# Pedestrian route choice with respect to new lift-only entrances design of underground space: Case study of a metro station area at hilly terrain in Hong Kong

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## Abstract

The intensive development for the metro system has leveraged to the building of underground infrastructure that facilitates pedestrian movement from underground to surface, and from surface to surface. However, it is still unclear with newly built stations how willing are inhabitants to use the underground space network as a second level of regional pedestrian system parallel to the surface street network. Our case study is conducted in the underground pedestrian systems connected to cavern-type metro stations, which feature a new lift-only entrance design at hilly terrain. Based on a face-to-face questionnaire-based survey conducted in a new station area of a hilly neighborhood, a binary mixed logit model is developed to estimate the effect of route attributes, trip characteristics, socio-demographics, and walking preferences on the decision to use the alternative underground walking routes. Binary choice sets are based on the shortest paths under- and above- ground derived from a three-dimensional pedestrian network, same as the alternative-specific variables regarding distance, estimated walking time, mobility-aid facilities (e.g., lift), and walking barriers (e.g., staircase). The route attributes, especially travel time and the existence of lift-only exit, have an important effect on the intention to use underground routes. The results also show that the elderly, the disabled, and those living near stations are more willing to use underground walking routes. The findings can be used to support strategies for urban/transport planners concerned with the future implementation of underground pedestrian networks in three-dimensional multi-layered cities.

**Keywords:** Underground space network; Route choice; Metro station; Hilly neighborhoods; Hong Kong

## Final version

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## 1. Introduction

For compact cities, the complex form of compressed, multi-layered and highly connected cities with (underground) metro systems is considered as a response to support high population density. In Hong Kong, the latest form of multi-layered development links the underground concourses of the Mass Transit Rail (MTR) system to the surface (Wallace and Ng, 2016). Given the continued underground development in Hong Kong, as well as similar projects in the Asian countries (e.g., China, Japan, and Korea) and elsewhere in the world (Broere, 2016; Cui et al., 2013; Cui and Lin, 2016), it is critical to understand whether the scheme delivers public benefits that are commensurate with expectations to embrace a multi-layered three-dimensional view of cities. Literature has demonstrated that the integration with walking environment on the enhancement of internal circulation of major catchment areas around activity centers and transportation interchanges promotes residents' internal movement in terms of walking trips and physical activities (e.g., Huang et al., 2017) and external movement in terms of public transit usage (e.g., Sun et al., 2016) and transport mode choices (e.g., Chan et al., 2022). However, it is still unclear, with newly built stations, how willing are inhabitants to use the underground space network as a second level of regional pedestrian system parallel to the surface street network.

This paper studies the underground pedestrian systems within the station area of Hong Kong in the context of a newly built metro line in hilly terrain in Western District. A selected case study is based on the new West Island Line of the MTR opened in December 2014, extending the existing Island Line to the western end of Hong Kong Island at Kennedy Town. Along the way are two intermediate stations – Sai Ying Pun (SYP) and Hong Kong University (HKU). To accommodate everyone's needs as possible while balancing against technical considerations such as the trains' turning radius and ground conditions in the hilly terrain of the Western District, public consultation was the key to determine the locations of exits (Tam et al., 2016). After the determination of the locations of exits, the pedestrian network of the Western District was then required to expanded by approximately 3 kilometers in the underground space, which includes various features, such as lift shafts and walkways. Through the underground pedestrian network, about 95% of the residents of the area are brought into the walking catchment of the stations (MTRC, 2013) and improve the connectivity of pedestrian network (Tam, 2015). It also helps facilitate the movement of people and provide a safe environment for them by allowing the residents to move about more easily and efficiently in an area full of narrow pavements and steep slopes.

To address the accessibility issues for these deep stations, the MTR took a different approach to their deep level stations with high-speed lifts, featuring the *new lift-only entrances* (**Figure 1a**). The use of high-capacity elevators is one of the most important features in the underground pedestrian network, which allows the pedestrians to travel from deep stations to areas that are not accessible by traditional means. This provides a new experience for the pedestrians/metro riders in Hong Kong. Each lift-only entrance is served with four or eight lift high-capacity elevators with separate boarding areas and alighting lobbies, which can help minimize the circulation conflicts and provide an accessible environment for the mobility impaired. The lifts typically serve only two levels (i.e., ground and station) without intermediate floors, allowing passengers to effectively travel vertically without multiple stops. HKU Station is now the deepest and largest cavern-type station in the MTR network, which is 70 meters below ground at one of the exits at the University of Hong Kong (Exit A); while SYP has an exit on Bonham Road (Exit C) located on a hill 50 meters above the station (MTRC, 2014). **Figure 1b** and **Figure 1c** show the cross-section of the two stations in the hilly neighborhood. The pedestrian network in the study area has been maintained for a decade despite the scrape and rebuilding of buildings (Nagamune and Kinoshita, 2016), and is composed of various features, such as stairs, walkways, and elevators. Sai Ying Pun Station connects the business district to the west, the residential areas to the south, and the Bonham Road area to the east. The HKU Station features three entrances in the downhill residential areas and three uphill entrances on Pok Fu Lam Road. The new metro stations are designed to connect the hillside and lower levels in the Western District, for the convenience of passengers and pedestrians alike (Legislative Council, 2009). While network analysis reveals a significant improvement in the value of pedestrian access to new transit stations (Higgins, 2019), the actual pedestrian behaviors and their perceptions of the improvement are still understudied.

It is important to study the use of these pedestrian facilities in metro systems because they are very expensive (Tam, 2010) and thus requires careful planning. While in the planning process of the cases, we can see the role of public participation and the close working with businesses, citizens, and interest groups, and their importance to optimizing the use of underground space has been suggested by the literature (Cui et al., 2021; Little, 2018), it is always important to evaluate, if any, the difference between expectation and reality in planning implementation (Smith, 2018). It is also important to study the use of these pedestrian facilities in metro systems because they are very expensive (Tam, 2010). The introduction of lifts is occurring in other metro systems around the world (Swift et al., 2021), however often for the purposes of ensuring universal accessibility, and we know relatively little about how they are used and how effective they are for the case of lift-only entrance in a geographically constrained context - hilly terrain. Our choice model, which is based on a face-to-face questionnaire-based survey, investigates the following questions:

a) How do pedestrians choose between surface and underground routes when walking surface to surface that are at different levels of elevation?
b) who are the groups on benefits that are more likely to use underground walking facilities?

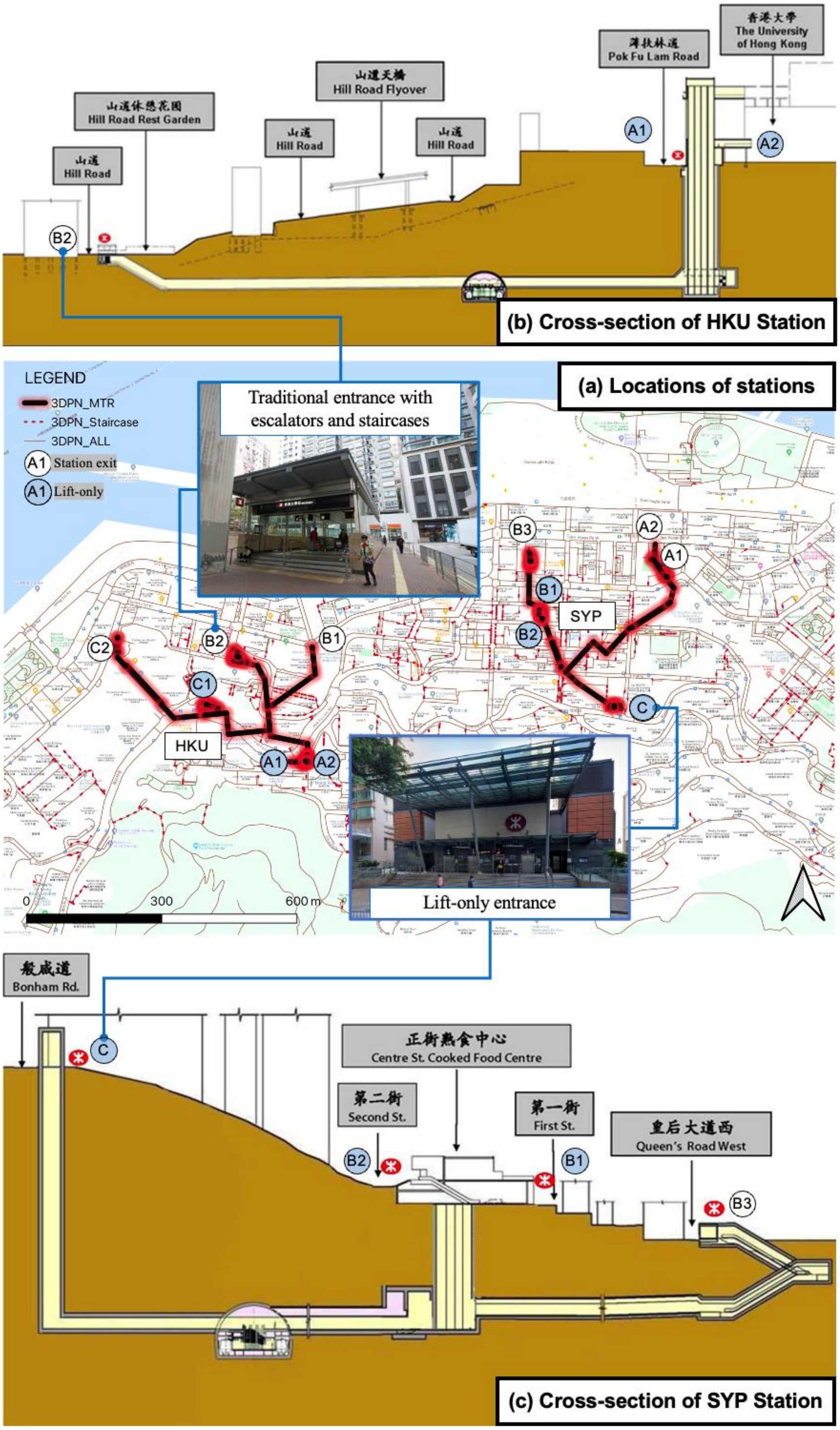


Figure 1 (a) the locations of two stations (created by the authors) and cross-section of (b) HKU and (c) SYP stations (modified from Wong (2015) by the authors)

## 2. Literature review

### 2.1 The layered city and the role of underground pedestrian space

Underground pedestrian systems that provide alternative walking options for pedestrians have been implemented in a considerable number of cities across the world (Cui et al., 2015, 2021). The city's three-dimensional (3D) vertical space has an impact on its citizens' everyday lives, particularly in hilly locations and cities with multi-layer pedestrian networks from underground structures. In particular, more efforts are needed for vertical movements, especially for walkways with slope and vertical barriers (e.g., staircases), which affect walking accessibility (Tang et al., 2020; Zhao et al., 2020). It is expected that urban spaces encourage pedestrian mobility by improving their walkability. With the 3D vertical transformation in urbanization in recent years, a three-dimensional analysis framework that focuses on 3D vertical spatial components can better reveal the characteristics of modern cities (Graham and Hewitt, 2013; Harris, 2015). For instance, Higgins (2019) applied an improved pedestrian accessibility measure in Hong Kong to incorporate the 3D network and topography. Zhao et al. (2020) developed a walkability scoring system based on networks and amenities and compared walkability scores using the 3D pedestrian network and road network of Hong Kong. Gu et al. (2021) redefined the amenity value of the urban landscape regarding 3D accessibility and visibility and conducted a case study in the mountain city in Chongqing.

With rapid economic growth and urbanization in the recent two decades, the development of underground space has made great progress (Chen et al., 2018a). Such development was initially stimulated and promoted by urban development problems such as traffic problems, resource shortages, and city resilience needs (Sun and Leng, 2021). The utilization of underground space not only plays a vital role in saving land, alleviating traffic pressure, and improving the utilization of resources but also, microscopically, provides utilities for pedestrians, such as a shelter for bad weather (Balsas, 2021) and road crossing facilities (Patra et al., 2020), which has a close relationship to neighborhood characteristics (e.g., mountainous, compact city) (Chen et al., 2018b). Meanwhile, these underground facilities are sometimes driven by private investment. Privately financed underground planning requires clear and objective measures for the expected performance of planned space. In particular, Hong Kong has encouraged dense building at transportation hubs by providing density incentives in exchange for specific public goods. Infrastructure is financed by private investment and designed to enable pedestrian mobility from below to the surface while improving the travel experience and offering public open space amenities (Zacharias and He, 2018). Nevertheless, underground facilities contain significant design flaws that may limit the creation of an underground facility or necessitate particular design and management solutions to overcome them (Yuan et al., 2019). For instance, underground pedestrian systems that connect metro stations or transit hubs experience high-density pedestrian traffic and consequently a stressed thermal environment (Sinha and Rajasekar, 2020). The resulted comfort level has been identified as the most important factor in the willingness to walk in an underground space (Zacharias and Wang, 2021). Flow control plans, for instance in Asian countries with large populations (e.g., China, Japan, and Korea), have been implemented to reduce the risk of crowd accidents during morning rush hours and festivals (Gu et al., 2019). However, flow control does not only increase pedestrians' walking distance, in the light of the seamless pedestrian interfaces with shopping malls but also causes opposition from shop owners. Therefore, understanding pedestrians' behavior is important for planning, evaluating, and improving the underground space (Cui et al., 2021), and understanding how an existing pedestrian and commercial system works can help in defining the parameters for future development (Zacharias, 2015).

## 2.2 Pedestrian choices in a multi-level urban environment

*Route choice* of pedestrians is complex: stated and revealed preference surveys have been used to determine the extent to which the pedestrian environment explains the deviation of actual routes from the shortest routes (Guo and Loo, 2013; Muraleetharan and Hagiwara, 2007). Earlier literature has suggested that route selection is a complex cognitive process that is affected by the distance and direction judgment of pedestrian actual route choices (Okabe et al., 1986). Meanwhile, the metabolic cost of the negotiation of obstacles has also been recognized as are an important determinant of human behavior and subsequent route decisions (Hayes and Norman, 1984). In this regard, different computational models have been developed as a means of exploring possible routes, with special attention on physical efforts required for walking downhill or uphill (Minetti et al., 2002; Páez et al., 2020). Route gradient/slope is particularly a major factor for choosing a route or even travel mode choice, considering the walking speed (Aghabayk et al., 2021) and physical capacities needed for gradients (Tscharaktschiew and Müller, 2021), with a focus on the elderly (Joseph and Zimring, 2007; Van Cauwenberg et al., 2011), in bad weather conditions (Fossum and Ryeng, 2022), and in a mountainous area (Pingel, 2010a; Tscharaktschiew and Müller, 2021). Understanding how different routes in that reality meet traveler's multi-criteria preferences and abilities could improve wayfinding and navigation services (Socharoentum and Karimi, 2016), and provide a walkability evaluation framework for policy and operational decisions (Koh and Wong, 2013).

Studies on pedestrian *vertical choice* present a rational starting point for building a more diverse and multi-dimensional agenda for understanding pedestrian behaviors in urban vertical cities. The earliest efforts in transportation studies focus on adjacent stair-versus-escalator choice using subway stations as a case study (Cheung and Lam, 1998a). Later studies adopted additional data to account for the effects of opposite flows using survey count data (Srikukenthiran et al., 2013), elevation difference (Li et al., 2015) and surrounding network characteristics using GIS data (Zhang et al., 2015a), congestion and waiting time at stairs and escalators using Bluetooth data (van den Heuvel et al., 2015), motivational signs using CCTV data for before/after analysis (Eves et al., 2009). Although previous studies mainly focused on the case in subway stations, González-González et al. (2021) presented a larger-scale Revealed Preference study to investigate the use of on-street vertical facilities in a hilly neighborhood. It was suggested that, contrary to expectations, accessibility from vertical facilities to public services or commercial areas was weighted less important compared to accessibility to population when estimating route usage. As a result, it was recommended that these types of walking amenities be installed along pedestrian routes in locations with sufficient population density, rather than in well-equipped core districts, so that the number of prospective users justified the investment and maintenance expenses. Their result is coherent with the concept of transit-oriented development, while it is usually densely populated in station areas. Such facilities are effective to reduce built environment barriers to walking, especially in a hilly area (Anciaes and Jones, 2016). The above-mentioned studies allowed researchers to draw on the principles, patterns, and strategies adopted by pedestrians and justify installing vertical walking facilities in station areas, as well as in hilly neighborhoods.

With the transformation of urbanization as 3D vertical systems in recent years, walking choices in layered cities become a complex decision process that consists of *both horizontal and vertical choices*. Recent studies have started to include information about the pedestrian environment in the estimation of walking routes. For example, three-dimensional data have been used to generate evacuation routes that consider aspects such as scenery, slopes, and areas susceptible to flooding (Byon et al., 2010). A topography-sensitive cognitive model for analysis and prediction of pedestrian movement is developed based on a three-dimensional network to account for the topography that affects visibility (spatial awareness of pedestrians) and physical effort (walking downhill or uphill) during travel and route selection (Greenberg et al., 2020; Sun et al., 2015). The vertical urbanisms not only require a three-dimensional analysis framework for evaluating 3D accessibility (Sun et al., 2021; Xu et al., 2022), but also demand for the realization of pedestrian choice in accounting for 3D vertical choices between layers of pedestrian networks. For example, Law et al. (2021) suggested that an unattractive alternative could lead to overcrowding of major pedestrian corridors by redirecting people to the one they perceived reasonable. They presented an example of green corridors in an urban center in Hong Kong that provide an alternative with considerable detoured distance, further segment the district, and prevent the merging and crossing of the various types of activities. It is therefore of importance to understand the choice behaviors of the pedestrian in a layered network. This study aims to examine the effectiveness of the underground pedestrian system leveraged from metro development in delivering pedestrians at different levels of elevation in hilly terrain. Further, the influencing factors that affect the willingness of people to choose the underground network as a second level of pedestrian system parallel to the surface street network are investigated.

## 3. Data collection and methods

### 3.1 Questionnaire design

Our questionnaire survey consists of three sections, including self-reported route choice, attitude to walking, and socio-demographic information. To reliably collect data on pedestrians' trips to/from/through the metro station, face-to-face questionnaire survey were conducted. During the survey, a filter question was asked to identify our target respondents, who are not entering/leaving metro stations for metro transit services. Respondents were then asked to recall their route choices from the current location (one of the exits) to the other exits. Face-to-face survey allows investigators to help respondents recall their walking trips' origin and destination. For instance, walking on the surface passing through a convenience store next to station exit *A* and a restaurant next to station exit *B* is equivalent to making a surface choice for walking between exit *A* and exit *B*. A total of ($N$ - 1) choice scenarios were recorded, where $N$ = total number of exits in a station. Trip characteristic (current walking trip) includes trip purpose, trip companion, and trip frequency. Their attitudes of walking, including "pro-shortest distance", "pro-shortest waiting time", "pro-least effort" and "pro-interaction" were measured using a five-point Likert scale (i.e., "Strongly disagree" = 1, "Somewhat disagree" = 2, "Neutral" = 3, "Somewhat agree" = 4, and "Strongly agree" = 5). Socio-demographic information includes sex, age, disability, and household characteristics.

Measurements and statistics of variables are summarized in **Table 1**.

Table 1 Measurements and statistics of variables.

| Variable | Data source | Statement/question | Code | Mean (SD) |
|---|---|---|---|---|
| **Route choice** | Questionnaire | According to your habit, when you walk from [current metro station]'s [current exit] to [one of the other exits], which path, surface or underground, do you usually choose? | Underground = 1; surface = 0 | 0.53 (0.50) |
| **Route attribute** | | | | |
| *Elevation difference* | 3DPN | Elevation difference that requires physical efforts (e.g., staircase, slope) | meter | 15.21 (23.74) |
| *Travel time* | 3DPN/ Site audit | Walking time | minute | 7.16 (3.01) |
| *Distance* | 3DPN | Walking distance | meter | 432.22 (201.97) |
| *Staircase* | 3DPN | Staircase (distance) | meter | 9.51 (19.16) |
| *Crossing* | 3DPN | Crossing (distance) | meter | 13.76 (18.56) |
| *Informal crossing* | 3DPN | Crossing without a traffic light (distance) | meter | 8.67 (15.36) |
| *Lift-only* | 3DPN | Is the route passing through any of the lift-only entrances of MTR stations? | Yes = 1; No = 0 | 0.35 (0.48) |
| *Up-hill* | 3DPN | Route direction | Yes = 1; No = 0 | 0.45 (0.50) |
| **Social demographics** | | | | |
| *Gender* | Questionnaire | Male or female | Male = 1; Female = 0 | 0.49 (0.50) |
| *Age* | Questionnaire | Age | >=40 years old = 1; 15-39 years old = 0 | 0.38 (0.49) |
| *Disability* | Questionnaire | Any type of disability (visual, hearing, physical) | Yes = 1; No = 0 | 0.04 (0.19) |
| *Residence* | Questionnaire | Are the locations of your home near HKU/SYP Stations (about 10 minutes walking distance)? | Yes = 1; No = 0 | 0.46 (0.50) |
| *Home location at other MTR stations* | Questionnaire | Are the locations of your home near any other MTR stations (about 10 minutes walking distance)? | Yes = 1; No = 0 | 0.79 (0.41) |
| *Living with family* | Questionnaire | Are you living with family members in your household? | Yes = 1; No = 0 | 0.85 (0.37) |
| *Lift-installed apartment* | Questionnaire | Does your apartment have a lift installed? | Yes = 1; No = 0 | 0.85 (0.37) |
| *Car ownership* | Questionnaire | Does your household own a car? | Yes = 1; No = 0 | 0.11 (0.31) |
| **Trip characteristics** | | | | |
| *Trip purpose* | Questionnaire | What is the purpose of this walking trip? | 1: Work/study; 0: Other | 0.32 (0.47) |
| *Trip companion* | Questionnaire | Walking with companion (observation) | Yes = 1; No = 0 | 0.36 (0.48) |
| Frequency | Questionnaire | Frequency of walking with the current routing | Five-point Likert scale: "1-2 per a half year" =1, "1-2 per a month" = 2, "3-4 per a week" = 3, "1-2 per a week" = 4, "everyday" = 5 | 3.02 (1.17) |
| **Attitude to walking** | | | | |
| *Shortest distance* | Questionnaire | I intend to walk with a path with the shortest distance. | Five-point Likert scale: "Strongly disagree" = 1, "Somewhat disagree" = 2, "Neutral" = 3, "Somewhat agree" = 4, and "Strongly agree" = 5 | 3.67 (1.00) |
| *Shortest waiting time* | Questionnaire | I intend to walk with a path with the shortest waiting time (e.g., traffic light, lift). | | 3.09 (0.89) |
| *Least effort* | Questionnaire | I intend to walk with a path with the least effort (e.g., fewer staircases, slope). | | 4.04 (0.80) |
| *Least crowdedness* | Questionnaire | I intend to walk with a path with the least crowdedness. | | 3.21 (0.84) |
| **Capability** | | | | |
| *Difficulty in walking* | Questionnaire | Self-reported walking difficulty | Four-point scale from "No difficulty" = 1, "Sometimes" = 2, "Often" = 3, and "Always" = 4 | 1.74 (0.96) |
| *Walking speed* | Questionnaire | Self-reported walking speed | Three-points scale from "Slow" =1, "Average" = 2, and "Fast" =3 | 1.97 (0.54) |
| *Familiarity with MTR* | Questionnaire | I am familiar with the current MTR station's layout. | Five-point Likert scale: "Strongly disagree" = 1, "Somewhat disagree" = 2, "Neutral" = 3, "Somewhat agree" = 4, and "Strongly agree" = 5 | 3.61 (1.05) |
| *Familiarity with street* | Questionnaire | I am familiar with the street layout nearby. | | 3.99 (0.89) |
| *Familiarity to nearby facilities* | Questionnaire | I am familiar with mobility-aid facilities nearby apart from the station. | | 3.84 (0.85) |

### 3.2 Survey administration

The face-to-face questionnaire-based survey was administered by trained university students. Respondents were randomly selected around the exits of HKU and SYP metro stations. Before conducting the main survey, we performed a pilot survey or pre-investigation (with 15 valid samples) at HKU station in December 2021. We interviewed our respondents and sought their feedback on our questionnaire design to check for further improvements. This pilot study helped us finalize our variable selection. The fieldwork was then conducted in January 2022. Survey took place across all days of the week. 110 and 103 responses were collected from participants at HKU and SYP stations respectively. A total of 213 responses × (6 - 1) exits = 1065 scenarios of route choices were recorded.

### 3.3 Binary mixed logit model

In this section, we present the details for estimating a binary choice model between underground and surface routes as alternatives in a hilly neighborhood.

#### 3.3.1 Choice set generation

Exit-to-exit walking routes are considered a part of the ordinary walking routes (e.g., Home-ExitA-ExitB-Shop in Figure 2). The hypothesis of considerable usage of exit-to-exit routes is based on the observations and informal interview during fieldwork by the first author, who is a local resident and works nearby. In the hilly terrain, it is common for residents to walk up-and-downhill for daily necessity (restaurant, shop, transport, etc.). For those who have no experience walking underground, we assume that they should by some mean walking ‘by-pass’ the metro exits, and this can be informed to respondents when doing a face-to-face questionnaire.

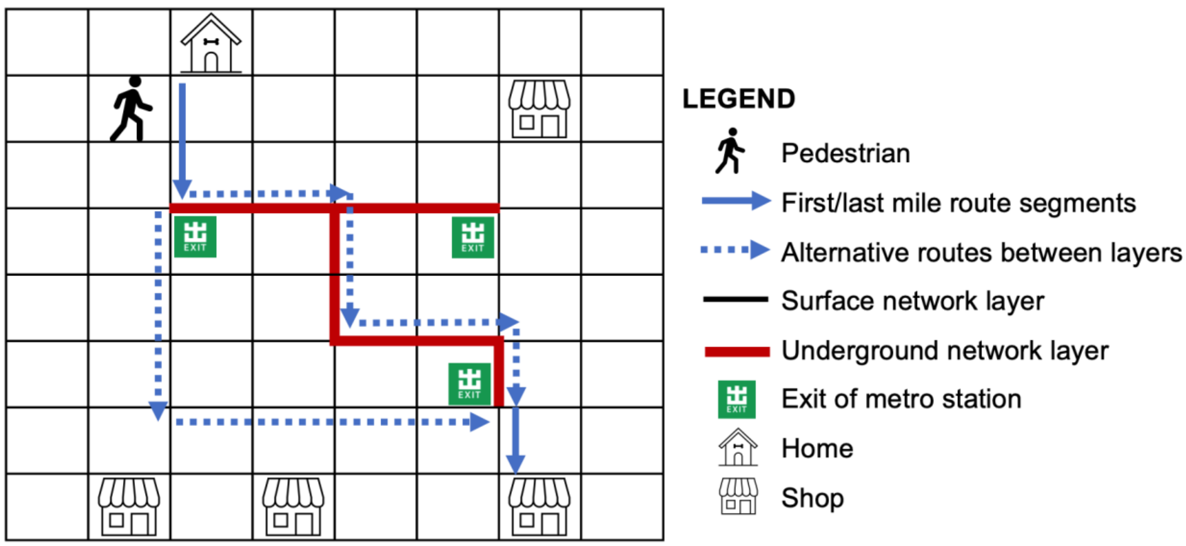


Figure 2 Illustration of Exit-to-Exit routes

The walking route data are obtained from the route planning service provided by HKeMobility, which computes optimal routes with the shortest travel time using an algorithm described by Pun-Cheng (2018). Specifically, we crawl the information on recommended walking routes of sampled walking trips from metro exits to exits. An entire route typically comprises several sub-links (e.g., walking-escalator-crossing-staircase-walking). For the short distance of a segment of path choice (Figure 2), we assume pedestrians follow the optimal paths for the surface network. The same is applied to underground routes, considering only one viable route can be derived with the simple layout of stations (Figure 3). The information includes the total distance and travel time and the distance for the sub-links. The walking route data allow the estimation of various indicators following the method described above. **Figure 2(a)** shows an example of a walking route provided by HKeMobility, which is based on the 3D pedestrian network dataset in **Figure 2(b)**. Since the underground network is simple with only one viable route between exits, to evaluate the attributes of underground routes, we use the shortest paths obtained from the 3D pedestrian network dataset (Transport Department, 2020) with surveyed walking time during the site audit.

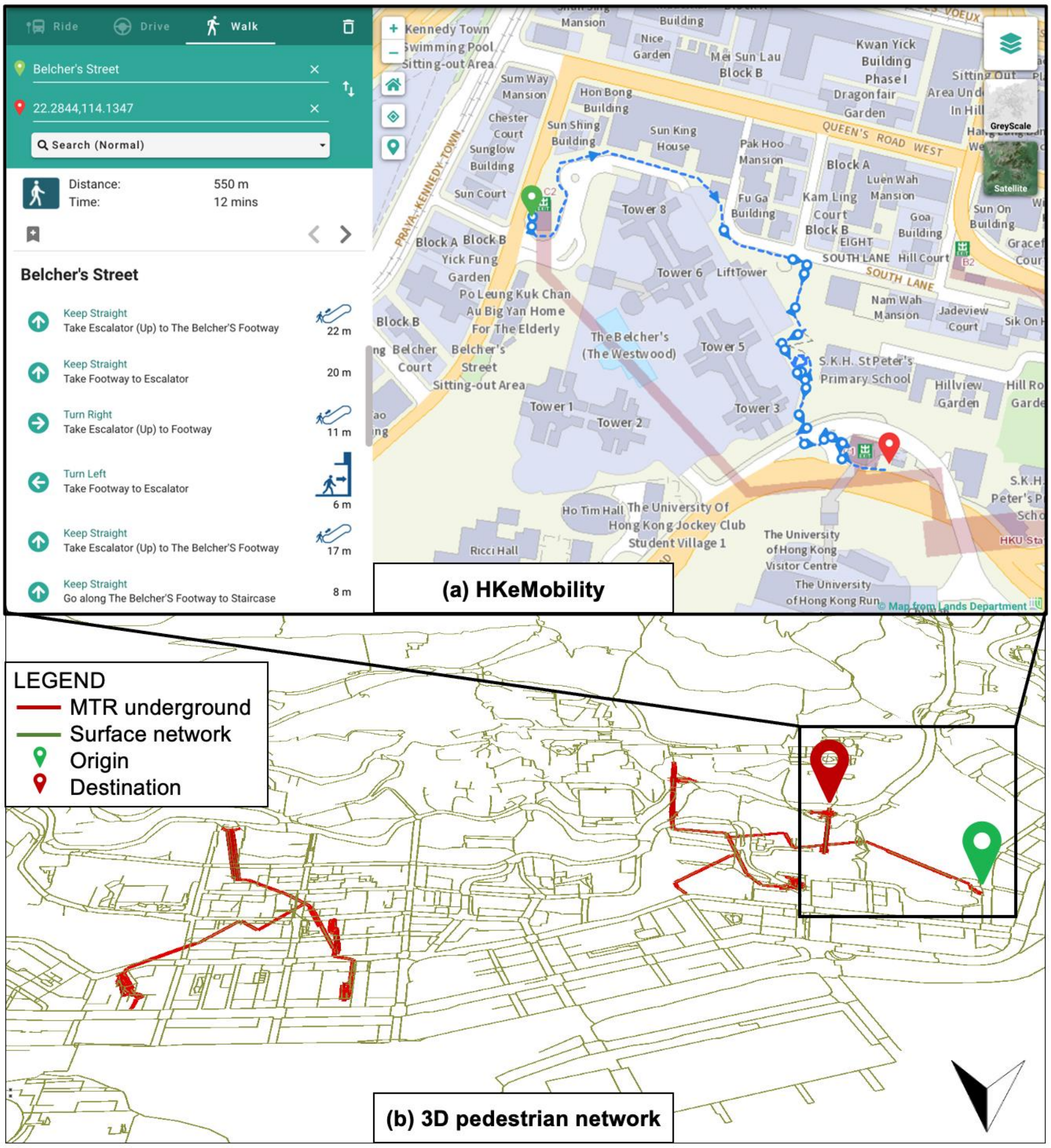


Figure 3 (a) Walking route searching on HKeMobility[1] based on (b) the 3D pedestrian network dataset

[1] https://www.hkemobility.gov.hk/en/route-search/walking

### 3.3.2 Model specifications

We estimate a binary mixed logit model in which the dependent variable is a dichotomous variable coded as 1 for the decision to walk underground and 0 for the decision to walk on the surface. Based on the framework of random utility theory, the utility of choosing an alternative consists of two components, including the alternative-specific attributes and individual-related attributes, which can be defined as:

$$U_{n,i,s} = \beta^{A}_{n,i,s} X^{A}_{n,i,s} + \beta^{C}_{n,i,s} X^{C}_{n,i,s} + \varepsilon_{n,i,s} \quad (1)$$

where $U_{n,i,s}$ represents the utility of individual *n* choosing alternative *i* in choice situation *s*; $X^{A}_{n,i,s}$ is a vector (A × 1) of the alternative-specific attributes; $X^{C}_{n,i,s}$ is a vector (C × 1) of the case-specific attributes; the vectors $\beta^{A}_{n,i,s}$ and $\beta^{C}_{n,i,s}$ are parameters that need to be estimated.

Considering that each respondent was asked with a set of five scenarios, *panel effects* were included in the model specification as well. Therefore, to deal with the serial correlation within an individual (i.e., the panel effect), the random disturbance term $\varepsilon_{n,i,s}$ is defined as:

$$\varepsilon_{n,i,s} = \beta^{0}_{i} + \eta_{n,i} + \zeta_{n,i,s}\ , \eta_{n,i} \sim N\left(0, \sigma^{2}_{\eta_i}\right), \zeta_{n,i,s} \sim G\left(0, \sigma_{\zeta_i}\right) \quad (2)$$

where $\beta^{0}_{i}$ is an alternative-specific constant. To reflect the panel effect, $\eta_{n,i}$ is assumed to be an error component that is individual-specific. This random component varies across individuals but is invariant over different choice situations for the same individual. In addition, it is assumed that $\eta_{n,i}$ follows a normal distribution with zero mean and standard deviation σ. Lastly, the random disturbance term, $\zeta_{n,i,s}$, is assumed to be independently and identically Gumbel distributed across transportation alternatives, individuals, and choice situations with a standard deviation $\sigma_{\zeta_i}$.

**Figure 3** presents the modeling framework of the proposed binary mixed logit model. The explanatory variables are the alternative-specific attributes (i.e., route attributes) and case-specific attributes (i.e., the socio-demographic variables, the trip characteristic variables, as well as individual capability, attitude to walking variables).

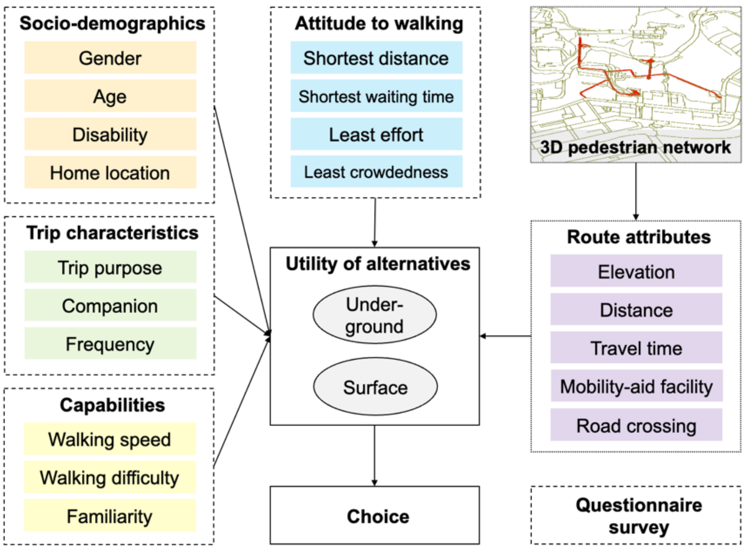

Figure 4 Modeling framework

## 4. Results

The coefficient estimation and marginal effects are reported in **Tables 2 and 3** respectively. As the main variables in this research, the variables that represent the existence of '*lift-only*' entrances and *uphill/downhill* movement have a significant impact on the underground/surface route decisions. The results suggested a decrease in the probability of choosing an underground route if it passes through the 'lift-only' entrances, and the effect increases for downhill movements. For the *time* variable, a longer travel time decreases the probability of choosing a route. The negative effect is coherent with the fact that pedestrians try to take the minimum time in the trip (Gärling and Gärling, 1988). Interpreting the 'lift-only' variable together with the travel time variable suggests that the additional waiting time for lifts that contributes a considerable proportion of travel time of underground route demotes the willingness of pedestrians to choose it. Compared to uphill cases, pedestrians are less likely to use a lift to overcome elevation differences for the downhill cases, considering the cost of downhill walking is lower than uphill walking (Bosina and Weidmann, 2017).

Furthermore, the existence of (in)formal *crossing*, which is an alternative specific variable, demotes the willingness to use underground routes. The results are coherent with studies on choices between at-grade signalized and separated crossing (e.g., bridge and subway) (e.g., Patra et al., 2020). The safety benefits of the crossing facility could attract the route's usage; in this study, the surface route with (in)formal crossing is generally less attractive. The *distance* variable lacks prediction power. The possible reason behind this is that most of the origin-destination in choice scenarios are of large elevation difference, and thus their routes are with slopes or mobility-aid facilities. While for the general case (i.e., walking on a flat surface) the time and distance would be positively correlated, for our case in hilly terrain, the distance variable that neglects the effort of pedestrians spent on walking on slopes is not suitable compared to the travel time variable.

Among the case-specific variables, *age* and *disability* variables have strong effects. Older age, in general, increases the probability of choosing the underground route. This result is consistent with the fact that older people are more likely to walk flat routes and avoid the gradients in routes (Basu et al., 2021). It is also noticed that older pedestrians and people with disability tended to select the underground route. This can be associated with the fact that underground routes have pedestrian facilities (lift and escalators etc.) that help to avoid the steep slopes on the surface route. Respondents generally prefer the shortest travel time route and therefore may be averse to the "lift only" entrance, however, such mobility-aid facilities are vital to old age and disabled people. The *residents* of the area were found to have decreased probability of selecting the underground route. The residents are more familiar with the MTR exits and pedestrian facilities in HKU and SYP areas and are generally more interested in selecting the routes with convenient shopping opportunities and social interaction (Dong et al., 2019). Thus compared with the underground routes, surface routes are relatively more attractive for shopping and social interactions.

Regarding the trip characteristics, *work/study purposes* increase the probability of choosing an underground route. It is possibly because of the connection of MTR entrances to the university campus, educational and transport facilities nearby. *Car ownership* also decreases the probability of selecting the underground route. This might be because car owners are often less willing to use public transport and thus are unaware of the underground routes passing through the MTR stations, however, the reasoning requires further investigation.

Finally, for the *attitude* to walking variable, the preference for a route with the shortest distance negatively influences the willingness of underground usage. It is possibly because underground routes are detour routes in both horizontal and vertical manner. Furthermore, the results indicate that the preference for routes with the shortest travel time and least effort increases the probability of choosing an underground route. The contradictive results between travel time and attitude to time variables might be due to the perceptions of slope and time especially in a mountainous area (Pingel, 2010b) and the simultaneous positive effects of the two variables are to a certain degree coherent with Pingel's findings. Regarding the crowdedness, it was found statistically insignificant, which is contrast with our expectation considering that the time and thus the crowdedness at lift lobbies could be a crucial factor for the route choice (van den Heuvel et al., 2015), suggesting a further investigation with a better way to capture such effect is required by both quantitative and qualitative way. Finally, when it comes to the capability variable, *familiarity* with MTR and nearby mobility-aid facilities shows the opposite effects on underground/surface choice. People who are familiar with MTR facilities are likely to use the underground routes, while those who are familiar with nearby mobility-aid facilities are less likely to use the underground routes.

Table 2 Coefficient estimation

| | **HKU and SYP Stations** | | **HKU Station** | | **SYP Station** | |
|---|---|---|---|---|---|---|
| | Coefficient | Std. Error | Coefficient | Std. Error | Coefficient | Std. Error |
| **Route attribute** | | | | | | |
| *Elevation difference* | -0.058*** | 0.012 | -0.060*** | 0.017 | -0.075*** | 0.028 |
| *Travel time* | -0.552*** | 0.140 | -0.501 | 0.360 | -0.587*** | 0.232 |
| *Distance* | 0.001 | 0.002 | 0.005 | 0.461 | 0.001 | 0.002 |
| *Staircase* | 0.026 | 0.007 | 0.016 | 0.012 | 0.005 | 0.015 |
| *Crossing* | -0.042*** | 0.015 | -0.028 | 0.029 | -0.021 | 0.032 |
| *Informal crossing* | -0.023*** | 0.007 | -0.057*** | 0.017 | -0.010 | 0.161 |
| *Lift-only*Uphill* | -0.580* | 0.317 | -0.965 | 0.590 | 0.517 | 0.596 |
| *Lift-only*Downhill* | -2.006*** | 0.406 | -2.067*** | 0.659 | -1.014 | 0.716 |
| **Social demographics (Ref: surface)** | | | | | | |
| *Gender: Male* | -0.187 | 0.230 | -0.358 | 0.321 | -0.525 | 0.410 |
| *Age: Older adult* | 0.636** | 0.306 | 0.787 | 0.496 | 0.971* | 0.517 |
| *Disability* | 2.153*** | 0.646 | 1.662 | 1.028 | 2.117** | 0.950 |
| *Residence* | -0.371* | 0.311 | 0.724* | 0.403 | -1.421** | 0.553 |
| *Home location at other MTR stations* | -0.195 | 0.311 | -0.088 | 0.393 | -1.112* | 0.597 |
| *Living with family* | -0.001 | 0.311 | 0.003 | 0.432 | 0.116 | 0.559 |
| *Lift-installed apartment* | 0.364 | 0.330 | 1.823** | 0.714 | -0.341 | 0.440 |
| *Car ownership* | -0.697* | 0.373 | -0.845 | 0.527 | -0.073 | 0.632 |
| **Trip characteristics (Ref: surface)** | | | | | | |
| *Trip purpose: Work/study* | 0.777*** | 0.270 | 0.473 | 0.353 | 0.919* | 0.504 |
| *Trip companion* | 0.234 | 0.236 | -0.100 | 0.329 | 0.313 | 0.373 |
| *Frequency* | 0.237** | 0.108 | 0.163 | 0.181 | 0.427** | 0.165 |
| **Attitude to walking (Ref: surface)** | | | | | | |
| *Shortest distance* | -0.588*** | 0.136 | -0.006 | 0.215 | -1.134*** | 0.227 |
| *Shortest time* | 0.258* | 0.151 | -0.275 | 0.204 | 0.604** | 0.268 |
| *Least effort* | 0.962*** | 0.168 | 0.620** | 0.241 | 0.993*** | 0.314 |
| *Least crowdedness* | -0.116 | 0.140 | -0.139 | 0.209 | -0.284 | 0.231 |
| **Capability (Ref: surface)** | | | | | | |
| *Difficulty in walking* | 0.219 | 0.146 | 0.186 | 0.206 | 0.252 | 0.238 |
| *Walking speed* | 0.400 | 0.251 | 0.576 | 0.354 | 0.260 | 0.415 |
| *Familiarity with MTR* | 0.402** | 0.158 | 0.115 | 0.202 | 0.986*** | 0.323 |
| *Familiarity with street* | 0.044 | 0.201 | 0.008 | 0.262 | 0.240 | 0.357 |
| *Familiarity with nearby facilities* | -0.553** | 0.229 | -0.594 | 0.353 | -0.825** | 0.352 |
| Constant | -5.781*** | 1.404 | -4.957*** | 1.930 | -5.939*** | 2.374 |
| Log likelihood | -377.63791 | | -174.82414 | | -166.905 | |
| Wald Chi-Squared | 190.78 | | 112.27 | | 95.08 | |

Note: *p < 0.10, **p < 0.05, ***p < 0.01

Table 3 Marginal effects (ME) for underground route choice

| | **HKU and SYP Stations** | | **HKU Station** | | **SYP Station** | |
|---|---|---|---|---|---|---|
| | ME | Std. Error | ME | Std. Error | ME | Std. Error |
| **Route attribute** | | | | | | |
| *Elevation difference, surface* | -0.006*** | 0.001 | -0.006*** | 0.002 | -0.007*** | 0.002 |
| *Travel time, surface* | -0.051*** | 0.013 | -0.047 | 0.034 | -0.053*** | 0.018 |
| *Distance, surface* | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 |
| *Staircase, surface* | 0.003 | 0.001 | 0.002 | 0.001 | 0.001 | 0.001 |
| *Crossing, surface* | -0.004*** | 0.002 | -0.003 | 0.003 | -0.002 | 0.003 |
| *Informal crossing, surface* | -0.002*** | 0.001 | -0.005*** | 0.002 | -0.001 | 0.002 |
| *Lift-only*Uphill, underground* | -0.060* | 0.033 | -0.095* | 0.057 | -0.050 | 0.057 |
| *Lift-only*Downhill, underground* | -0.209*** | 0.039 | -0.204*** | 0.062 | -0.097 | 0.067 |
| **Social demographics** | | | | | | |
| *Gender* | -0.019 | 0.024 | -0.035 | 0.032 | -0.050 | 0.039 |
| *Age* | 0.066** | 0.032 | 0.078 | 0.049 | 0.093* | 0.048 |
| *Disability* | 0.224*** | 0.065 | 0.164 | 0.100 | 0.203** | 0.089 |
| *Residence* | -0.039* | 0.032 | 0.071* | 0.039 | -0.136*** | 0.051 |
| *Home location at other MTR stations* | -0.020 | 0.033 | -0.009 | 0.039 | -0.107* | 0.058 |
| *Living with family* | -0.000 | 0.033 | 0.000 | 0.043 | 0.011 | 0.0535 |
| *Lift-installed apartment* | 0.038 | 0.034 | 0.180*** | 0.067 | -0.032 | 0.043 |
| *Car ownership* | -0.073* | 0.038 | -0.083 | 0.051 | -0.007 | 0.061 |
| **Trip characteristics** | | | | | | |
| *Trip purpose* | 0.081*** | 0.027 | 0.047 | 0.035 | 0.088* | 0.047 |
| *Trip companion* | 0.024 | 0.025 | -0.010 | 0.032 | 0.030 | 0.036 |
| *Frequency* | 0.025** | 0.011 | 0.016 | 0.018 | 0.041** | 0.016 |
| **Attitude to walking** | | | | | | |
| *Shortest distance* | -0.061*** | 0.013 | -0.001 | 0.021 | -0.109*** | 0.020 |
| *Shortest time* | 0.027* | 0.015 | -0.027 | 0.020 | 0.058** | 0.024 |
| *Least effort* | 0.100*** | 0.016 | 0.061*** | 0.023 | 0.095*** | 0.028 |
| *Least crowdedness* | -0.012 | 0.015 | -0.014 | 0.021 | -0.027 | 0.022 |
| **Capability** | | | | | | |
| *Difficulty in walking* | 0.023 | 0.015 | 0.018 | 0.020 | 0.024 | 0.023 |
| *Walking speed* | 0.042 | 0.026 | 0.057 | 0.035 | 0.025 | 0.040 |
| *Familiarity with MTR* | 0.042*** | 0.016 | 0.011 | 0.020 | 0.095*** | 0.030 |
| *Familiarity with street* | 0.005 | 0.021 | 0.001 | 0.026 | 0.023 | 0.034 |
| *Familiarity with nearby facilities* | -0.058** | 0.023 | -0.059 | 0.036 | -0.079** | 0.033 |

Note: *p < 0.10, **p < 0.05, ***p < 0.010.

## 5. Discussions

In this section, we summarize the main findings concerning the research questions stated in the introductory section and sketch out a way forward in terms of interesting avenues for follow-up research as follows:

One of the focuses of this paper is to examine whether the project, in particular, the lift-only entrance design is effective regarding its intention to enhance the connectivity along the hillside. Our results reveal that lift-only entrance, indeed, is less effective than expectation for promoting the usage of underground pedestrian facilities, especially for downhill movement. It is not surprising since our model also reveals the strong effect of travel time on pedestrian route choice behavior. In addition, waiting time at vertical transportation facilities has been identified as one of the factors that demote the usage due to the congestion at the bottlenecks (Cheung and Lam, 1998b; van den Heuvel et al., 2015; Zhang et al., 2015b). The current lift-only entrances are the bottlenecks at the underground platform level, especially during peak hours of commuting (Lui, 2018). If a similar route is also taken by pedestrians to ingress/egress to/from underground via vertical facilities, it causes congestion at the vertical facilities. Growing ridership of MTR must be supported by efficient facilities in the train stations, that meet the demand of riders and ensure a fluent flow of pedestrians. Local pedestrians should also be distributed over different routes in the station to optimize the efficiency of facilities and ensure pedestrian comfort, therefore encouraging the use of underground pedestrian systems. Compared to distance, time had a dominating effect on route choice. Installing mobility-aid facilities for horizontal movement (e.g., travelators) could be adopted to increase the attractiveness of long-distance routes (e.g., Exit C2 at HKU station and Exit A at SYP station).

The paper also focuses on identifying the groups on benefits that are more likely to use underground walking facilities. In such an old neighborhood, the older population makes up a higher proportion of the population. They are considered to stick to the original travel plan and a potential reason could be due to the ability to access travel information (Chorus et al., 2006; Grotenhuis et al., 2007), in this study the location of exits, station layout, etc. However, our results suggest that older adults are more willing to use the underground pedestrian network, because they have been familiar with the underground facilities in their neighborhoods. Meanwhile, residents in nearby areas and those who are familiar with other vertical transport facilities apart from the station area (e.g., the escalator-walkway system in the shopping mall connecting Exit C1 and C2, and that near the wet market connecting Exit A1 to C) are less likely to use the underground walking facilities. Again, a potential reason could be the higher sensitivity to the extra waiting time for lift transport. In this regard, the existing facilities in the MTR underground metro station found some way for their success, however, should they be continuously reviewed and evaluated for improvements.

## 6. Implications to the development of underground pedestrian system in Hong Kong

Hong Kong’s steep hilly terrain poses significant constraints on its urban development. The shortage of developable landforms a key driver to explore other sustainable and innovative approaches to expand land resources. Underground space are viable sources of land supply, which can provide solution space for a broad variety of land uses and help address problems encountered in the congested urban environment (Wallace and Ng, 2016). Hong Kong has been using underground space for commercial, community, transport and utility facilities for many years. Most of them are planned on individual project basis (Ho et al., 2016), including basements of buildings to accommodate car parks as well as provide space for retail and commercial activities, pedestrian links (e.g., subways and pedestrian connections of metro stations), transportation (e.g., road and railway tunnels) and other utilities (e.g., underground networks of water, sewerage, drainage). The earliest civil rock caverns in Hong Kong were formed as part of tunnel networks for railways - the first large cavern in Hong Kong was built between 1982 and 1985 to house the Tai Koo Station of the MTR Island Line (Malone, 1996). To unleash the potential of systematic utilization of underground space, it is of necessity to draw lessons from existing cases by understanding the user behaviors and concerns. In this section, we discuss the implications to the development of underground pedestrian system in Hong Kong in two aspects: (a) walkability and connectivity improvement and (b) urban (re-)development and (re-)generation.

### 6.1 Walkability and connectivity improvement

Improving walkability and connectivity is one of the major goals for building underground pedestrian systems (Cui et al., 2010). On flat ground, it might simply be a space below in a cityscape that may thereby be seen as ‘deepened’ and developed in all its dimensions. (Labbé, 2016); however, in hilly terrain, it is a space making use of slopes so as to be accessible at any level as mobility is in certain degree restricted by the hilly terrain. The difference could be revealed from the inconsistence between our modelling results and a qualitative interview findings on the elderly’s choices in Hong Kong context. Sun and Lau (2021)’s go-along interview study in a flat land area in Kowloon suggested that older participants have concerns to use footbridges and undergrounds due to either a lack of effortless connecting facilities or longer walking in the station underground regarding walkability. Using underground facilities subjectively means an additional walking/efforts and detours. On the other hand, our modelling results suggest that older pedestrians are more willing to use underground facilities. The results may at first glance seem counterintuitive, but they are pointing to the same fact that walking/energy efforts are of major concerns of older people as suggested by the literature (e.g., Rosso et al., 2021). Studies of walking often include an experienced resistance due to the effort of climbing stairs that is an addition to the actual time use resistance (Daniels and Mulley, 2012; Greenberg et al., 2020), as both require more energy efforts. On flat area, while slope is neglectable, people concerns are at the additional walking/efforts when using alternative routes. In hilly terrain, however, it is a different story, especially like the study area which is full of narrow sidewalks, staircases and steep slopes. In addition, the new seamless connection of escalators/lifts with the new underground pedestrian networks could potentially attract older people, as suggested by Sun and Lau (2021) that they are much desirable for them to walk between surface street and station underground. Our results could therefore supplement existing studies on underground utilization by revealing that topography can play a significant role in the outcome regarding walking behaviors and the usage of underground facilities.

### 6.2 Urban (re-)development and (re-)generation

Urban regeneration following public transport investments is a topic of growing interest as older, developed cities continue to upgrade public transport and the public realm in general (Cui and Nelson, 2019; Eliasson et al., 2020; Kasraian et al., 2016). During redevelopment of existing older urban areas, underground development can be constructed concurrently beneath new facilities with minimum disruption to the surface and public (Cui et al., 2021). Prime land areas that have become vertically constrained are likely to adopt underground options in the future, particularly if incentives are available to the private sector. In this regard, metro development could be the forerunner considering that the existing practices and laws that railway developers may acquire the underground space beneath private lots with permission from the Government and the private lot owners, given that the development will be built for a public purpose and compensation is settled (Wallace and Ng, 2016). Many examples of metro stations in Hong Kong have accommodated various underground subway connections to private developments and have been able to improve underground connectivity to existing underground stations.

Given the revealed successfulness of the new underground infrastructure with lift-only entrance design at HKU and SYP Stations in the old neighborhood located in hilly terrain (i.e., willingness of pedestrian to use the underground for local connectivity), it appears to be possible to expand the use of underground space into larger-scale (re-)development considering that grade separation pedestrian system is an desirable way for pedestrian circulation to overcome the limitations of congested and traffic compromised street networks (Cui et al., 2013) and for minimal impact to the surrounding communities and general public (CEDD, 2009). Indeed, some of the existing metro stations are building caverns and underground space in close proximity to densely populated residential areas. There are numerous examples of use of underground space in Hong Kong not only as caverns but as deep basements in the city. Integration of some of these facilities into a connected underground city can be achieved as demonstrated by the successful integration of Tsim Sha Tsui and Tsim Sha Tsui East Stations with connections to various shopping and retail complexes further expanding the feeling of a connected underground city space (Zacharias and He, 2018). Another useful comparison would be with the central-middle escalator system in Central area (Zacharias, 2013). The overground system creates new spaces for circulation and public gathering, which connects directly to the existing pedestrian networks and buildings. The placement of landings and transitional spaces from the Escalator to ground or to upper floors of surrounding buildings is also of importance, which caused the redirection of pedestrian flows between the surface streets and the Escalator system. The system demonstrated how to implement a facility for pedestrian movement to generate a transformation in the built form and in the activity structure of a substantial urban area. Following this, a supplement survey could help to investigate the potential trip difference between layers with the associational environment factors along the trip.

## 7. Conclusion

Using the face-to-face questionnaire-based survey, we examine the layer choice between underground and surface pedestrian networks in a new station area of a hilly neighborhood. We demonstrate that the new lift-only entrance design can affect the pedestrian’s layer choices. Travel time, especially the waiting time for lift transport, is the major determinant of the willingness for underground usage. This is also coherent to the fact that residents in nearby areas and those who are familiar with other vertical transport facilities are less likely to use the underground walking facilities. It is also revealed that old age and disabled pedestrians are highly willing to use the underground pedestrian routes as those routes are accompanied by essential pedestrian facilities such as lifts and travelators.

This research contributes to both the underground pedestrian facilities design and transportation literature by reporting the keys determinants for the usage of alternative underground pedestrian routes leveraged by the construction of the metro station. While the ridership of MTR must be supported by efficient facilities in the train station to ensure a fluent flow of riders, the benefits of local pedestrians should also be considered. To optimize the efficiency of facilities and ensure pedestrian comfort, and subsequently encourage the use of underground pedestrian systems, the existing facilities in underground metro stations should be continuously reviewed and evaluated. In Hong Kong, the metro network has been expanded in an urban area with mostly flat terrain, and the newly planned stations located on Hong Kong Island are mostly in a hilly area (Chan et al., 2021). Therefore, the lesson from our case study could help planners to better understand pedestrian behaviors, and to support strategies for urban/transport planning concerned with the future implementation of underground pedestrian networks in the layered city.

Nevertheless, the model on its own it has several limitations. The sample sizes were not large enough, even in 1065 responses, to investigate the combination of effects (e.g., car ownership + age + trip purpose), but they do allow to build a binary choice model to study the effects of individual variables. Since the sample size for the choice model may not be representative of the population of interest (in part because the small size makes it more difficult to be representative, but also because people willing to engage in questionnaire survey may differ from the population at large in relevant ways), some variables may be found statistically insignificant even if they do impact choice behavior with the implication is that these characteristics may be overlooked. However, sample size limitations do not affect identifying as important those variables that are significant. In addition, some variables are difficult to be obtained from the questionnaire might be relevant, for instance, the congestion and waiting time at lifts; this is worthwhile to be investigated through go-along interview.

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