13 on the attractiveness coefficient model. Pedestrians initially aim for the transit facility with the  
14 highest attraction coefficient. As they move, they continually compare the attraction coefficients  
15 of transit and commercial facilities to decide their next destination. The model is represented as a  
16 flowchart (Figure 1).

17 The route choice decision-making model for pedestrians in a station is based on comparing  
18 the attraction coefficients of transit and commercial facilities. Pedestrians initially aim for the  
19 transit facility with the highest attraction coefficient, and at each decision point, they compare  
20 the attraction coefficients of transit and commercial facilities to decide their path, updating their  
21 destination accordingly. This conceptual model forms the foundation for the subsequent pedestrian  
22 simulation.

### 23 PEDESTRIAN SIMULATION IN METRO STATIONS

24 This section presents the simulation of pedestrian behavior within a metro station with integrated  
25 commercial facilities, using the AnyLogic simulation system, based on the pedestrian route choice  
26 model developed in the previous section.



**FIGURE 1** Flowchart of route choice model.

### 1 Simulation Environment Setup

2 Setting up the simulation environment involves two main steps: processing base maps and config-  
 3 uring the simulation environment in AnyLogic. Using a metro station as an example, we create  
 4 CAD base maps for the platform and concourse levels of the station. These maps include essential  
 5 elements for quantitative analysis, such as commercial facilities and transit facilities (entry/exit

1 gates and escalators). The CAD base maps are imported into AnyLogic using the "CAD drawing"  
 2 function in the Presentation palette module. Facilities like commercial areas, escalators, entry/exit  
 3 gates, and security check zones are modeled using the "walls," "escalators," and "nodes" modules.

4 The metro station space includes transit facilities and commercial facilities. Transit facili-  
 5 ties encompass gates, escalators, and platforms, while commercial facilities are distributed across  
 6 both the hall and platform levels.

## 7 Behavioral Logic Modeling for Pedestrians

8 Modeling pedestrian behavior involves using the AnyLogic pedestrian library to establish behav-  
 9 iors within the station. This includes basic actions such as entering/exiting the station, using esca-  
 10 lators, being attracted by commercial facilities, and waiting for trains on the platform, and logically  
 11 connecting these behaviors.

12 Similarly, the logic for exiting passenger flows involves alighting from trains, using escala-  
 13 tors, and passing through exit gates, with potential attractions from vending machines or commer-  
 14 cial stores.

15 While basic behavioral logic models the fundamental event chains of pedestrian entry,  
 16 exit, and commercial consumption, comprehensive modeling requires a more detailed depiction  
 17 of pedestrian route choice decision-making. These behaviors depend dynamically on pedestrian  
 18 attributes, facility characteristics, and passenger flow organization, necessitating the creation of  
 19 pedestrian agents for more refined modeling.

## 20 Simulation Implementation of Route Choice Models

21 In AnyLogic, personalized pedestrian route choice is achieved by creating pedestrian agents, where  
 22 each agent represents an individual pedestrian. The model includes real-time dynamic attractive-  
 23 ness calculations towards all types of facilities. This process of creating pedestrian agents and  
 24 implementing the model in AnyLogic involves the following steps:

- 25 1. *Creation of pedestrian agent*: A pedestrian agent (collection) is established to input  
 26 individual pedestrian parameters. Based on survey data, pedestrians are characterized  
 27 by gender, age, and purpose, with different decision behaviors assigned according to  
 28 survey results.
- 29 2. *Real-time Output  $d_{ij}$  and  $c_j^n$* : The step involves the fundamental decision logic for  
 30 pedestrians. The attractiveness coefficient  $A_{ij}$  (see Equation 1) is calculated to determine  
 31 each pedestrian agent's route choice. Real-time calculation of  $d_{ij}$  and  $c_j^n$  is required.  
 32 *Implementation of  $d_{ij}$  calculation*: Coordinates of transit and commercial facilities are  
 33 selected and outputted in code logic. This involves linking to escalator variables within  
 34 the main model to output spatial escalator coordinates for subsequent calculations.  
 35 *Implementation of  $c_j^n$  Calculation*:  $c_j^n$  represents the number of people queuing at real-  
 36 time equipment and facilities. A coordinate range in front of a facility is defined, and  
 37 pedestrians appearing and staying in this range within a set time unit (10 seconds in this  
 38 study) are identified as waiting in line for service.
- 39 3. *Attractiveness coefficient calculation*: Parameters  $E_{ij}$ ,  $F_{ij}$ ,  $N_j$ ,  $T_j$ , and  $a_{ij}$  are assigned  
 40 based on purpose, gender, and facility type. Given the varied composition of passenger  
 41 flows at different times and stations, random generation of passengers by gender and  
 42 purpose is assumed for simulation and analysis. Random generation of pedestrian agent  
 43 gender and purpose is inputted to derive values influencing the attractiveness coefficient

1 calculation.

2 4. Implementation of Pedestrian Agent Behavior: Each pedestrian agent's behavior is con-  
3 trolled based on calculated attraction parameters. While the decision-making logic for  
4 facility selection is determined by the model, the specific path-finding behavior and mi-  
5 croscopic movements of pedestrians are consistent with the assumptions of the social  
6 force model.

## 7 **Simulation Execution and Model Validation**

8 After constructing the behavioral simulation for all pedestrians in the station, the entire simulation  
9 system is executed. This simulation system models and displays pedestrian behaviors and com-  
10 plete paths under all decision possibilities: pedestrian entry and exit from the station, movement  
11 towards commercial facilities, queueing for consumption, escalator boarding, and disembarking.  
12 Due to the simplified station layout, lacking real station structures and passenger flow data for  
13 direct comparison, alternative validation methods for the simulation system are necessary.

14 Pedestrian simulation model validation methods include:

- 15 • *Comparative verification method*: Contrasting simulation model results with actual ob-  
16 served data to validate model accuracy.
- 17 • *Parameter calibration method*: Iteratively adjusting model parameters using real passen-  
18 ger flow data to enhance accuracy.
- 19 • *Sensitivity analysis*: Comparing simulation outputs under different parameters to observe  
20 any unreasonable fluctuations, thus testing model consistency and stability.
- 21 • *Literature Review Method*: Systematically analyzing relevant studies to evaluate the ef-  
22 fectiveness of model construction and parameter selection.
- 23 • *Benchmarking Method*: Comparing simulation outputs with those of similar scenarios to  
24 assess the model's conformity with reality.

25 Due to the abstraction of station structures, direct validation using actual passenger flow  
26 data is unfeasible. Therefore, the benchmarking method is attempted for simulation model vali-  
27 dation. Shanghai Jing'an Temple subway station serves as a benchmark due to its similar spatial  
28 layout to the abstract station constructed earlier, with comparable commercial layouts.

29 Actual subway station spatial structures and passenger flow data from Jing'an Temple  
30 station are collected for comparison, including distributions of passenger flows at different en-  
31 trances/exits and commercial facilities.

32 Jing'an District station combines a typical subway station with commercial spaces. Inside  
33 Jing'an Temple station, both paid and unpaid areas feature bakeries and various vending machines  
34 (beverages, blind boxes, self-service ID photos, etc.). Connections from exits lead to walkways  
35 hosting multiple commercial shops (bakery, clothing retail, cellphone repair, etc.).

36 Field research indicates an average queuing time of 10 seconds at entry gates, with an  
37 average queue length of 4 people within 5 minutes, increasing to 20 seconds and 6 people during  
38 peak periods. Exit gates average a 9-second queue with 5 people over 5 minutes, rising to 22  
39 seconds and 6 people during peak periods. These average queue times fall within the simulation's  
40 confidence interval, affirming the effectiveness of the simulation model.

41 Using Jing'an Temple station as a benchmark, the validity of simulated passenger and  
42 commercial behaviors is assessed. Vending machines within the station, similar in distribution to  
43 the simulated subway station, serve as the benchmark for commercial facilities. With an aver-  
44 age service duration of 34 seconds per vending machine and recording 10 passengers generating

1 commercial behavior within the station, their entry, deviation, and walking speeds align with simu-  
2 lation results. The distribution of station flows (commercial facilities, entrance/exit gates, escalator  
3 entrances) within 10 minutes of simulation runtime also correlates well with observed distribution  
4 patterns.

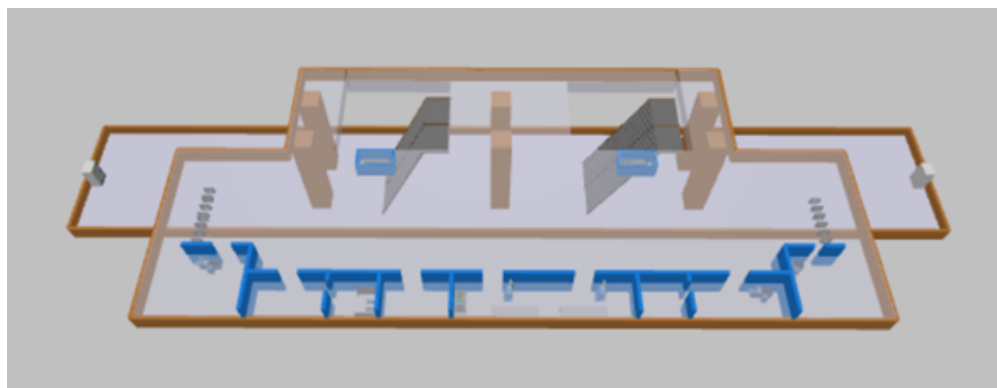
5 Based on benchmarking validation results, this section establishes that the attractiveness-  
6 based passenger flow simulation can be applied to the evaluation and optimization of stations with  
7 commercial amenities.

## 8 CASE STUDY

9 In this section, we apply the attractiveness-based route choice model to evaluate and optimize a  
10 typical metro station. This case study demonstrates how the model can assess passenger flow  
11 organization and spatial layout limitations and provide corresponding optimization measures.

### 12 Case Design

13 We used the station layout described before, designed to mimic the typical transit and commercial  
14 environments of the Shanghai Metro subway system. Figure 2 schematizes this layout. The eval-  
15 uation and optimization outcomes could apply to most stations with commercial facilities in the  
16 Shanghai metro system.



**FIGURE 2 Top-down view of the environment setup for the example metro station.**

17 This station includes transit facilities and commercial facilities. Transit facilities encom-  
18 pass gates, escalators, and platforms. The gates are distributed on both sides of the station hall  
19 level, with three sets of entry gates and three sets of exit gates on each side, serving as the starting  
20 and ending points for transit access. Both sets are of the AFC (Automatic Fare Collection) type,  
21 with a passage width of 60 cm to ensure single-person passage while preventing tailgating. The  
22 reaction time is set at 0.5 seconds each time.

23 The escalator connects the platform level and the hall level, with two sets of up-and-down  
24 escalators on both sides. The step width is set at 80 cm, the lifting height at 10 meters, and the  
25 running speed at 0.65 m/s.

26 Commercial facilities are distributed across the station hall level and the platform level. Six  
27 commercial stores are side-by-side on one side of the station hall level, with two vending machines  
28 symmetrically arranged on the escalator side and two at the head and tail of the platform level.

1 To analyze the station's performance and propose optimizations, we created six compara-  
2 tive scenarios, focusing on the flow line, transit facility, and commercial facility aspects of station  
3 operations, in addition to a baseline scenario.

4 In terms of flow line design scenarios, in Scenario A, all entry gates are relocated to the  
5 left side of the station hall and all exit gates to the right side of the station hall. In Scenario B,  
6 barriers are added near the escalators to create a buffer zone, and the path when using the escalator  
7 is extended.

8 Regarding the transit facility design scenarios, in Scenario C, the number of service gates  
9 is reduced to 2 entry and 2 exit gates, and in Scenario D, the escalator speed is increased from 0.65  
10 m/s to 0.7 m/s.

11 Concerning the commercial layout design scenarios, Scenario E modifies the entrance num-  
12 bers: store D has an additional entrance (an increase from 1 to 2 entrances), whereas the entrances  
13 of store E are reduced (from 2 to 1 entrance). In Scenario F, the vending machines are relocated to  
14 the entry/exit gate areas.

15 These scenarios aim to test different aspects of station performance, such as passenger  
16 flow efficiency, queue lengths, and commercial facility utilization under different spatial layouts or  
17 passenger flow organizations. The results from these simulations provide insights for enhancing  
18 the station's operational efficiency and passenger experience.

## 19 **Simulation Results and Analysis**

20 Using the pedestrian simulation framework outlined before, we analyzed the results of the six  
21 scenarios. Table 6 provides an overview of the key simulation results in comparison to the base  
22 scenario.

23 Relocating all entry gates to the left and all exit gates to the right (Scenario A) increases  
24 the average passage time for entry gates from 15 seconds to 18 seconds, a 20% increase, and queue  
25 length from 4 to 5 people, leading to a temporary delay in flow capacity of around 10%.

26 Introducing barriers near escalators, creating buffer zones and increasing the passage time  
27 for the left and right downward escalators by 4 seconds each (Scenario B) reduces queue lengths  
28 by one person, indicating decreased congestion near escalator entries.

29 Reduced gate numbers in Scenario C create temporary congestion in the gate area, causing  
30 entry times to increase by approximately 12%, while Scenario D demonstrates improved flow near  
31 escalators due to higher operational speeds.

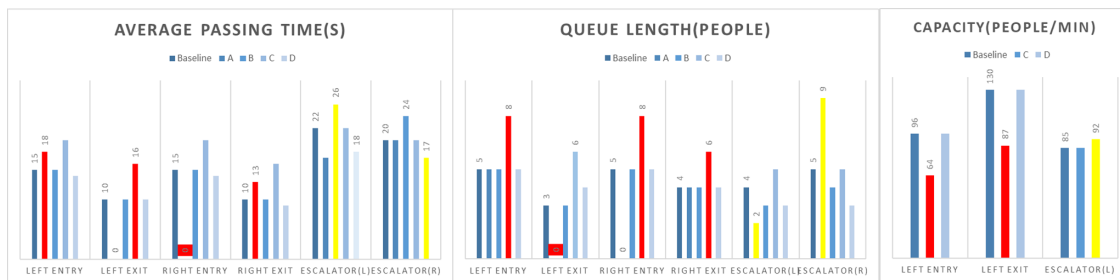
32 Scenario D increases the escalator speed from 0.65 m/s to 0.7 m/s, reducing average pas-  
33 sage time and queue lengths for the left downward escalator, with a 15% reduction in waiting time.  
34 This adjustment improves efficiency without significantly affecting the gate capacity. Figure 3 pro-  
35 vides a quantitative comparison between the different transit facility scenarios (scenarios A, B, C,  
36 and D).

37 Scenario E changes the number of entrances and exits. Adding an extra entrance to store  
38 D reduces the average queue length from 4 people to 1 person, effectively dispersing pedestrian  
39 queues by 75% and improving the efficiency of pedestrian movement. This adjustment also de-  
40 creases wait times for entering the store by over 20%, facilitating smoother pedestrian flow.

41 In Scenario F, relocating commercial points A and B from the side of the escalator near  
42 the gate reduces the number of pedestrians stopping by, lowering the queue length at commercial  
43 point A from 2 to 1 and reducing the average passing time from 15 seconds to 12 seconds. Figure 4  
44 provides a quantitative comparison between the different commercial facility scenarios (scenarios

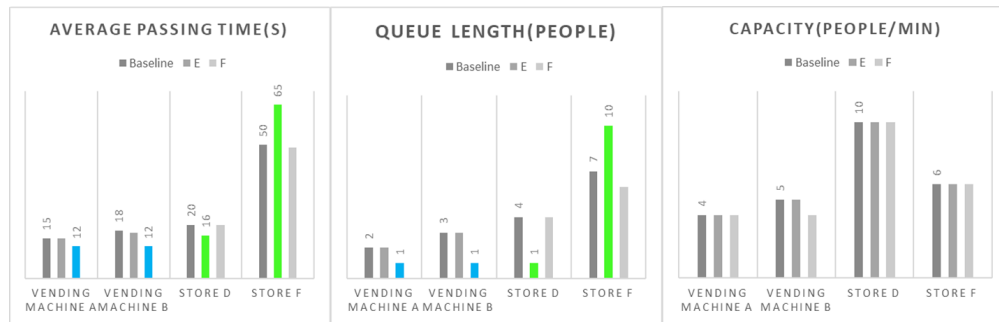
**TABLE 6 Simulation Results**

Criterion	Facility	Scenario					
		Baseline	A	B	C	D	F
Average Passing Time (s)	Left Entry	15	18	15	20	15	
	Left Exit	10	0	10	16	10	
	Right Entry	15	0	15			
	Right Exit	10	13	10			
	Escalator(L)	22	17	26	23	18	
	Escalator(R)	20	25	24			
	Vending Machine A	15					15
	Vending Machine B	18					17
	Store D	20					16
	Store F	50					65
Quene Length (people)	Left Entry	5	5	5	8	5	
	Left Exit	3	0	3	6	4	
	Right Entry	5	0	5			
	Right Exit	4	4	4			
	Escalator(L)	6	2	3	5	3	
	Escalator(R)	5	9	4			
	Vending Machine A	2					2
	Vending Machine B	3					3
	Store D	4					1
	Store F	7					10
Capacity (people/min)	Left Entry	96			64	96	
	Left Exit	130			87	130	
	Escalator(L)	85			85	92	
	Vending Machine A	4					4
	Vending Machine B	5					5
	Store D	10					10
	Store F	6					6



**FIGURE 3 Results of Quantitative Indicators (Transit Facilities).**

- 1 E and F).
- 2 The capacity of commercial facilities remains relatively unchanged across all scenarios,
- 3 suggesting that the number of entrances and spatial positioning affect waiting times and queue



**FIGURE 4 Results of Quantitative Indicators (Commercial Facilities).**

1 lengths more than service capacity.

## 2 Recommendations for Spatial Optimization

3 Based on the simulation results and analysis of different scenarios, we propose the following rec-  
 4 ommendations for optimizing the spatial layout of stations with commercial facilities, which are  
 5 also applicable to regular metro stations:

- 6 • *Station hall configuration*: Set up both entry and exit gates at each station entrance. Gates  
 7 should not be located too far apart or concentrated only on one side of the hall. Placing  
 8 gates in close proximity can streamline passenger flow and prevent congestion in isolated  
 9 areas.
- 10 • *Escalator buffer zones*: For areas with excessive crowding near escalators, it is benefi-  
 11 cial to install buffer barriers. These barriers can increase the walking path length and  
 12 effectively reduce the number of people queuing at the escalator entrance.
- 13 • *Adjusting Escalator Speed*: Within the design standards for metro systems, increasing  
 14 the escalator speed can alleviate passenger congestion at the escalator entrances. Addi-  
 15 tionally, adjusting the number of operational gates during peak and off-peak hours can  
 16 manage congestion and operational costs effectively. Reducing the number of gates dur-  
 17 ing off-peak times can lower costs without significantly impacting the passenger flow.
- 18 • *Commercial Facility Layout*: The design of commercial store entrances directly affects  
 19 the accessibility within the store. If a store frequently experiences internal congestion  
 20 or has high-depth areas, adding an extra entrance can enhance internal accessibility, re-  
 21 duce queue lengths, and decrease the average service time. Moreover, the location of  
 22 commercial facilities (such as vending machines) can influence both the accessibility of  
 23 the commercial point and the walking space around it. Commercial facilities should be  
 24 placed in locations that do not obstruct pedestrian flow, which can reduce congestion  
 25 on main pathways, although this may increase walking distances and potentially reduce  
 26 commercial revenues.

## 27 DISCUSSION AND CONCLUSION

### 28 Discussion

29 In this study, we modeled and simulated pedestrian route choice behaviors within metro stations  
 30 with commercial facilities, specifically focusing on the impact of commercial spaces on individual  
 31 behavior and passenger flow. Our results demonstrate that incorporating factors such as subjective

1 distance and time perception can more accurately simulate the behavior and distribution of passen-  
2 gers within a metro station. These findings have important implications for the spatial design and  
3 passenger flow organization of these metro stations. For existing stations with fixed spatial layouts,  
4 our findings focus on optimizing facility placement and flow organization, including adjustments  
5 like elevator speed. For new stations, the evaluation framework can inform both initial design and  
6 operational planning.

7 Our results can help designers more effectively configure the location of commercial spaces  
8 and transit facilities. By understanding pedestrian preferences for specific types of commercial  
9 spaces, station layouts can be optimized to maximize commercial value in high-traffic areas while  
10 offering targeted services in low-traffic zones. Such optimizations can improve the overall con-  
11 sumer experience and increase the frequency of use of commercial spaces, thereby boosting com-  
12 mercial revenues.

13 This study contributes to existing theory by providing a more individualized prediction of  
14 pedestrian decision-making. Unlike existing studies that often overlook the subjective perceptions  
15 of passengers, our model introduces subjective distance and time-perceived variables, which can  
16 more accurately predict pedestrian paths and the distribution of passenger flow under different  
17 spatial layout scenarios. This approach enhances the predictive accuracy of simulations and allows  
18 for proactive adjustments in passenger flow organization within metro stations, providing a new  
19 perspective on understanding complex passenger behavior.

## 20 **Conclusion**

21 This paper establishes a decision-making model for pedestrian walking behavior in metro stations  
22 with commercial facilities. The aim is to more accurately simulate pedestrian behavior and passen-  
23 ger flow distribution to evaluate and optimize the spatial layout and organization of passenger flow.  
24 The decision-making model is based on the attractiveness coefficient between individual pedestri-  
25 ans and different types of facilities. A questionnaire survey was designed to analyze the walking  
26 decision-making preferences of different genders, ages, and travel purposes within the station.

27 In addition to considering the utility of pedestrians from previous studies, our model intro-  
28 duces subjective distance coefficients and subjective time coefficients. These coefficients measure  
29 the impacts of perceived distance and perceived waiting time on decision-making for facilities.  
30 The established attractiveness coefficient model further incorporates the decision logic of pedes-  
31 trian route choice within the station, constructing the walking chain of pedestrians with facilities  
32 as decision nodes.

33 We implemented the established decision-making model in AnyLogic, a microsimulation  
34 software for social force modeling, to project the distribution and posture of passenger flow within  
35 the station. The validity of the simulation results was proven using the benchmarking method.  
36 Finally, we applied the simulation model to six different spatial layout and passenger flow orga-  
37 nization scenarios to evaluate the passing capacity of the equipment and facilities and to identify  
38 potential congestion areas. This demonstrated the applicability of the established model and sim-  
39 ulation system.

40 The simulation results clearly demonstrate the distribution of passenger flow within the  
41 station, identify safety hazards and capacity bottlenecks, and provide a feasible basis for evaluating  
42 and optimizing the spatial layout.

43 There are several areas for future research. Firstly, due to the wide variety of underground  
44 commercial types, it was impossible to conduct pedestrian preference surveys for all commercial

1 types; thus, only a few common formats were selected. Secondly, the limited sample size may  
2 have introduced biases in certain age groups, potentially limiting the broader applicability of find-  
3 ings. Future research could address this by increasing the sample size and employing more precise  
4 sampling methods to achieve a balanced distribution across demographic groups. While this study  
5 primarily uses data from the Jing'an Temple station, future research will include additional stations  
6 with diverse passenger compositions to enhance the generalizability of the findings. Additionally,  
7 the collection of commercial behavior decision-making data could incorporate video surveillance  
8 data from subway stations.

9 In designing the research questionnaire, the time and distance perception questions were  
10 based on picture and text explanations, which might differ from actual pedestrian decision-making  
11 processes. Future studies could use dynamic drawings, videos, or virtual reality to observe pedes-  
12 trian choices more accurately. This would better reflect pedestrians' perceptions in real-world  
13 scenarios.

14 This study offers an improved framework to better understand and optimize pedestrian  
15 behaviors in metro stations with commercial facilities, based upon established wayfinding mod-  
16 els and microscopic simulation tools. It provides valuable insights for urban planners and transit  
17 authorities to enhance station design and functionality.

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## 22 **AUTHOR CONTRIBUTIONS**

23 The authors confirm contribution to the paper as follows: study conception and design: X. Sun,  
24 L. Hong; data collection: X. Sun; analysis and interpretation of results: X. Sun; draft manuscript  
25 preparation: X. Sun, L. Hong, M. Cools. All authors reviewed the results and approved the final  
26 version of the manuscript.

## 27 **DECLARATION OF CONFLICTING INTERESTS**

28 The authors declared no potential conflicts of interest with respect to the research, authorship,  
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