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# From Passenger Preferences to Station-Area Optimization: A Discrete Choice Experiment on Metro Entrance/Exit Choice in Shanghai

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**Abstract**

Uneven distribution of passenger flows across metro entrances/exits is prevalent. Previous studies primarily examined built-environment factors influencing established exit-level flow disparities from an objective perspective. This study, however, incorporates passengers' subjective preferences to provide a more comprehensive understanding of the environment–behavior mechanisms shaping entrance/exit choice. A visual stated preference method was employed to construct choice scenarios with 12 environmental attributes grouped into two complementary dimensions of path accessibility and environmental quality. Multinomial logit models were then applied to estimate passengers' entrance/exit choice preferences, and the results informed a two-dimensional exit-level evaluation framework, demonstrated through a case study of Xujiahui Station in Shanghai. Compared with empirical studies, this study employs a discrete choice experiment, which circumvents the modeling challenges posed by the limited number of entrances/exits at individual stations and systematically integrates a range of station-internal and urban environmental attributes into a unified utility-based framework to evaluate their contributions. The results reveal the relative importance of various environmental attributes, together with their varying levels, in shaping passengers' entrance/exit choices and indicate that path accessibility exerts a stronger influence on decision-making than environmental quality. The proposed exit-level evaluation framework also serves as a practical tool for assessing resource allocation status at individual station areas, providing a foundation for policy formulation to support more human-centered, equitable, and fine-grained station-area governance.

**Keywords:** entrance/exit choice preference; discrete choice experiment; environment-behavior mechanisms; station-area resource allocation; city-station integration

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## 1. Introduction

Over the past two decades, in response to pressing urban challenges such as uncontrolled spatial expansion, traffic congestion, and air pollution, China's urban rail transit system has expanded rapidly, with both the number of metro lines and the density of the network steadily increasing [1–3]. Concurrently, the number of interchange stations has risen [4]. Many of these stations, shaped by the sequencing of rail line construction and constrained by aboveground and underground conditions, comprise several independent concourse units linked by underground passageways, resulting in dispersed and complex in-station pedestrian systems [5,6]. At the same time, to enhance connections with surrounding urban

areas and to provide balanced service coverage, these stations are typically equipped with multiple metro entrances/exits. However, in real-world operations, metro entrances/exits within the same station often experience uneven passenger flows, especially at interchange stations with multiple entrances/exits [7,8]. Appropriately addressing this issue is critical for promoting efficient and equitable development of station areas as well as advancing city–station integration. On one hand, severe imbalances in exit-level passenger flows should be avoided to prevent overloading or underutilization, thereby safeguarding the operational stability of the metro system [9,10]. On the other hand, attention should also be given to the alignment between the distribution of passenger flows and the arrangement of surrounding facilities, thereby fostering more human-centered and equitable station-area development [11].

In this context, developing a comprehensive understanding of metro passengers' entrance/exit choice mechanisms in relation to station-area environments is essential, as it supports both the identification of uneven flow distribution across metro entrances/exits and the formulation of rational station-area resource allocation strategies. To date, several studies have examined exit-level passenger flows in relation to the built environment from an objective perspective [12–14], adopting a post-diagnostic approach to interpret established flow disparities. However, research incorporating a subjective perspective, aimed at exploring passengers' "desired states" by assessing their choice preferences and trade-offs among different environmental attributes, remains scarce. Correspondingly, the underlying environment–behavior mechanisms have not been adequately investigated.

Notably, the observed passenger flows at metro entrances/exits are a form of revealed choice. These outcomes are not only shaped by the current physical context but also fail to capture the trade-offs underlying passengers' decision-making processes [15,16]. Therefore, while empirical studies identified key environmental attributes within the existing environment that influence passengers' entrance/exit choice behavior and offered references for interpreting flow disparities, they fall short of fully identifying the environmental factors considered by passengers as well as their relative importance. As a result, they offer limited guidance for the rational and equitable allocation of resources within station areas. Specifically, equitable resource allocation should not be understood as simply concentrating more or better resources on high-volume entrances/exits, as this may reinforce imbalances. Rather, a systematic, exit-level assessment of the environmental attributes considered by passengers during entrance/exit selection is required. Such an approach allows for a rapid diagnosis of each entrance/exit's strengths, weaknesses, and improvement potential, thereby informing the development of more targeted and human-centered strategies.

As metro stations with complex underground pedestrian systems and multiple entrances/exits continue to increase, issues concerning exit-level passenger flow distribution and resource allocation are expected to warrant greater attention. Accordingly, this study is conducted from a passenger-centered perspective to explore the following three questions: (1) How do passengers trade off various station-internal and urban environmental attributes when selecting a station entrance/exit during their metro journeys? (2) How can the estimated preference structure contribute to explaining the observed exit-level flow disparities? (3) What new insights can the estimated preference structure provide for station-area optimization?

To address these questions, a visual stated preference method was employed [17,18]. Twelve station-internal and urban environmental attributes, categorized into two complementary dimensions of path accessibility and environmental quality, were incorporated into a discrete choice experiment (DCE), from which two multinomial logit (MNL) models were estimated to quantitatively assess passengers' entrance/exit choice preferences. Based on the experimental findings, a two-dimensional exit-level evaluation framework was

developed, and its applicability and potential to inform station-area optimization were demonstrated through a case study of Xujiahui Station in Shanghai.

The practical contributions of this study are twofold. First, it incorporates subjective preference data to provide new evidence for interpreting exit-level flow disparities within individual stations, thereby informing user-oriented guidance strategies to mitigate overloading or underutilization. Second, it proposes an exit-level evaluation framework that serves as a systematic analytical tool for promoting human-centered and equitable station-area development policies.

## 2. Literature Review

### 2.1. Metro Entrance/Exit Space Under City–Station Integration

Within the context of city–station integration [19,20], metro entrances/exits, serving as crucial links between transit systems and urban spaces, have been discussed in academic research from both station and urban perspectives. At the station level, studies have identified a significant positive correlation between the number of entrances/exits at individual stations and their overall passenger volumes, underscoring the role of entrance/exit provision in improving station service performance [21–23]. From the urban perspective, research has shown that the spatial layout and configuration types of metro entrances/exits are key contributors to urban vitality and higher land values in station areas, respectively [7,24]. Collectively, these studies affirm the importance of metro entrances/exits. However, most of them still treat the characteristics of station entrances/exits, such as their number, as merely one of several explanatory variables for dependent outcomes such as passenger flow, rather than considering the entrances/exits themselves as independent analytical units. This suggests that metro entrances/exits have not received sufficient scholarly attention.

With the ongoing refinement of city–station integration, related studies in recent years have expanded across multiple dimensions. These include, but are not limited to, the optimization of the rail transit system, such as train arrival and departure scheduling [25,26], fare strategy formulation [27], and passenger flow management [28,29], as well as of station interiors, including entrance halls, ticket-checking areas [30], and transfer passages [31]. However, research focusing on metro entrances/exits still remains limited. A search conducted in the Web of Science database using the keywords “Metro Exit” and “Metro Entrance” revealed that, between 2020 and 2025, only four studies in the daily travel context treated metro entrances/exits as independent analytical units. Two of these studies are related to the topic of this paper, focusing on passenger flow disparities among metro entrances/exits, and will be discussed in detail in the following subsection [13,14]. Of the remaining two, one focused on identifying the factors influencing passenger satisfaction with metro entrances/exits in cold-climate regions to reveal differences in micro-level experiences [32], while the other proposed an entrance/exit imbalance index to quantify accessibility disparities among entrances/exits within the same station [33]. Although limited in number, the two studies highlight the necessity of adopting metro entrances/exits as the basic unit of analysis, as this approach enables the identification of internal imbalances within individual station areas. Such a perspective is of significant importance for promoting the rational allocation of station-area resources and advancing fine-grained governance strategies that support city–station integration.

### 2.2. Environment–Behavior Studies on Metro Entrances/Exits

Existing environment–behavior studies on metro entrances/exits have primarily focused on two distinct contexts—emergency evacuation and daily travel. In evacuation-related studies, several have incorporated passengers’ entrance/exit choice mechanisms into evacuation dynamics models to examine how decision-making parameters and station

environmental features affect evacuee distribution patterns across metro entrances/exits and the overall evacuation efficiency of metro stations [34,35]. Complementarily, several studies have adopted a passenger-centered perspective, examining how individuals make entrance/exit choices during evacuation based on perceived environmental attributes [36–38]. However, although evacuation studies from both objective and subjective perspectives have yielded valuable insights, evacuation behavior is fundamentally distinct from daily travel in its rapid-escape motives, and the findings are therefore difficult to generalize to ordinary contexts such as commuting or shopping.

Compared with evacuation-oriented research, environment–behavior studies on metro entrances/exits within the daily travel context remain relatively scarce. Between 2020 and 2025, only two relevant studies were identified in the Web of Science database, along with one additional study in the China National Knowledge Infrastructure database. Among these, the distribution of passenger flows across metro entrances/exits has typically served as the basis for investigating environment–behavior relationships. As a single-station study, Xu et al. [12] examined People's Square Station in Shanghai, employing the choice value of the street-level pedestrian network at each metro entrance/exit and the distribution of points of interest (POIs) within the catchment area to explain exit-level flow disparities. For a broader scale, Chen et al. [13] analyzed 23 representative metro stations and 36 metro entrances/exits in Xi'an, China, drawing on 21 urban environmental indicators to construct regression models that explained 38–83% of ridership variation at the station level and 16–51% at the entrance/exit level. Yan et al. [14] investigated 65 metro stations and 256 entrances/exits in Xiamen, China, employing 16 environmental indicators to analyze their associations with both exit-level passenger volumes and passenger distribution ratios across entrances/exits within stations.

In addition to their limited number, the reviewed studies within the daily travel context share several common limitations. (1) Theoretically, these studies aimed at explaining established flow disparities at metro entrances/exits from an objective perspective, whereas passengers' subjective trade-offs and choice preferences received little attention. (2) Methodologically, the limited number of entrances/exits within a single station presents challenges for statistical modeling. For instance, a widely accepted rule of thumb in regression analysis requires at least ten samples per independent variable to reduce risks such as unstable parameter estimates, multicollinearity, and overfitting. As a result, when modeling exit-level passenger volumes at a single station, traditional regression models have limited capacity to incorporate multiple environmental attributes reliably, restricting their ability to capture the combined effects of multiple factors. Similarly, extending the analysis to include entrances/exits from multiple stations may introduce inter-station heterogeneity, potentially compromising the explanatory validity of the model. (3) Analytically, the selection of explanatory variables in these studies placed greater emphasis on urban environmental factors, whereas station-internal attributes received comparatively less attention.

In response, this study employed a DCE to examine metro passengers' entrance/exit choice preferences in the daily travel context. The academic contributions of this study are threefold. (1) It identifies metro passengers' subjective trade-offs and the preference structure in entrance/exit choices, thereby advancing a more comprehensive understanding of the environment-behavior mechanisms. (2) It generates a synthetic dataset of choices by constructing virtual scenarios through orthogonal experiments, thereby overcoming the constraints of the limited entrance/exit sample size at individual stations. (3) It assigns equal emphasis to station-internal and urban environmental attributes in the experimental design, and integrates them into a unified utility-based framework for quantitative anal-

ysis through MNL models, thereby enabling a comprehensive assessment of the relative importance of station-level and city-level factors.

## 3. Materials and Methods

### 3.1. Attribute Selection

Although research on metro travel behavior has expanded in recent years, studies that simultaneously address entrance/exit areas and consider both station-internal and urban environmental factors remain limited. Most existing works focused exclusively on either underground or aboveground settings, and a reliable environmental attribute framework applicable to metro entrance/exit areas has yet to be established. Against this background, this study employed an inductive construction approach aimed at developing an attribute set that is both scientifically sound and experimentally feasible. Exit-related environmental attributes were collected separately from underground and aboveground spaces based on relevant literature, while closely aligning with the requirements of the visual stated preference experiment conducted in this research.

The underground space refers to the station interiors and the directly connected underground public spaces. Existing studies, however, have incorporated underground environmental attributes into analyses only in a fragmented manner, lacking a systematic framework. To ensure representativeness and comprehensiveness in attribute selection, this study reviewed three categories of research: evacuation behavior within metro stations, in-station route choice under the daily travel context, and the use and vitality of underground public spaces. Although these studies do not focus exclusively on metro entrances/exits, the environmental attributes they examined are applicable to exit-level analyses, as these spaces are typically directly connected to metro entrances/exits. The following literature provided an empirical foundation for selecting underground attributes. Specifically, evacuation studies showed that path length and entrance/exit width are important determinants of passengers' entrance/exit choice [34–38]. Meanwhile, escalator allocation was found to significantly influence passengers' in-station route choice [39,40]. In addition, factors such as spatial configuration, spatial aesthetics, and the integration of transport and commercial functions were also recognized as important influences shaping passengers' use and perception of underground spaces [41,42].

The aboveground space refers to the street segments directly connected to metro entrances/exits. Existing research in this area, by contrast, is well-developed and has examined a wide range of aboveground environmental attributes. Based on existing research, eight representative works that are both academically influential and thematically relevant were selected. These works reflect mainstream perspectives and form a systematic basis for selecting aboveground attributes [43–50].

Based on the above literature, the core principles guiding attribute selection include:

(1) Principle of validity. As an initial exploration driven by the stated preference approach, the attribute selection was designed to balance behavioral explanatory power and respondents' cognitive burden. To this end, a strategic focusing strategy was adopted to construct a concise yet effective set of attributes covering both underground and aboveground environments, with the aim of clarifying their relative importance. Accordingly, indicators that have been consistently validated in previous studies and shown to exert significant and robust effects on pedestrian behavior were given priority for inclusion.

(2) Principle of applicability. Given that this study treats metro entrances/exits as independent analytical units and focuses on the daily travel context, the selected attributes must be directly related to metro entrance/exit choice and be capable of capturing environmental variations among different entrances/exits within the same station.

Attributes relevant to daytime travel were prioritized. Macro-scale or homogeneous indicators (e.g., block size) were excluded.

(3) Principle of experimental operability. The selected physical environmental attributes must be stable, measurable, and easily perceived by respondents, while also capable of being clearly represented through visualization to ensure consistent understanding in the stated preference experiment. For example, abstract concepts such as spatial configuration need to be concretized into intuitively comparable indicators, such as walking distance and number of turns.

Notably, this study acknowledges the fundamental importance of pedestrian safety in congested urban environments. However, the focus of this research lies in passengers' entrance/exit choice preferences. Accordingly, behavioral validity, as supported by existing literature, remains the primary principle guiding attribute selection, complemented by considerations of spatial heterogeneity and experimental operability. Within this framework, environmental factors related to pedestrian safety (e.g., entrance/exit width, sidewalk width, and street-crossing difficulty) were prioritized, ensuring that the proposed attribute framework is theoretically grounded, methodologically sound, and practically relevant.

Finally, six underground attributes were included in this study: ① Walking distance from platform to metro entrance/exit; ② Number of turns from platform to metro entrance/exit; ③ Entrance/exit width; ④ Types of vertical transportation facilities at metro entrance/exit; ⑤ Interior spatial aesthetics of metro entrance/exit; ⑥ Underground commercial vitality near metro entrance/exit.

Similarly, six aboveground attributes were retained: ① walking distance from urban origin/destination to metro entrance/exit; ② number of turns from urban origin/destination to metro entrance/exit; ③ street-crossing obstacles near metro entrance/exit; ④ sidewalk width near metro entrance/exit; ⑤ aboveground commercial vitality near metro entrance/exit; ⑥ street greening level near metro entrance/exit.

To avoid the cognitive burden of presenting all 12 selected attributes simultaneously within a single choice task [51], and more importantly, to ensure that the experimental design aligns with passengers' perceptual structure of the travel environment, the attributes were reorganized under a dual-logic framework. At the theoretical level, drawing on the classical distinction between accessibility and attraction in travel behavior research [52], the 12 attributes were reorganized into two complementary dimensions: path accessibility and environmental quality. The former emphasizes walking efficiency and continuity, reflecting the ease with which passengers travel from the platform or from urban origins or destinations to a specific metro entrance/exit. The latter focuses on spatial attractiveness and walking comfort, reflecting passengers' willingness to use a particular entrance/exit. At the spatial-structural level, the division between underground and aboveground attributes was retained to guide the construction of the virtual experimental scenarios. In this way, the theoretical framework was transformed into an evaluation system with a clear spatial structure, consistent with passengers' aggregated perception of in-station and out-of-station environments.

The final classification is presented in Table 1, with each attribute assigned three levels to construct choice scenarios. Specifically, levels for entrance/exit width were defined following the "Code for Design of Metro" [53]; levels for sidewalk width were defined with reference to both the "Standard for Urban Comprehensive Transport System Planning" [54] and the existing conditions in Shanghai; and levels for the remaining attributes were defined based on typical environmental features observed around metro entrances/exits in Shanghai.

**Table 1.** Attribute and level definition.

| Dimension | Category | Attribute | Literature | Definition | Level |
|---|---|---|---|---|---|
| Path accessibility | Underground attributes | In-station walking distance | Xu and Chen [7], Cai et al. [34], Huo et al. [35], Feng et al. [36], Mandal et al. [37], Mandal et al. [38] | The shortest walking distance from platform to metro entrance/exit. | 150 m; 300 m; 450 m |
| | | In-station turns | Gu and Osaragi [41] | The number of turns along the shortest path from platform to metro entrance/exit. | None; 4 turns; 8 turns |
| | | Vertical transportation | Damen et al. [39], Van den Heuvel et al. [40] | Types of vertical transportation facilities at metro entrance/exit. | Only stairs; Stairs and escalator; Stairs, escalator, and elevator |
| | Aboveground attributes | Out-of-station walking distance | Guo and Loo [44], Lue and Miller [47], Liu et al. [49], Chen et al. [50] | The shortest walking distance from urban origin/destination to metro entrance/exit. | 200 m; 400 m; 600 m |
| | | Out-of-station turns | Sun et al. [45], Lue and Miller [47], Chen et al. [50] | The number of turns along the shortest path from urban origin/destination to metro entrance/exit. | None; 4 turns; 8 turns |
| | | Street-crossing difficulty | Sun et al. [45], Chen et al. [50] | Street-crossing obstacles near metro entrance/exit. | Overpass; Wide road (≥6 lanes); None |
| Environmental quality | Underground attributes | Entrance/exit width | Cai et al. [34] | The width of metro entrance/exit. | 3 m; 4.5 m; 6 m |
| | | Underground commercial vitality | Xu and Chen [42] | The scale of underground commercial facilities near metro entrance/exit. | None; Convenience store; Connected mall |
| | | Entrance/exit spatial aesthetics | Xu and Chen [42] | The quality of wall and floor surfaces in metro entrance/exit space. | Worn; Neutral; Refined |
| | Aboveground attributes | Sidewalk width | Guo [43], Guo and Loo [44], Sun et al. [46], Liu et al. [48], Liu et al. [49] | The width of pedestrian walkway connected to metro entrance/exit. | 2 m; 4 m; 6 m |
| | | Street commercial vitality | Guo [43], Guo and Loo [44], Liu et al. [48] | The density of street-front shops near metro entrance/exit. | No shops; Scattered shops; Continuous shops |
| | | Street greening level | Sun et al. [46], Liu et al. [48], Liu et al. [49] | The level of street greenery near metro entrance/exit. | No greenery; Trees only; Trees and shrubs |

It is also worth noting that while previous studies have highlighted the role of spatial cognition in shaping passengers' route choices [55], this study's virtual scenarios provided all respondents with uniform information about each metro entrance/exit alternative. Thus, variations in choice outcomes primarily reflect differences in individual preferences rather than in spatial cognition. Moreover, environmental attributes related to wayfinding, such as signage, were not included in the experiment.

### *3.2. Discrete Choice Experiment*

#### 3.2.1. Experimental Design

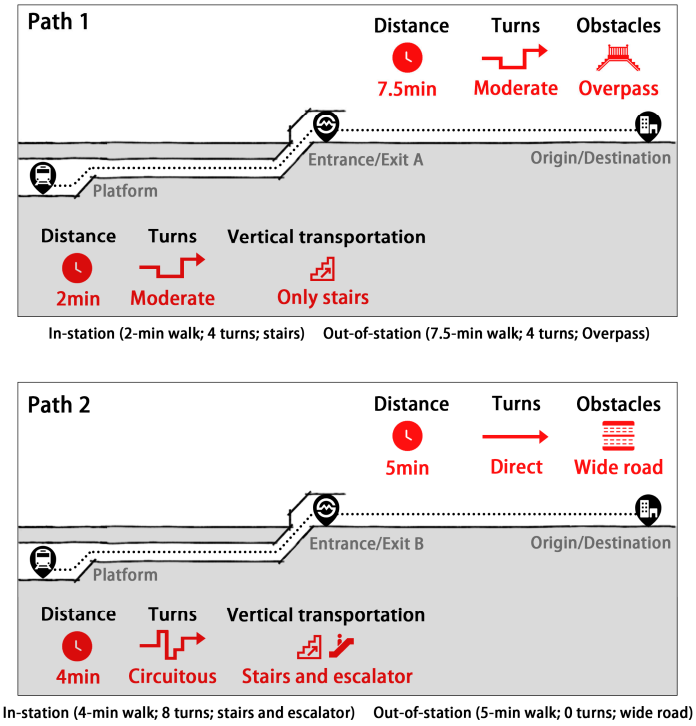
In a DCE, respondents are presented with a series of choice tasks constructed by systematically combining attribute levels. Their choices reveal preferences and allow estimation of the relative importance of each attribute and its levels. To ensure a manageable number of choice tasks while maintaining representativeness, an orthogonal design was adopted. For each dimension, six attributes with three levels were used to construct choice tasks. This process initially yielded two sets of 26 choice tasks, with two alternatives per task. Subsequently, extreme combinations with limited comparative value were removed, resulting in 22 tasks for the path accessibility dimension and 24 for the environmental quality dimension.

To establish a controlled, full-information context for decision-making, all choice tasks were visually presented (Figure 1) [18]. For the path accessibility dimension, attribute levels were illustrated through icons with brief descriptions. Walking distances were converted into walking times based on an average speed of 80 m per minute to better reflect respondents' perceived walking effort. For the environmental quality dimension, pedestrian-perspective scenes were constructed using modular components in modeling software and later refined in Photoshop. To ensure that each attribute was clearly recognizable within the scenes, they were outlined with wireframes and labeled with corresponding levels. In addition, a color-coding scheme was applied, with red indicating the varying attributes and blue denoting the common ones, so that respondents were fully informed of all attributes under investigation and could focus on essential trade-offs.

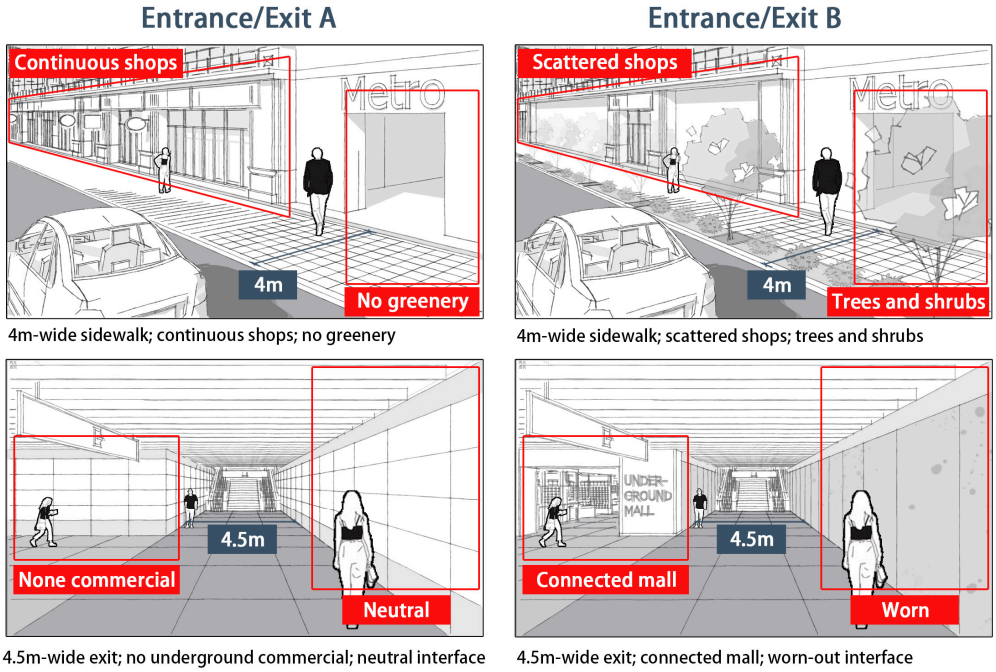
Following the construction of tasks, they were compiled into questionnaires. To reduce respondent burden, the 22 path accessibility tasks and 24 environmental quality tasks were randomly distributed across four questionnaire versions. Each version contained five or six tasks related to path accessibility and six related to environmental quality, yielding a total of 11 or 12 tasks per questionnaire.

#### 3.2.2. Questionnaire Survey

The survey comprised two parts. The first part collected information on respondents' broad sociodemographic characteristics and metro travel habits. The second part comprised 11 or 12 scenario-based choice tasks, which participants were instructed to complete with reference to their most recent metro travel experience. After completing the tasks, respondents were required to answer two supplementary questions. One asked them to select the three most important attributes from six under the path accessibility dimension, and the other did the same under the environmental quality dimension. These questions served as a check of internal consistency in responses. Specifically, for each questionnaire, if a respondent selects scenario B in a choice task where scenario A offers superior levels on two or more of the three attributes they identified as most important, while the remaining attribute levels of the two scenarios are comparable, the response is considered inconsistent and should be excluded.




(**a**)




(**b**)

**Figure 1.** Examples of choice tasks. (**a**) Choice task for path accessibility; (**b**) Choice task for environmental quality.

The survey questionnaire was developed on the Wenjuanxing online platform and distributed via two channels with separate questionnaire links for each from late May to mid-June. Participants were required to be between 18 and 60 years old. First, in-person recruitment was conducted at Tongji University, Tongji University Station, and several three-line interchange stations with high passenger volumes in Shanghai, randomly inviting strangers to participate, targeting university students and on-site metro passengers with typically high metro usage frequency. Second, online recruitment was conducted through

public posts on Xiaohongshu and Sina Weibo, inviting users whose IP-based location labels indicated Shanghai to participate, thereby enhancing sample diversity. Participants voluntarily scanned the Quick Response code to fill out the questionnaire and could exit at any time. The questionnaire platform was configured not to collect respondents' source details, thus all collected data were anonymized. After data collection, responses were screened based on completion time and internal consistency.

For designs considering only main effects, the minimum sample size requirement was estimated using Orme's empirical formula [56] (pp. 62–65):

$$N > \frac{500c}{ta} \tag{1}$$

where $c$ is the largest number of levels for any one attribute; $t$ is the number of choice tasks per respondent; and $a$ is the number of alternatives per task. Based on this formula, the required minimum sample size was 125. In total, 312 valid responses were collected, with an approximate 2:1 ratio between in-person and online recruitment, ensuring both a sufficient representation of frequent metro users and overall respondent diversity, while meeting the required sample size. The detailed characteristics of the survey respondents are summarized in Supplementary Materials (Table S1).

#### 3.2.3. Model Construction

According to random utility theory, individuals are assumed to compare attribute-level combinations during decision-making and choose the alternative with the highest utility. Based on this framework, two MNL models were constructed separately for the path accessibility and environmental quality dimensions. To account for the potential non-linear effects of different levels within the same attribute on utility, dummy coding was applied. For each three-level attribute, one level was specified as the reference level, with its coefficient fixed at zero and excluded from estimation. The remaining two levels were represented by binary dummy variables (0 or 1), with their coefficients indicating the utility difference relative to the reference level. For reference level specification, attributes related to path length and number of turns were assigned their maximum levels as references, while the remaining attributes were assigned the most commonly observed levels in Shanghai metro station areas. The utility function is expressed as follows:

$$V_i = \sum_{j=1}^{6} \sum_{s=1}^{2} \alpha_{j,s} X_{j,s,i} \tag{2}$$

where $V_i$ is the total utility of metro entrance/exit $i$; $j$ indexes the attributes; and $s$ indexes the dummy-coded levels of each attribute. $\alpha_{j,s}$ is the utility coefficient of the $s$-th dummy-coded level of attribute $j$. $X_{j,s,i}$ is a binary variable that equals 1 if entrance/exit $i$ takes the $s$-th dummy-coded level of attribute $j$, and 0 otherwise.

Finally, the MNL models were estimated using NLOGIT 6. The anonymized and coded dataset used for the estimation of the MNL models is available in Supplementary Materials (Dataset S1).

## 4. Case Study

Based on the parameter estimates, a two-dimensional exit-level evaluation framework was constructed to assess metro entrance/exit performance. To examine its applicability, a case study was conducted at Xujiahui Station in Shanghai. First, the framework was employed to calculate two-dimensional subjective scores for each metro entrance/exit at Xujiahui Station based on built environment attributes, and the relationship between the subjective scores and observed exit-level passenger volumes was examined to val-

idate its explanatory power. Second, the framework was applied to classify the metro entrances/exits and perform attribute-level analysis, demonstrating its practical utility for guiding station-area optimization.

### *4.1. Xujiahui Station*

Xujiahui Station, located in Shanghai's Xuhui District, is an interchange hub for Metro Lines 1, 9, and 11 (Figure 2). The station consists of three concourses linked by underground corridors. As of July 2025, 18 numbered entrances/exits providing ground-level access, together with one unnumbered underground passage connecting the Line 9 and Line 11 concourses to the Grand Gateway 66, were in operation. This study focused on the evaluation of the 18 numbered entrances/exits.

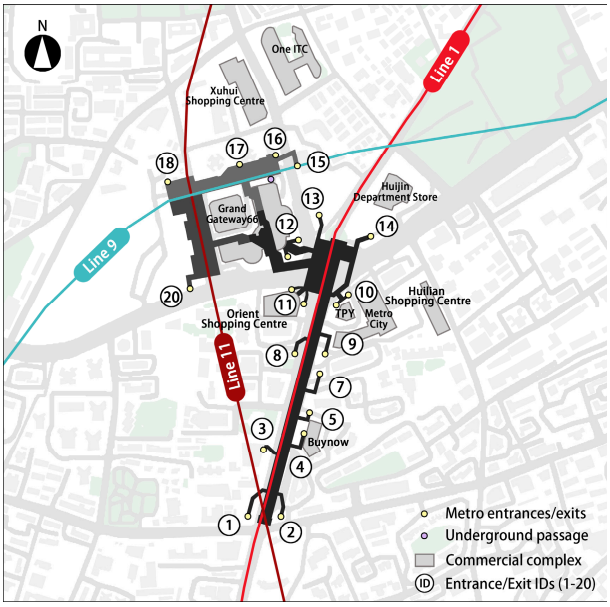



**Figure 2.** Xujiahui Station.

### *4.2. Scoring of Metro Entrances/Exits*

Prior to the scoring, the pedestrian catchment area of Xujiahui Station was delineated. According to the "Guidelines for Planning and Design of Urban Rail Transit Areas" [57], the typical catchment radius of metro stations in China is 500–800 m. A previous study further indicated that the effective catchment radius of most metro stations in Shanghai is typically less than 800 m [58]. Accordingly, this study defined the catchment area of Xujiahui Station as the union of 600 m isochrones centered on each entrance/exit, derived from the street-level pedestrian network and representing an approximate 10 min walking distance. The delineation was performed in GIS and resulted in a total area of approximately 1.59 km$^2$.

Subsequently, the path accessibility score was calculated for each metro entrance/exit. Within the framework of the discrete choice model, the utility function assumes additive separability, meaning that the partial utility of each attribute can be independently estimated and aggregated to obtain overall utility [59]. Based on this principle, exit-level scoring was conducted (Figure 3).

The scoring of in-station walking distance and number of turns was conducted as follows. First, an underground pedestrian network of Xujiahui Station was constructed. For each of the three concourses, a centrally located vertical circulation node connecting its platform and concourse level was selected as the first set of sample points, while the 18 numbered metro entrances/exits were defined as the second set. Second, using GIS-based shortest path analysis, the shortest entry and exit paths between each metro

entrance/exit and the platforms were computed. During this process, only inbound faregates were considered for entry paths and only outbound faregates for exit paths. Based on the shortest-path results, weighted scores were calculated for each metro entrance/exit:

$$T_i^{(a)} = \sum_{j=1}^{3} w_j^{(in)} \left( \alpha_{a,1} X_{a,1,j}^{(in)} + \alpha_{a,2} X_{a,2,j}^{(in)} + \alpha_{a,3} X_{a,3,j}^{(in)} \right) + \sum_{k=1}^{3} w_k^{(out)} \left( \alpha_{a,1} X_{a,1,k}^{(out)} + \alpha_{a,2} X_{a,2,k}^{(out)} + \alpha_{a,3} X_{a,3,k}^{(out)} \right) \quad (3)$$

where $T_i^{(a)}$ is the weighted score of metro entrance/exit $i$ for attribute $a$. $j$ and $k$ index the entry and exit paths connected to metro entrance/exit $i$, respectively. $w_j^{(in)}$ and $w_k^{(out)}$ are the weights of entry path $j$ and exit path $k$, respectively, determined by the 2024 average daily ridership (in 10,000 persons per day) of the metro lines served by the platforms to which these paths are connected—97.3 for Line 1, 93.6 for Line 9, and 81.3 for Line 11. $\alpha_{a,1}$, $\alpha_{a,2}$ and $\alpha_{a,3}$ are the utility coefficients for the three levels of attribute $a$. Binary variables $X_{a,1,j}^{(in)}$, $X_{a,2,j}^{(in)}$ and $X_{a,3,j}^{(in)}$ equal 1 if entry path $j$ corresponds to level 1, 2, or 3 of attribute $a$, and 0 otherwise. Similar definitions apply to the binary variables of exit paths $k$.

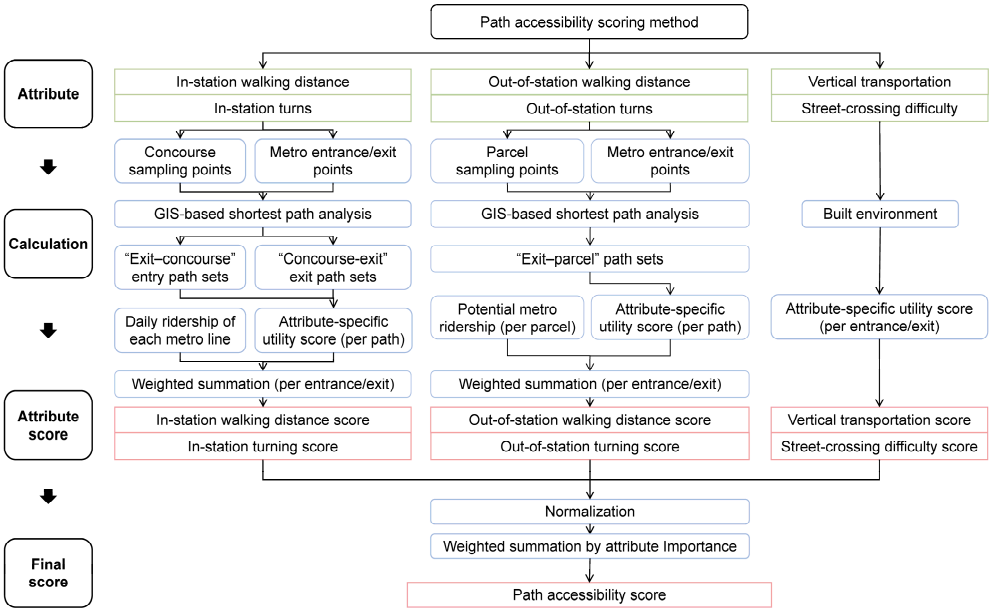



**Figure 3.** Path accessibility score calculation.

The scoring of out-of-station walking distance and number of turns was conducted as follows. First, a pedestrian street network within the catchment area of Xujiahui Station was constructed. Parcel boundaries were delineated concurrently based on the "Unit Plan of Xuhui District, Shanghai" [60]. For each parcel, a sampling point was placed on the pedestrian network nearest to its centroid, constituting the first set of nodes, while the second set comprised the 18 numbered metro entrances/exits of Xujiahui Station together with the metro entrances/exits of adjacent stations. Second, using GIS-based shortest path analysis, each parcel was assigned to its nearest metro entrance/exit. Only parcels linked to one of the 18 numbered entrances/exits of Xujiahui Station were retained for further scoring, together with their corresponding paths. This approach ensured that the subsequent scoring and analysis focused specifically on the core pedestrian catchment of Xujiahui Station and controlled edge effects.

The potential parcel-level metro ridership was then estimated. First, the building area of each parcel was approximated using building footprint and height data obtained from the Baidu Map Open Platform in 2024. Second, the parcel-level travel demand was calculated by multiplying the building area by the reference daily trip generation rates defined for

different building types in the "Technical Standards of Traffic Impact Analysis of Shanghai Construction Project" [61]. Representative trip generation rates for the main land-use types include 1.1 trips/$m^2$ for commercial, 0.7 for residential, 0.3 for business office, 0.1 for cultural venues, and 0.07 for urban parks. Third, the potential parcel-level metro ridership was derived by scaling the estimated parcel-level travel demand in proportion to the 2024 average daily ridership of Xujiahui Station. Based on the generated path sets and the potential parcel-level metro ridership, weighted scores were calculated for each metro entrance/exit:

$$T_i^{(a)} = \sum_{j=1}^{n} w_j \left(\alpha_{a,1} X_{a,1,j} + \alpha_{a,2} X_{a,2,j} + \alpha_{a,3} X_{a,3,j}\right) \tag{4}$$

where $T_i^{(a)}$ is the weighted score of metro entrance/exit $i$ for attribute $a$. $j$ indexes the parcel-to-exit paths assigned to metro entrance/exit $i$. $w_j$ is the potential metro ridership of the parcel associated with path $j$. $\alpha_{a,1}$, $\alpha_{a,2}$ and $\alpha_{a,3}$ are the utility coefficients for the three levels of attribute $a$. Binary variables $X_{a,1,j}$, $X_{a,2,j}$ and $X_{a,3,j}$ equal 1 if path $j$ corresponds to level 1, 2, or 3 of attribute $a$, and 0 otherwise.

Notably, the Line 9 and Line 11 concourses of Xujiahui Station are directly connected to the Grand Gateway 66 through an underground passage. As a result, a portion of the metro ridership generated by the commercial complex is diverted via this passage. Since this passage was not included in the scoring samples, only 50% of the potential metro ridership generated by the commercial space of Grand Gateway 66 was considered in the estimation. This was a simplifying assumption that differed by approximately 13% from the observed passenger flow split, and given the inherent variability in field measurements, such an approach was adopted to ensure consistency and comparability in the estimation of potential ridership.

The scores for vertical transportation and street-crossing difficulty were directly calculated based on the corresponding partial utility functions, with reference to the observed built environment conditions. However, in cases where a metro entrance/exit is located near an intersection with crossing obstacles on both streets, the utilities of individual obstacles were calculated separately and then summed to capture their combined effect.

After calculating the scores for all six attribute categories, a min–max normalization was applied to remove differences in units and value ranges across categories, thereby facilitating subsequent weighted aggregation:

$$T_i^{(a)norm} = \frac{T_i^{(a)} - \min\left(T^{(a)}\right)}{\max\left(T^{(a)}\right) - \min\left(T^{(a)}\right)} \tag{5}$$

where $T_i^{(a)norm}$ is the normalized score of attribute $a$ at metro entrance/exit $i$, and $T_i^{(a)}$ is the corresponding original score. $\max(T^{(a)})$ and $\min(T^{(a)})$ represent, respectively, the maximum and minimum value of the original scores of attribute $a$ across the 18 metro entrances/exits.

The relative importance of each attribute was calculated as the ratio of its utility range to the sum of utility ranges across all six attributes [56] (pp. 79–81):

$$\lambda_a = \frac{\max(\alpha_{a,1}, \alpha_{a,2}, \alpha_{a,3}) - \min(\alpha_{a,1}, \alpha_{a,2}, \alpha_{a,3})}{\sum_{b=1}^{6} \max(\alpha_{b,1}, \alpha_{b,2}, \alpha_{b,3}) - \min(\alpha_{b,1}, \alpha_{b,2}, \alpha_{b,3})} \tag{6}$$

where $\lambda_a$ is the relative importance of attribute $a$. $b$ indexes the attributes. $\max(\alpha_{a,1}, \alpha_{a,2}, \alpha_{a,3})$ and $\min(\alpha_{a,1}, \alpha_{a,2}, \alpha_{a,3})$ are the maximum and minimum utility coefficients of attribute $a$, respectively.

Finally, for each metro entrance/exit, the six normalized attribute scores were aggregated through a weighted summation according to their relative importance, yielding the path accessibility score:

$$S_i^{acc} = \sum_{a=1}^{6} \lambda_a T_i^{(a)norm} \quad (7)$$

where $S_i^{acc}$ is the path accessibility score of metro entrance/exit $i$. $a$ indexes the attributes. $\lambda_a$ is the relative importance of attribute $a$. $T_i^{(a)norm}$ is the normalized score of attribute $a$ at metro entrance/exit $i$.

In addition, the environmental quality score for each metro entrance/exit was calculated directly from the utility function, as this dimension does not involve one-to-many data structures.

### *4.3. Collection of Passenger Flow Data*

Passenger flow data at the 18 entrances/exits of Xujiahui Station were collected on two weekdays and two weekend days with clear weather (28 June, 29 June, 3 July, and 4 July 2025). Manual counts of inbound and outbound passengers were conducted at each metro entrance/exit during four intervals: 8:00–9:30, 10:00–11:30, 14:00–15:30, and 17:00–18:30. Within each interval, a continuous 6 min count was carried out, corresponding to the maximum 6 min headway between same-direction trains at the station. Each 6 min count of inbound or outbound passengers at a specific entrance/exit and time interval was treated as an independent observation, yielding 288 observations in total.

### *4.4. Regression Analysis*

For each of the 18 entrances/exits, the average inbound and outbound passenger volumes (persons per 6 min) were first calculated for weekdays and weekends separately. A weighted average daily passenger volume was then calculated using a 5:2 ratio, reflecting the proportion of weekdays to weekends. Subsequently, linear regression models were constructed with weekday, weekend, and weighted daily passenger volumes as dependent variables, and with the path accessibility and environmental quality scores as independent variables, to examine the relationship between entrance/exit usage intensity and the subjective evaluation outcomes.

In addition, the study also replicated a commonly used shortest-distance method for estimating exit-level passenger volumes. Potential parcel-level metro ridership within the station catchment area was first obtained from the procedure described in Section 4.2 and then aggregated at the entrance/exit level based on nearest-exit assignment. Subsequently, a comparative regression model was constructed using the shortest-distance-based exit-level ridership estimates as the independent variable, enabling a direct comparison with the subjective scores in explaining the observed passenger volumes at Xujiahui Station.

## 5. Results

### *5.1. Parameter Estimation Results*

The estimation results of the MNL models are presented in Table 2 (Supplementary Materials, Table S2, for full estimation outputs including exact $p$-values). The McFadden's $R^2$ values for the path accessibility and environmental quality models are 0.263 and 0.169, respectively, suggesting a good fit for the former and an acceptable fit for the latter. Given the relatively weaker performance of the full-sample environmental quality model, an exploratory subgroup analysis was performed to examine whether trip-purpose segmentation could offer additional insights. As shown in Table 3 (Supplementary Materials, Table S3, for full estimation outputs including exact $p$-values), the McFadden's $R^2$ values for the two

subgroups are 0.214 and 0.156, respectively, with an overall fit of 0.179, indicating improved explanatory power compared with the full-sample model.

According to the parameter estimates, in the path accessibility model, all six attributes showed significant effects on passengers' entrance/exit choice preferences. Among the in-station and out-of-station attributes, walking distance proved to be the most influential, followed by the number of turns. The relative importance of out-of-station turns was slightly higher than that of in-station turns, suggesting that metro passengers are subjectively more sensitive to route continuity and directional changes along external walking paths when choosing a metro entrance/exit, while showing moderate tolerance toward directional shifts within the station. In addition, several attributes exhibited significantly negative utilities. The presence of pedestrian overpasses (−0.813) or wide road crossings (−0.679) near metro entrances/exits considerably reduced the likelihood of those entrances/exits being selected. Likewise, metro entrances/exits equipped only with stairs (−0.438) were significantly less preferred than those with both stairs and escalators. Although the provision of elevators is expected to enhance accessibility, its effect on entrance/exit choice preference was not statistically significant.

**Table 2.** Full-sample model estimation results.

| **(a). Path Accessibility.** | | |
|---|---|---|
| **Attribute** | **Level** | **Coefficient** |
| In-station walking distance | 150 m | 1.246 *** |
| | 300 m | 0.500 *** |
| | 450 m | 0 |
| In-station turns | None (Direct) | 0.901 *** |
| | 4 turns (Moderate) | 0.473 *** |
| | 8 turns (Circuitous) | 0 |
| Vertical transportation | Only stairs | −0.438 *** |
| | Stairs and escalator | 0 |
| | Stairs, escalator, and elevator | 0.032 |
| Out-of-station walking distance | 200 m | 2.061 *** |
| | 400 m | 1.113 *** |
| | 600 m | 0 |
| Out-of-station turns | None (Direct) | 1.480 *** |
| | 4 turns (Moderate) | 0.736 *** |
| | 8 turns (Circuitous) | 0 |
| Street-crossing difficulty | Overpass | −0.813 *** |
| | Wide road | −0.679 *** |
| | None | 0 |
| McFadden's $R^2$ | 0.263 | |
| **(b). Environmental quality.** | | |
| **Attribute** | **Level** | **Coefficient** |
| Entrance/exit width | 3 m | 0 |
| | 4.5 m | 0.097 |
| | 6 m | 0.036 |
| Underground commercial vitality | None | 0 |
| | Convenience store | 0.584 *** |
| | Connected mall | 0.921 *** |
| Entrance/exit spatial aesthetics | Worn | −0.712 *** |
| | Neutral | 0 |
| | Refined | 0.333 *** |
| Sidewalk width | 2 m | −0.573 *** |
| | 4 m | 0 |
| | 6 m | −0.064 |
| Street commercial vitality | No shops | 0 |
| | Scattered shops | 0.532 *** |
| | Continuous shops | 0.986 *** |
| Street greening level | No greenery | −0.694 *** |
| | Trees only | 0 |
| | Trees and shrubs | −0.111 |
| McFadden's $R^2$ | 0.169 | |

Significance levels: *** $p < 0.01$.

**Table 3.** Subgroup model estimation results.

| Attribute | Level | Coefficient (Leisure Travelers) | Coefficient (Commuters) |
|---|---|---|---|
| Entrance/exit width | 3 m | 0 | 0 |
| | 4.5 m | −0.067 | 0.211 * |
| | 6 m | −0.094 | 0.150 |
| Underground commercial vitality | None | 0 | 0 |
| | Convenience store | 0.791 *** | 0.467 *** |
| | Connected mall | 1.235 *** | 0.715 *** |
| Entrance/exit spatial aesthetics | Worn | −0.484 *** | −0.834 *** |
| | Neutral | 0 | 0 |
| | Refined | 0.334 ** | 0.341 *** |
| Sidewalk width | 2 m | −0.613 *** | −0.568 *** |
| | 4 m | 0 | 0 |
| | 6 m | −0.025 | −0.097 |
| Street commercial vitality | No shops | 0 | 0 |
| | Scattered shops | 0.491 *** | 0.541 *** |
| | Continuous shops | 1.111 *** | 0.910 *** |
| Street greening level | No greenery | −0.969 *** | −0.574 *** |
| | Trees only | 0 | 0 |
| | Trees and shrubs | −0.158 | −0.101 |
| McFadden's $R^2$ | | 0.214 | 0.156 |
| Overall McFadden's $R^2$ | | 0.179 | |

Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

In the environmental quality models, parameter estimates from the full-sample and two subgroup models revealed differentiated preference structures. In the full-sample model, passengers collectively preferred metro entrances/exits located near areas with vibrant underground and aboveground commercial activity, featuring aesthetic spatial design, and connected to sidewalks with appropriate width and well-developed greenery. However, entrance/exit width was not found to have a significant effect on passengers' entrance/exit choice preferences under daily travel scenarios, contrasting with findings from evacuation research [34,62]. This may be attributed to the 3 m minimum entrance/exit width adopted in our experiment, following the "Code for Design of Metro" [53], which is generally adequate for regular pedestrian flows, thus further increases in width provide limited improvements in entrance/exit attractiveness. In the subgroup models, leisure travelers showed the following order of importance among the significant attributes: underground commercial vitality, street commercial vitality, street greening level, entrance/exit spatial aesthetics, and sidewalk width, reflecting their clear preference for metro entrances/exits directly connected to vibrant commercial spaces. In comparison, commuters showed the following order of importance among the significant attributes: entrance/exit spatial aesthetics, street commercial vitality, underground commercial vitality, street greening level, sidewalk width, and entrance/exit width. Compared with leisure travelers, commuters placed greater emphasis on the spatial aesthetics of metro entrances/exits, with worn-out surfaces associated with a substantial negative utility (−0.834), and the effect of commercial vitality was less pronounced. Additionally, the effect of entrance/exit width became statistically significant, as a 4.5 m width yielded a slightly positive utility (0.211) relative to the 3 m baseline, significant at the 10% level.

### *5.2. Case Study Results*

The linear regression results for the observed exit-level passenger volumes at Xujiahui Station and the corresponding two-dimensional subjective scores are presented in Table 4.

When a single-dimensional score was used as the explanatory variable, the path accessibility score exhibited strong explanatory power for exit-level passenger distribution,

particularly on weekdays ($R^2$ = 0.698). In comparison, models based solely on environmental quality scores produced weaker yet statistically significant fits. This finding confirms that travel efficiency serves as the primary determinant of passengers' entrance/exit choice, whereas environmental quality acts as a secondary yet meaningful moderator, which is consistent with the travel behavior theory that emphasizes minimizing travel effort. Furthermore, the two environmental quality models revealed that the score derived from leisure travelers' preferences provided a slightly better explanation of observed passenger volumes than that based on commuters. This difference may be associated with the dense concentration of commercial facilities in the Xujiahui area—one of Shanghai's ten major commercial centers—which attracts a steady flow of leisure-oriented passengers, or alternatively, it may indicate that commuters place greater emphasis on path accessibility over environmental quality when selecting metro entrances/exits.

**Table 4.** $R^2$ from regressions of exit-level passenger volumes on subjective scores at Xujiahui Station.

| Independent Variables | Weekday Volume | Weekend Volume | Average Daily Volume |
|---|---|---|---|
| Path accessibility score | 0.698 *** | 0.572 *** | 0.687 *** |
| Environmental quality score (Leisure travelers) | 0.281 ** | 0.325 ** | 0.306 ** |
| Environmental quality score (Commuters) | 0.159 | 0.204 * | 0.178 * |
| Path accessibility score + Environmental quality score (Leisure travelers) | 0.790 *** | 0.707 *** | 0.795 *** |
| Shortest-distance-based ridership estimates | 0.599 *** | 0.480 *** | 0.586 *** |

Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

When both dimensional scores were included as independent variables, the model fit improved considerably and yielded the highest explanatory power ($R^2$ = 0.795) for average daily passenger volumes, indicating a synergistic effect of the two-dimensional scores. Since the environmental quality score derived from commuter preferences did not reach statistical significance in the bivariate regression, it was excluded from the specification.

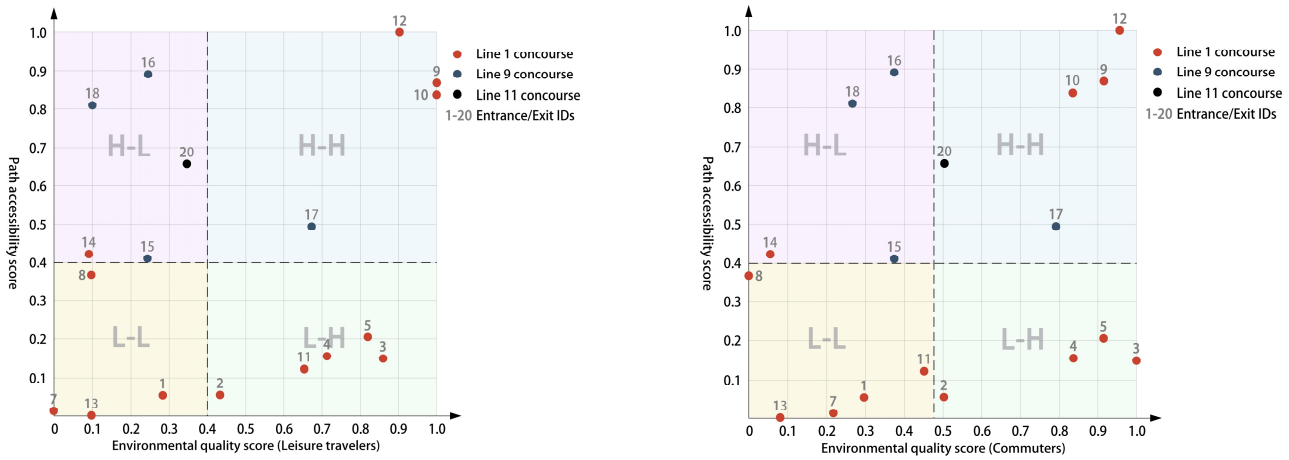
Overall, at Xujiahui Station, both path accessibility and environmental quality scores were significantly associated with observed passenger volumes. Moreover, the combined two-dimensional scores outperformed the shortest-distance-based estimates in explaining exit-level passenger distribution, providing preliminary empirical support for the applicability of the proposed subjective evaluation framework.

### *5.3. Entrance/Exit Classification Results*

Following the validation of its explanatory power, the evaluation framework was further applied to classify metro entrances/exits, serving as a practical tool for guiding station-area improvements. Specifically, the path accessibility and environmental quality scores for the 18 entrances/exits at Xujiahui Station were independently normalized and visualized in a two-dimensional space, where the entrances/exits were subsequently classified into four categories based on their relative positions. As shown in Figure 4, the classification of metro entrances/exits at Xujiahui Station falls into consistent categories across both groups of leisure travelers and commuters, except Entrances/Exits 11 and 20.

According to Figure 4, the H–L and L–H entrances/exits exhibit imbalances, thereby necessitating targeted interventions to achieve balanced development. The H–L entrances/exits, mainly connected to the Line 9 concourse, are perceived by passengers as offering high accessibility and therefore attract consistent usage. However, their surrounding environmental quality remains unsatisfactory and should be prioritized for improvement. In contrast, the L–H entrances/exits, all connected to the Line 1 concourse, provide relatively comfortable environments for metro passengers but suffer from limited accessibility. This is primarily due to their higher access costs, both to the platforms within the station and to most urban origins or destinations within the station's catchment area, compared with alternative entrances/exits. Consequently, optimization strategies should

consider both station-level and urban-level factors. Internally, improving circulation layouts and enhancing the signage system could help reduce in-station walking effort and navigation complexity. Externally, adjusting land uses and moderately increasing development intensity within these entrance/exit catchment areas may enhance their attractiveness as trip origins or destinations, thereby realizing the latent potential of the entrances/exits.




(**a**) (**b**)

**Figure 4.** Classification of metro entrances/exits at Xujiahui Station. (**a**) Leisure-based environmental quality scores; (**b**) Commuter-based environmental quality scores.

Beyond the two imbalanced categories, the remaining two types, H–H and L–L, represent opposite extremes that require distinct management strategies. The H–H entrances/exits, primarily connected to the Line 1 concourse, with several linked to the Line 9 and Line 11 concourses, exhibit superior performance in the two-dimensional evaluation. For these entrances/exits, future efforts may focus on reinforcing existing advantages through minor interventions or routine maintenance. Conversely, the L–L entrances/exits, all connected to the Line 1 concourse, performed poorly on both path accessibility and environmental quality, serving mainly as secondary components of the station-area pedestrian network. The optimization of these entrances/exits should be guided by a comprehensive assessment of necessity and potential, with site-specific strategies to integrate local resources and enhance spatial value.

Building on the entrance/exit classification, the evaluation framework was further extended to assess the performance of individual environmental attributes. As an illustration, one representative entrance/exit from each of the four categories was selected, and their attribute scores are presented in Figure 5.

In the figure, each sector corresponds to a specific attribute, with its area proportional to the attribute's relative importance weight. Attribute scores for each metro entrance/exit were obtained from the previously estimated partial utilities and normalized within each attribute category, thereby reflecting passengers' relative satisfaction with that attribute at each entrance/exit. To aid comparison across entrances/exits, the ninth-highest normalized score for each attribute is indicated by a black arc, which serves as a benchmark reference.

When using this figure to guide station-area optimization strategies, priority should be given to attributes represented by larger blank sectors and those with scores below the average. From these attributes, combinations that are more feasible to improve in practice can be identified, thereby guiding optimization interventions aimed at maximizing the overall score while ensuring an optimal balance between input and output.

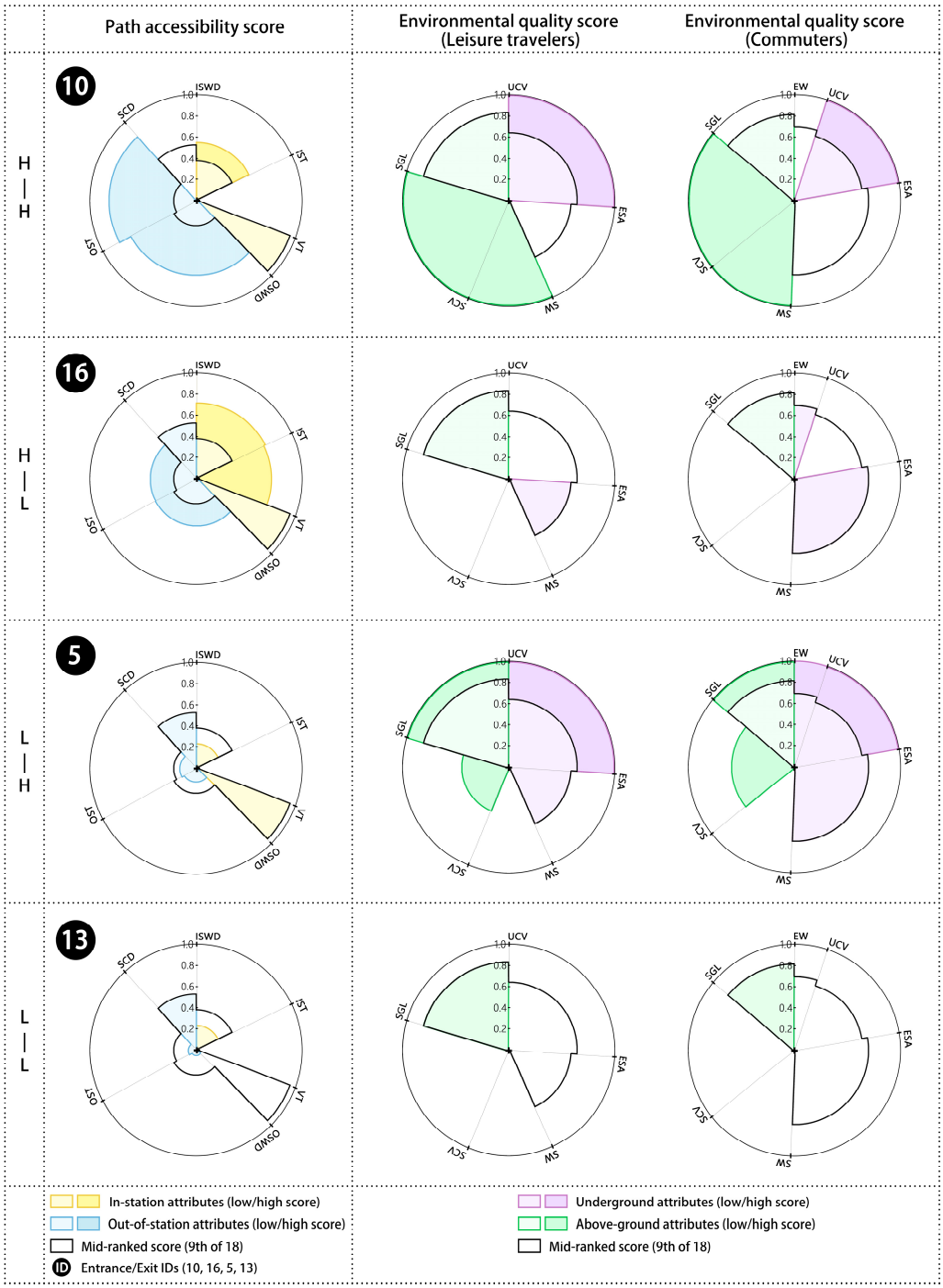



**Figure 5.** Attribute scores of representative entrances/exits at Xujiahui Station.

## 6. Discussion

### *6.1. Application Potential of Subjective Preference Data*

#### 6.1.1. Interpretation of Passenger Flow Distribution

Regarding the prevalent uneven distribution of passenger flows across metro entrances/exits, previous studies have primarily examined built-environment determinants from an objective perspective. This study, however, introduces a subjective perspective, analyzing passengers' stated preferences and underlying motivations for entrance/exit choice, thereby contributing to a more comprehensive understanding of the environment–behavior mechanisms. Moreover, by employing a DCE, this study circumvents the modeling challenges posed by the limited number of entrances/exits at individual stations in empirical

analysis, enabling the integration of multiple station-internal and urban environmental attributes together with their varying levels into a unified utility-based framework to assess their relative importance and combined effects.

To quantify passengers' subjective preferences, 12 station-interior and urban environmental attributes were incorporated into two complementary dimensions—path accessibility and environmental quality—followed by a DCE from which two MNL models were estimated. Results indicated that 11 of these attributes exerted significant effects on passengers' entrance/exit choice preferences to varying degrees. Across both dimensions, several station-interior and urban environmental attributes were identified as significant contributors, revealing the synergistic influence of station-level and city-level environments.

To examine the applicability of the estimated preference structure in explaining passenger flow distribution, a two-dimensional exit-level evaluation framework was developed and tested through a case study of Xujiahui Station in Shanghai. Each entrance/exit's performance was quantified by two-dimensional subjective scores and examined in relation to passenger volumes using linear regression analysis. This validation yielded three key insights. First, when a single-dimensional score was used as the explanatory variable, path accessibility exhibited greater explanatory power, suggesting that travel efficiency has a primary impact on passengers' entrance/exit choice behavior. This finding is broadly consistent with previous studies that reported correlations between exit-level passenger flows and choice values of the street-level pedestrian network at metro entrances/exits [12], as well as environmental variables related to building density and population density within entrance/exit catchment areas [13,14]. Yet, unlike prior work, our study defines the path accessibility score as a composite indicator derived from passenger preference data that comprehensively incorporates accessibility between entrances/exits and station platforms, accessibility between entrances/exits and urban origins or destinations, and the presence of walking barriers surrounding the entrances/exits. Second, although environmental quality showed weaker explanatory strength, its statistical significance suggests that it may function as a secondary factor influencing entrance/exit choice behavior. Nevertheless, most attributes within this dimension, such as entrance/exit spatial aesthetics, sidewalk width, and street greening level, have received limited attention in prior empirical studies, and their influence on entrance/exit choice behavior warrants further empirical validation. Third, when both dimension scores were included, the model's explanatory power was further improved, with the combined two-dimensional subjective scores outperforming the shortest-distance-based estimates in explaining exit-level passenger volumes at Xujiahui Station, indicating a synergistic effect of the two-dimensional scores. Collectively, these findings provide empirical support for the proposed evaluation framework and underscore the practical value of incorporating passenger preference data to identify and interpret disparities in exit-level passenger flow distribution.

#### 6.1.2. Guidance for Station-Area Optimization

The visualization of the two-dimensional evaluation results for each entrance/exit at Xujiahui Station also demonstrates that incorporating passengers' subjective preference data into micro-scale station-area optimization enables a shift from objective indicator–based assessments to diagnostics more closely aligned with passengers' actual needs. The proposed framework not only establishes an analytical foundation for identifying the relative strengths, weaknesses, and improvement potential of each entrance/exit but also provides strategic guidance for integrating station-internal and urban environmental interventions to enhance passenger experience, while emphasizing the coordinated development of path accessibility and environmental quality within station areas.

Building upon this foundation, the framework further contributes to improving investment efficiency and promoting equitable resource allocation across station areas. By translating passengers' utility preferences into a transparent sequence of priorities, it introduces a structured decision-making methodology that channels limited public budgets and facility upgrades toward interventions most effective in enhancing the overall satisfaction. Ultimately, this preference-driven approach advances the fine-grained governance of metro station areas toward a more human-centered and fiscally efficient direction.

### *6.2. Optimization Recommendations*

Guided by the results in Figure 5, targeted optimization strategies are proposed for the four representative entrances/exits.

For Entrance/Exit 10, modest improvements are recommended. In terms of path accessibility, its street-crossing difficulty score is below average. If removal of the adjacent overpass is not feasible, its acceptability could be improved by installing escalators or elevators. Regarding environmental quality, both entrance/exit width and spatial aesthetics fall below average. Renovation of the worn-out surfaces is recommended as a priority due to its higher expected impact.

For Entrance/Exit 16, the primary focus is on improving environmental quality. Introducing street-front shops or in-station convenience stores near the entrance/exit is expected to generate notable benefits. In addition, moderately widening the adjacent sidewalk or addressing the encroachment of pedestrian space by non-motorized vehicles would also contribute to improvement.

For Entrance/Exit 5, efforts should concentrate on enhancing its path accessibility score. Greater benefits could be achieved by adjusting building functions or moderately increasing development intensity within the entrance/exit's catchment area. Although improvements of in-station walking distance and the number of turns are constrained by the station's existing spatial configuration, targeted refinements in circulation design and signage may still be beneficial.

For Entrance/Exit 13, despite its lack of notable strengths, it holds significant potential for improvement. In terms of path accessibility, its relatively low external score is largely attributable to the ongoing redevelopment of the adjacent Shanghai No. 6 Department Store, where substantial enhancements anticipated upon project completion. Its low vertical transportation score could also be addressed by installing escalators. As for environmental quality, priority should be given to constructing an underground passage connecting the entrance/exit to the redeveloped commercial complex and introducing street-front retail at ground level. Renovating the entrance/exit's worn-out surfaces and moderately widening the adjacent sidewalk would also yield positive effects.

## 7. Conclusions

This study applied a visual stated preference method to systematically examine metro passengers' entrance/exit choice preferences. It contributes new evidence for explaining exit-level flow disparities by incorporating passengers' subjective preferences and develops a practical framework for exit-level assessment, thereby supporting more equitable and human-centered station-area development. The key results are summarized as follows.

First, by integrating 12 station-internal and urban environmental attributes into two complementary dimensions of path accessibility and environmental quality, and testing them in a DCE from which two MNL models were estimated, 11 attributes were found to significantly influence passengers' entrance/exit choice preferences, underscoring a joint contribution of both station-level and city-level environments. Second, based on the discrete choice model estimates, a two-dimensional evaluation framework was established and

validated through a case study of Xujiahui Station. Linear regression results showed that when a single-dimensional score was used, path accessibility offered stronger explanatory power for exit-level passenger volumes. When both dimensions were combined, the model fit improved further. Third, the practical utility of the framework was demonstrated by classifying the 18 entrances/exits at Xujiahui Station into four categories and analyzing representative entrances/exits at the attribute level. This enabled the formulation of targeted optimization strategies to guide station-area improvements.

However, this study still has several limitations that could be refined in the future. First, the universal applicability of the indicator set should be examined across a broader range of station areas. Further work is needed to assess whether supplementary or revised indicators are warranted in different contexts. Second, within the evaluation framework developed in this study, the relative importance of environmental attributes was determined solely from the MNL coefficient estimates, which may be sensitive to sample composition and attribute-level specifications. Moreover, interactions among attributes were not accounted for. Future research could address these limitations by incorporating expert scoring or other refinement methods to integrate multiple information sources, thereby tailoring attribute weights to different contexts. In addition, interaction terms could be introduced to better capture the joint effects of environmental attributes. Third, the DCE in this study presented identical information for each entrance/exit alternative to all respondents. Consequently, heterogeneity in spatial cognition between unfamiliar and frequent users was not considered by the experimental design and therefore not captured, even though such differences may lead to variations in entrance/exit preferences. In addition, wayfinding-related environmental attributes, such as signage, were not incorporated into the evaluation framework. Future research could complement this approach by designing comparative experiments with both newcomers and frequent users and explicitly incorporating wayfinding-related factors into the models. Finally, the experimental data used in this study were collected between May and July in Shanghai, which may introduce seasonal bias into the observed preferences. For instance, high summer temperatures may increase passengers' willingness to pay for attributes such as elevators or escalators, as well as for higher levels of street greenery. Future research could conduct multi-seasonal surveys within the same city to compare preferences across different climatic conditions. In addition, the case context and sample characteristics may limit the cross-cultural generalizability of the findings. Conducting similar experiments in cities with different cultural contexts would help examine the potential influence of cultural variations.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings15213941/s1, Table S1: Sample characteristics of the survey respondents; Table S2: Full-sample model estimation results; Table S3: Subgroup model estimation results; Dataset S1: Anonymized and coded dataset used for the MNL analysis.

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**Institutional Review Board Statement:** Approval waived. According to Article 32 of the *Measures for the Ethical Review of Life Science and Medical Research Involving Human Participants* ([2023] No. 4), research that utilizes anonymized information data, does not cause harm to the human body, and does not involve sensitive personal information or commercial interests can be exempted from ethical review.

**Informed Consent Statement:** This study utilized anonymized questionnaire data. Informed consent was obtained from all participants, who were informed that submitting the questionnaire would indicate their consent after being made aware of the research purpose.

**Data Availability Statement:** The anonymized survey data supporting the findings of this study are available from the corresponding author upon reasonable request due to privacy considerations and institutional restrictions. The metro station pedestrian network used for scoring was constructed with reference to the details of Xujiahui Station provided in the Metro Daduhui app, while the street-level pedestrian network was constructed with reference to Amap (Gaode) data.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| DCE | Discrete Choice Experiment |
| MNL | Multinomial Logit |

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