# Choice and equity: A critical analysis of multi-modal public transport services in Hong Kong


## Abstract

Equity and justice have long been central in transport policy. The emphasise on the importance of individuals' access to social and economic opportunities stresses the link between accessibility and concepts like agency and freedom of choice. It calls for a nuanced and comprehensive understanding of accessibility that considers specific contextual factors that limit people's transport choices, such as the design of public transport networks and services, government interventions, and competition between public transport companies. To promote people's potential mobility and freedom of choice, it is crucial to initially assess the spatial distribution of transport options. In this article, we synthesise the findings from existing scholarship on transport choice, reinforcing the need for (re)considering choice in transport equity. We propose a metric to evaluate the availability of transport choices by considering the trade-off between time and money. By analysing household survey responses on transport choices and transit service datasets, we investigate the spatial disparities in the availability of transport choices within a multimodal public transportation system in Hong Kong and explore how adjusting unappealing choices can potentially enhance transport equity.



**Keywords**: Transport equity; Choice set; Accessibility; Multimodal public transport system; Hong Kong

## 1 Introduction

Transport systems play a vital role in facilitating people's movement by offering a diverse range of travel options and routes. However, transport goes beyond mere point-to-point travel; it holds substantial social implications. The efficiency and variety provided by transport systems hold great importance to the public as they enable freedom of movement and access to economic and social opportunities (Freudendal-Pedersen, 2016; Sheller, 2016). Furthermore, travel itself is a lived experience that shapes our everyday lives and serves as a significant narrative element, ultimately influencing our overall quality of life (Chan and Zhou, 2021; Lee and Sener, 2016; Schwanen, 2021). It is important to recognise that social concerns are closely intertwined with the public's desire for efficiency, choice, and freedom, ultimately impacting both our collective and individual quality of life (Neutens et al., 2011; Schwanen et al., 2015).

Transport systems present a continuous trade-off between time and cost (Brueckner and Selod, 2006), where individuals must choose between faster routes with higher monetary expenses or slower, more affordable alternatives. Thus, transport services go beyond providing access to opportunities; they are instrumental in our ability to make choices and are integral to the political values of freedom-oriented societies. To fully grasp the value of transport choice, we can draw upon the concepts of autonomy and option values, which are seemingly interconnected. Personal autonomy stems from individuals' inherent drive to structure their lives around specific objectives (Deci and Ryan, 2000). For this inclination to be fully realised, there should be no constraints that impede this tendency. Choice, therefore, becomes an expression of agency and is exercised during moments of autonomy, with everyday transport decisions serving as one such moment (Delbosc and Vella-Brodrick, 2015). While the literature on this topic is limited (Chng et al., 2016; De Vos et al., 2013), it suggests that travel satisfaction is likely influenced by and dependent on the choice of travel mode, with active travel generally being the most conducive to satisfaction, while public transport use tends to be less satisfying. Option values, originally established in environmental economics, have gained attention from scholars for their social impact on transport. These values refer to individuals' willingness to pay in order to retain the option of using a specific transport service for future trips that are not currently anticipated or undertaken by other modes of transport (Geurs et al., 2006). They have been utilised in transport appraisal frameworks (Laird et al., 2009), which recognise the social function of transport in providing access to economic and social opportunities, regardless of whether an actual trip is taken.

To promote people's potential mobility and freedom of choice, it is essential to initially evaluate the spatial distribution of transport options. Building upon this context, this study focuses on analysing the services of a transit network to gain insights into potential spatial disparities in available travel mode choices for transit riders. By acknowledging that transport systems involve a continuous trade-off between time and cost (Brueckner and Selod, 2006), where individuals can opt for faster routes at a higher monetary expense or slower, more affordable alternatives, our assessment of choice sets considers the trade-off between monetary and travel time considerations. Specifically, we conduct a case study on multimodal public transport services in Hong Kong, enabling us to empirically operationalise the aforementioned concepts of equitable transport and choice sets, while exploring their policy implications.

The concept of equity is understood here in a broader sense, encompassing the overall distribution of available choices. While the notion of spatial equity has been influential in studies addressing the spatial justice of transport services and costs, we build upon this foundation to specifically examine the equity of choice. This pertains to individuals who lack alternative transport options to express their preferences due to geographical constraints. Our paper is outlined as follows:

- Firstly, we synthesise existing research on transport choice, reaffirming the importance of acknowledging choice within the context of equity studies. By rethinking the value of choice in the transport context, we can revisit and consolidate existing studies on transport choice and equity.

- Secondly, we propose a measurement to assess the extent of choice availability, utilising national surveys and transit service datasets. This approach complements existing studies on spatial equity of accessibility, which heavily rely on network-based Geographical Information Systems (GIS) (e.g., Guzman et al., 2017; Sun and Zacharias, 2020). Often, network data is static and fails to capture the temporal aspects of transport services, such as time-bounded transit services and traffic conditions. This limitation hinders our ability to analyse samples or areas at a more granular level, specifically the choice sets and variables between origin and destination. However, as illustrated in subsequent sections, it is feasible to overcome these challenges in metropolises like Hong Kong by leveraging route planning services based on historical traffic data and transit service schedules. Prior to the era of big data, this approach was difficult to apply to other cities, if not impossible.

- Thirdly, we conduct a case study focusing on the integrated bus and rail transit services in Hong Kong, providing an opportunity to explore the equity of choices within a multimodal transit network and its implications for transit-oriented development. Given the increasing availability of such data across cities and countries, the procedures and methodologies employed in this study can be replicated elsewhere. This opens the door for more comprehensive and systematic examinations of transport choice and equity, shedding light on issues such as autonomy, freedom of choice, and equality of opportunity, and how they can be realised within urban transport settings.

## 2 Literature review

The issue of transport equity and justice has long been a central focus in the field of transport studies, as evidenced by the works of various scholars (Banister, 1994; Kain, 1968; Levinson, 2010; Wachs and Kumagai, 1973). Numerous conceptualisations of equity and approaches for assessing the equity performance of transport systems exist. However, the core of justice concerns three fundamental questions: equity for "whom" (population measurement), "how" they should be distributed (inequality measurement), and "what" benefits and burdens should be distributed (cost/benefit measurement) (Guo et al., 2020; Pereira et al., 2017). This literature review delves into these questions of "whom", "how", and "what", while exploring the relevance of the concept of choice and autonomy in promoting transport equity. By examining these aspects, we aim to shed light on the relationship between choice, autonomy, and the pursuit of equitable transport systems.

When considering the question of "whom" in transport equity, the existing literature and practices have predominantly focused on population groups known to face transport disadvantages due to factors beyond their control, such as low income, disability, and historical discrimination (Lucas, 2019). These transport disadvantages can manifest in various ways. In line with Schwanen et al. (2015), this article defines transport disadvantage as a lack of access to essential resources, activities, and opportunities for interaction, as well as a lack of autonomy in travel choices and their consequences. Autonomy, in this context, refers to the perceived freedom to travel according to one's preferences, particularly in terms of the quality and range of available choices.

Regarding the question of “how” to distribute benefits, the transport literature commonly discusses two normative principles of fairness: spatial (horizontal) equity and social (vertical) equity. Spatial equity pertains to the degree of alignment between the distribution of fares paid and the utilisation of public transport services (Bandegani and Akbarzadeh, 2016; Cheng and Chen, 2015). On the other hand, social equity relates to the extent to which the distribution of benefits favours low-income individuals and other vulnerable groups (Brown, 2018; Farber et al., 2014; Nahmias-Biran et al., 2017). While providing a spatially equitable range of choices may seem more straightforward in theory, the reality is that the choice set available to a traveller is influenced by both objective factors (e.g., provision of transport services by different transit companies) and subjective factors (e.g., perception and knowledge of available transport services) (Chen et al., 2010; Chen and Subprasom, 2007; Eboli et al., 2018; Nkurunziza et al., 2012). Conversely, achieving social equity in the choice set is more complex. Focusing solely on individual freedom may overlook the fact that an individual's preferences and achievements are not solely determined by their individual choices but are influenced by the natural and social circumstances of their context. Inequalities can be considered fair only when they result from individuals’ choices and efforts. Given this context, this article establishes a strong foundation for addressing the spatial equity of choice, recognising its significance in the pursuit of transport equity.

When considering the question of “what” is to be distributed in transport-related inequalities, the literature highlights four interconnected aspects that significantly impact people's well-being and perception of equity:

1. Transport-related resources: This includes factors such as car ownership and proximity to transport services and infrastructure (Murray and Davis, 2001; Ong, 2002; Thomopoulos et al., 2009). However, focusing solely on these resources may provide only a partial understanding of individuals' ability to utilise them effectively for their mobility needs. People have diverse needs, preferences, and abilities, which must be taken into account to fully capture their capacity to access and utilise transport resources (Pereira et al., 2017).
2. People's actual mobility: This pertains to individuals' daily travel behaviour, encompassing variations in trip frequency, travelled distances, and travel time (Bills et al., 2012; de Vasconcellos, 2005; Kakar et al., 2021; Karner and Niemeier, 2013). However, this approach often fails to differentiate between inequalities in travel behaviour resulting from voluntary choices based on personal preferences and those imposed by external constraints beyond individuals' control.
3. Transport-related opportunities: This refers to the ease with which individuals can access places and opportunities from a given location. It is influenced by a complex interplay of factors such as individuals' characteristics, the transport system, and land use (Chan et al., 2021; Church et al., 2000; Delmelle and Casas, 2012; Oh and Chen, 2022; Sun and Zacharias, 2020; Welch, 2013; Xu et al., 2022a). Examining transport-related opportunities allows for a comprehensive understanding of how the built environment and transport infrastructure shape people's access to essential destinations and activities.

4. Externalities on society: These externalities encompass the broader impacts of transport on society, such as environmental pollution (Benmarhnia et al., 2014; Schindler and Caruso, 2021; Sider et al., 2015; Tsoi et al., 2021), safety (Ferenchak and Marshall, 2019; Marshall and Ferenchak, 2017; Najaf et al., 2017), congestion (Bendib, 2020; Sen et al., 2022), and so forth. The costs associated with these externalities are not adequately reflected in the immediate market value, such as fare, travel time, and distance (Chen and Zhou, 2022; Zhou et al., 2019). A comprehensive transport equity model should consider the true outcomes of transport services, accounting for their wider societal implications (Guo et al., 2020).

A relatively promising approach aforementioned to understanding the social value of choice is the focus from inequalities in accessibility levels (Pereira et al., 2017; Sun and Zacharias, 2020). Nevertheless, accessibility is regarded as ‘a necessary, though not sufficient, condition for the expansion of people’s freedom of choice and promotion of equality of opportunities’ (Pereira et al., 2017, p.177) such as employment, healthcare, and education. This perspective emphasises the link between accessibility and concepts of agency and freedom of choice (Kymlicka, 2002), necessitating a more nuanced understanding that recognises the diverse needs and constraints individuals face when making transport decisions (Pereira et al., 2017). Therefore, the missing piece in assessing transport equity lies in realising freedom and autonomy; and thus, we propose a working hypothesis that providing a spatially equitable choice set can contribute to this goal.

In this regard, recent advancements in the understanding of potential mobility, which is connected to freedom of movement and choice, support this hypothesis (Martens, 2012; Pereira et al., 2017; Sager, 2014). A higher level of potential mobility means greater options for destinations and opportunities within a specific area or transport activity zone. This distributive justice perspective can also be applied to the choices of transport services themselves, as seen in the concept of option value in transport appraisal (Geurs et al., 2006; Laird et al., 2009). A growing body of literature has shown that transport services offer more than just functional value in terms of moving people; they encompass diverse choices that expand the utility of money and time by considering the multifaceted value of travel.

Everyday travel decisions are influenced by individual preferences that go beyond financial and time considerations (Mokhtarian and Chen, 2004). Factors such as the trade-off between travel time and money (Hess et al., 2020), safety (Mouter et al., 2017), environmental benefits (Wang et al., 2020), autonomy (Bláfoss Ingvardson et al., 2020), aesthetic experience (Maskit, 2018; Mladenović et al., 2019), and the distinction between voluntary and forced travel choices strongly impact people’s perceived well-being (Martens et al., 2019). If we recognize that the availability of choices has become a prerequisite for accommodating diverse values and preferences that every citizen deserves (Martens, 2011), it becomes necessary to adopt a more sophisticated view of equity. This view acknowledges the intuitive and fundamental importance of having a range of options while considering context-specific factors that shape people's transport choices. These factors include personal constraints arising from the diversity of people's needs and constraints, as well as contextual factors such as the design of public transport networks and services resulting from government interventions and competition between companies. In an increasingly globalised and culturally diverse world, this conceptualisation highlights the need to distribute transport services and facilities based on the criterion of choice available to individuals, rather than solely on realised demand (Martens, 2012, 2011).

This conceptualisation becomes particularly relevant in an increasingly globalised and culturally diverse world, where the distribution of transport services and facilities should be assessed based on the criterion of choice availability, rather than solely on realised demand. The current paper stands apart from previous research by proposing a spatial justice perspective and a working hypothesis that more choices are desirable from an equity standpoint. Our aim is to address universal concerns about inequality of opportunities and basic needs regarding transport, as well as the contextual factors (i.e., choice availability) that influence people's transport choices. This perspective recognises that transport is not merely a means of accessing resources but an integral part of daily life, where transport choices are intertwined with individual freedom and autonomy. To illustrate this conceptual framework, we focus on the first dimension of "how" - defining spatial equity as equal access to a range of transport choices.

## 3 Methods and data

### *3.1 Study area and sampling of commuters*

Hong Kong, a densely populated city in southern China, is designated as a Special Administrative Region. With a population of over 7.4 million people and a land area of just 1,104 square kilometres, Hong Kong faces unique challenges in transport planning. The city has adopted a public transit-oriented policy and boasts a highly developed public transport system that caters to more than 90% of daily trips (Transport Department, 2020). Unlike many cities worldwide, Hong Kong operates its public transit services on a commercial basis, which offers increased efficiency (Tang and Lo, 2008, 2010). However, this approach requires the government to strike a delicate balance between efficiency and equity (Kristoffersson et al., 2017), taking into account factors related to both passengers and operators in transport planning, policies, and strategies (Tsoi and Loo, 2021). Hong Kong offers a diverse range of public transport modes and fare structures (Xiao et al., 2021). The transport system encompasses heavy rail, light rail, franchised buses, non-franchised buses, public light buses, trams, taxis, and ferries, all of which serve complementary roles. The heavy rail network serves as the backbone of the public transport system, while the light rail plays a vital role in the Northwest New Territories. Franchised buses, in addition to covering areas not accessible by rail, also provide feeder services to the railways. Other modes fulfil supplementary roles (Transport Department, 2017). For instance, the light rail transit serves the northern and southern parts of the New Territories West, while the tram operates along the northern shore of Hong Kong Island. **Figure 1** provides an overview of Hong Kong's multimodal transport network.

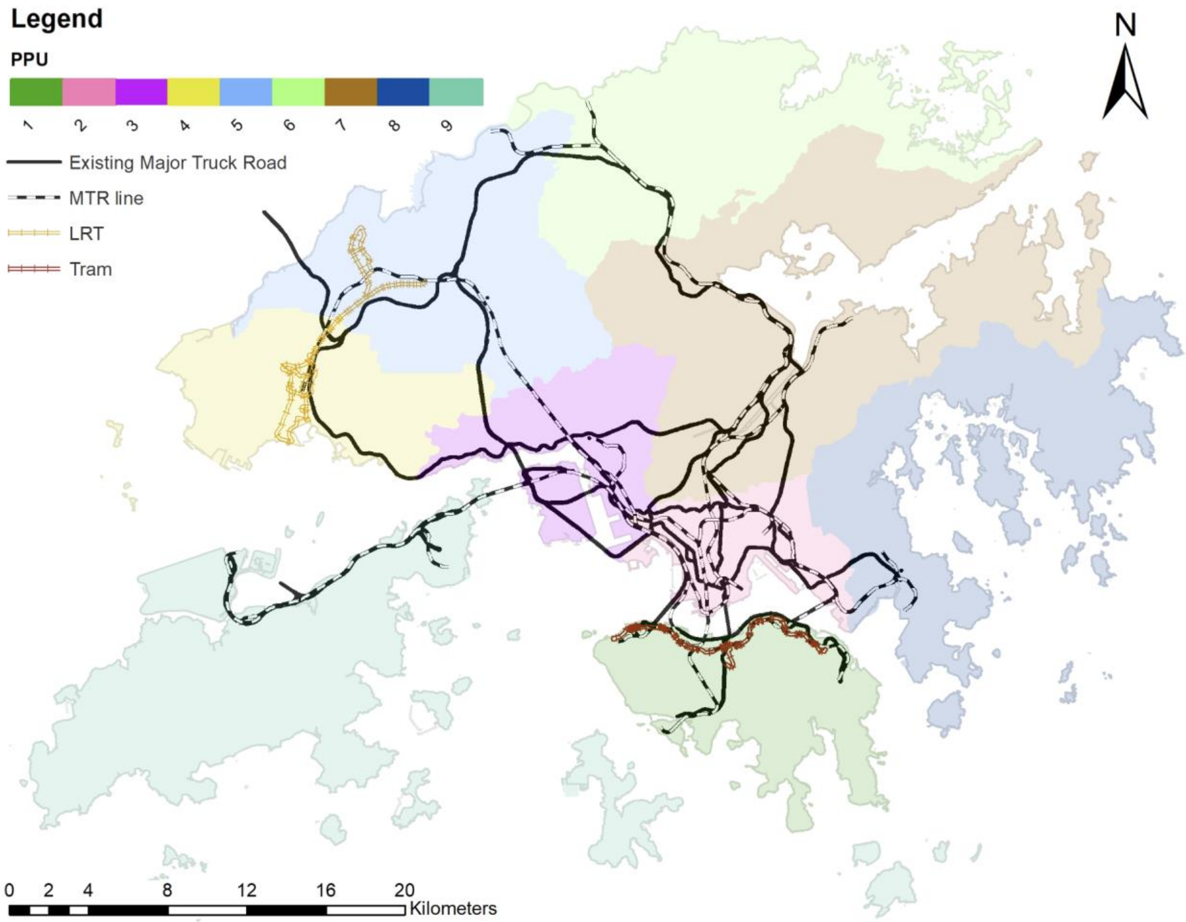


Figure 1 Hong Kong's multimodal transport network.

The trip data used in this study was obtained from the 2011 Travel Characteristics Survey (TCS). The TCS dataset provides comprehensive information on individual trip details, including departure and arrival times, location, and mode of transport. The survey was conducted on a random sample of individuals on a single workday. Trip locations were recorded at the street block level, allowing for precise analysis. The TCS also collected personal and household information from the participants. In total, more than 36,000 workers were surveyed in the 2011 TCS, with approximately 5,000 of them using private modes of transport such as private cars or taxis. To ensure data quality, any missing records among commuters were identified and removed from the analysis. After excluding these cases, a total of 27,904 cases were retained for further analysis. The spatial distribution of the trips is visualised in **Figure 2**, providing an overview of how trips were distributed across the study area.

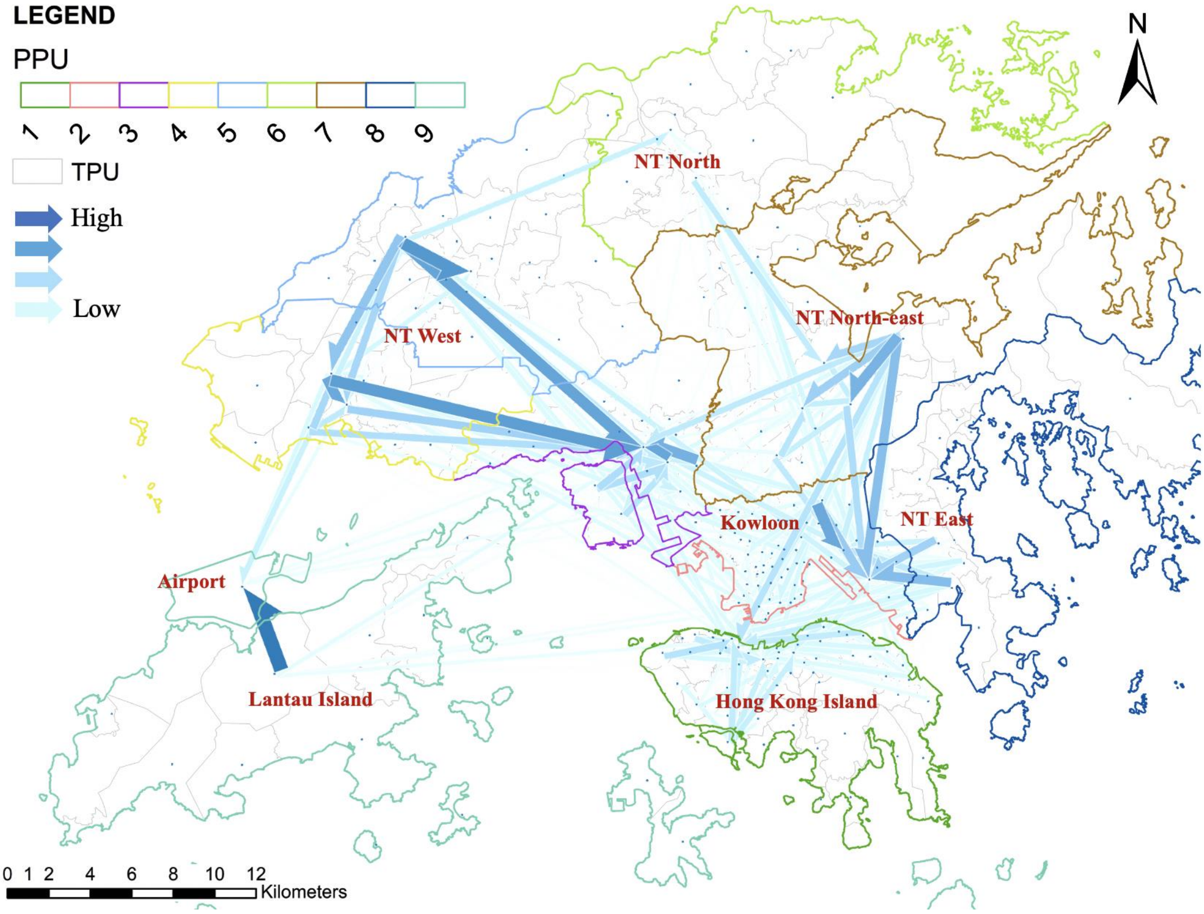



Figure 2 The major commuting routes and the relative volume of trips along each corridor (aggregated into TPUs). The higher the colour intensity of the arrows, the higher the demand between the corresponding O-D pairs.

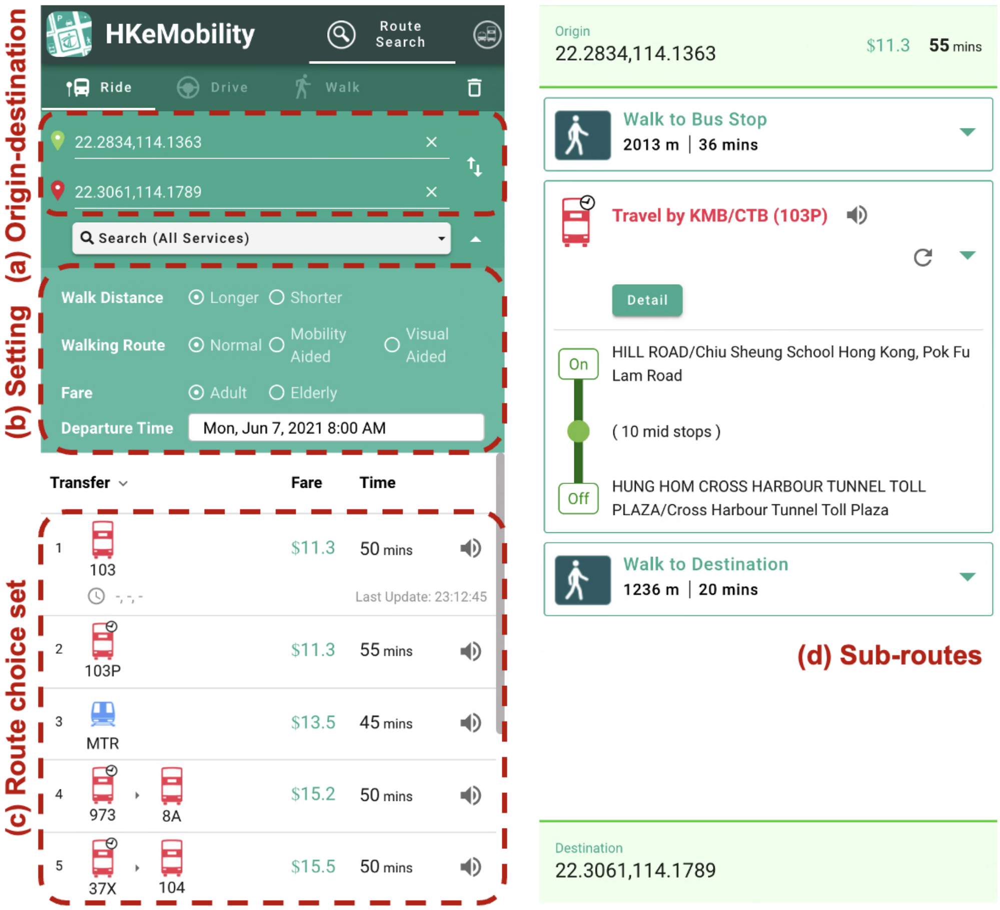
Table 1 Sample characteristics of 2011 TCS

| | Average for continuous variables (or % for discrete variables) |
|---|---|
| | Public transport commuters N = 27,904 |
| ***Personal characteristics*** | |
| Female | 45.9 |
| Age (y) | 40.1 |
| ***Household characteristics*** | |
| Household monthly income (HKD) | 38,400 |
| Household size | 3.41 |
| Income per capita (HKD) | 13,057 |
| ***Behavioural characteristics*** | |
| Commuting time (min) | 42.82 |
| Working hours (hour) | 9.68 |

### *3.2 Derivation of commuting choices*

The transit route data used in this study were obtained from the route planning service provided by HKeMobility. This service utilises an algorithm developed by Pun-Cheng (2012) and Pun-

Cheng and Chan (2016)[1] to compute reasonable routes for transit journeys. To collect the transit route information, we retrieved the recommended routes for sampled commuting trips from residences to workplaces. This was done by using the centroid coordinates of the corresponding street blocks, which serve as sub-units of the Transport Planning Units (TPUs). Each complete route consists of several sub-routes, such as walking, bus, railway, and walking again. In our analysis, we assumed that commuters are ordinary adults without any specific preferences for shorter walking distances or facilities that aid mobility. We also assumed a departure time of 8:00 am on weekdays, which is a common commuting time. The collected transit route data include various details, such as the total fare and travel time for the entire journey, the number of steps involved, and specific information for each sub-route, such as its duration, stations, transit routes, and boarding and alighting stations. By utilising this transit route data, we were able to estimate various indicators using the methodology described later. **Figure 3** provides an example of the route choice set offered by HKeMobility, showcasing the available options for commuters in terms of transit routes.




[1] We acknowledge the existing work on identifying reasonable choice sets in transit route planning, as described by Pun-Cheng (2012) and Pun-Cheng and Chan (2016). However, it is important to recognize that computer-based route planning may differ from human-based route planning, as highlighted in several studies (e.g., Huang et al., 2014; Li et al., 2022). The generated alternative routes provided by the public transit route planner are perceived by users to have varying quality, and it is necessary to incorporate a model that considers the evaluation process of route quality. In this paper, we propose an evaluation indicator called "optionality", which is based on the trade-off between fare and travel time. This indicator aims to capture the perceived value of different route options available to commuters. By considering the fare and travel time trade-off, we can assess the attractiveness and desirability of each route option within the choice set.

Figure 3 Example of route choice set provided by HKeMobility. (a) Input with coordinates of centroid of TPU; (b) Setting for ordinary travellers; (c) Reasonable choice set[1]; (d) Details information of a route including walking distance and travel time of each leg

### *3.3 Indicators of equity of transport choice*

Let $\boldsymbol{C}$ be the set of transport choices with size $\boldsymbol{S}$, with the number of unique travel modes $\boldsymbol{N}$ of an origin and destination (O-D) pair $\boldsymbol{p}$. We set the mean of fare $\boldsymbol{M_{mean,p}}$ and the mean of travel time $\boldsymbol{T_{mean,p}}$ for all transport choices $\boldsymbol{c}$ of $\boldsymbol{p}$ to be the benchmark for comparison. For all $\boldsymbol{c_p} \in \boldsymbol{C_p}$, the fare $\boldsymbol{M_{c,p}}$ and travel time $\boldsymbol{T_{c,p}}$ are compared to the mean of the fare and travel time of $\boldsymbol{p}$, which is mathematically described as:

$$\text{Degree of money savings for transport choice } \boldsymbol{c} \text{ for OD pair } \boldsymbol{p} = MS_{c,p} = \frac{M_{mean,p}}{M_{c,p}} \quad (1a)$$

$$\text{Degree of time savings for transport choice } \boldsymbol{c} \text{ for OD pair } \boldsymbol{p} = TS_{c,p} = \frac{T_{mean,p}}{T_{c,p}} \quad (1b)$$

A higher degree indicates greater savings of the corresponding component.

To determine a reasonable choice set, it is important to consider that individuals' ability to reach their destination depends on options that fit within their time and budget constraints (Martens, 2020). In this study, we define optionality $\boldsymbol{O_{c,p}}$ for a specific transport choice $\boldsymbol{c}$ of an OD pair $\boldsymbol{p}$ as the level of availability for selection. This is determined by the proportion of travel time to the monetary increase or reduction, expressed as the product of the mean monetary cost and the mean travel time (i.e., $\boldsymbol{M_{mean,p}} \times \boldsymbol{T_{mean,p}}$). Mathematically, it can be described as follows:

$$O_{c,p} = \frac{M_{mean,p} \times T_{mean,p}}{M_{c,p} \times T_{c,p}} = MS_{c,p} \times TS_{c,p} \quad (2)$$

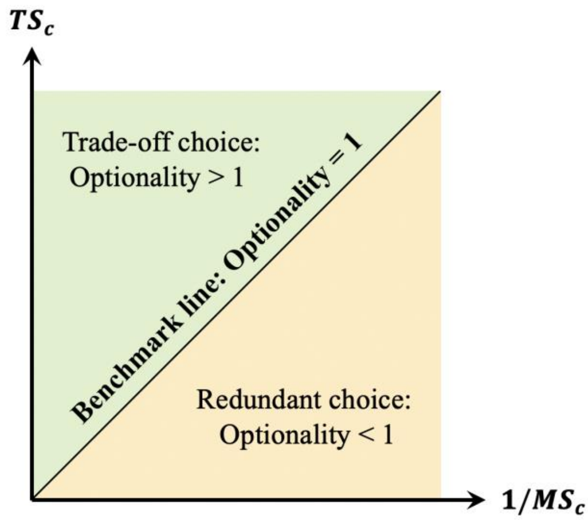



Figure 4 Illustrations of transport choice optionality.

We categorise choices into two types: time-saving choices and money-saving choices. Time-saving choices are identified when the time-saving $\boldsymbol{TS}$ is greater than 1, indicating that these choices enable travellers to save time compared to the mean travel time for a specific origin-destination pair. Similarly, money-saving choices are identified when the money-saving indicator $\boldsymbol{MS}$ is greater than 1, indicating that these choices allow travellers to save money compared to the mean fare for the same origin-destination pair. In this study, we adopt a benchmark line, represented by $\boldsymbol{O}$ equals to 1, as shown in **Figure 4**. This benchmark line serves as a reference point to filter out redundant choices that provide poor utility in terms of the trade-off between money and time. For a choice to be considered acceptable, the ratio of TS to MS should maintain a reasonable level, as defined in **Eq. 2**. This means that travellers can trade off one unit of time for one unit of money without incurring a significant cost.

We focus on identifying the trade-off choice sets that offer the highest degree of money and time savings for each origin-destination (O-D) pair. These optimal choices, denoted as $\boldsymbol{MS_{hc}}$ and $\boldsymbol{TS_{hc}}$, represent the maximum potential for saving money and time, respectively, within each O-D pair. At the O-D level, we utilise these variables to evaluate the inequity experienced by individuals who are time-poor or money-poor. This evaluation is quantified through a mathematical expression:

For the trade-off choice (acceptable choice) sets, we are interested in the choice with the greatest degree of money and time savings for each O-D pair, denoted as $\boldsymbol{MS_{hc}}$ and $\boldsymbol{TS_{hc}}$, respectively, which is mathematically described as:

$$MS_{hc,p} = max\{MS_{c,p}\} \tag{3a}$$

$$TS_{hc,p} = max\{TS_{c,p}\} \tag{3b}$$

While an $\boldsymbol{O}$ value of 1 or greater indicates that a transport choice maintains its utility in terms of the trade-off between money and time, it is important to note that routes with $\boldsymbol{O}$ values less than 1 are not necessarily useless. There may be choices that offer significant time savings but come at unreasonably high prices. We are particularly interested in examining the spatial distribution of such choices and exploring how adjustments in fare and travel time can enhance the quality and range of choices. By making these adjustments, we aim to improve the reasonableness of choices, allowing individuals to make a wider variety of trade-offs between money and time. Ultimately, this can help reduce inequity in transport options.

### *3.4 Numerical examples*

**Figure 5** is an example with a specific origin-destination (O-D) pair to illustrate the features of optionality measures. In this example, the choice set is generated by a route planning service platform, as shown in **Figure 3**. The choice set consists of four options:

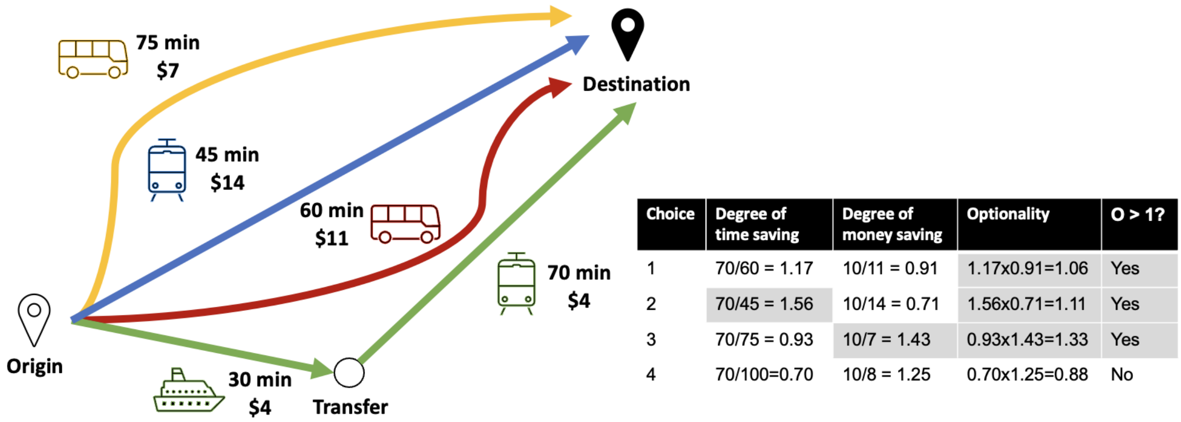
1. Bus: Travel time of 60 minutes and fare of $11.
2. Rail: Travel time of 45 minutes and fare of $14.
3. Bus: Travel time of 75 minutes and fare of $7.
4. Ferry/Rail: Travel time of 100 minutes and fare of $8.

The mean travel time for this O-D pair is 70 minutes, and the mean fare is $10. We can calculate the degree of time and money savings for each choice compared to the mean values. The degree of time and money savings for the choices are as follows:

1. Time saving: 1.17 (17% higher than the mean), Money saving: 0.91 (9% lower than the mean).
2. Time saving: 1.56 (56% higher than the mean), Money saving: 0.71 (29% lower than the mean).

3. Time saving: 0.93 (7% lower than the mean), Money saving: 1.43 (43% higher than the mean).
4. Time saving: 0.70 (30% lower than the mean), Money saving: 1.25 (25% higher than the mean).

Next, we calculate the optionality of each choice to determine whether they maintain their utility in terms of the trade-off between money and time (i.e., $\boldsymbol{O} \geq 1$). Based on the optionality values, we find that choice 4 is deemed unreasonable due to its low optionality ($\boldsymbol{O} < 1$), indicating that the time saving it offers does not justify the cost in terms of money. This example demonstrates how optionality measures can be used to assess the reasonableness of choices within a given choice set, particularly in relation to the trade-off between money and time.




| Choice | Degree of time saving | Degree of money saving | Optionality | O > 1? |
|---|---|---|---|---|
| 1 | 70/60 = 1.17 | 10/11 = 0.91 | 1.17x0.91=1.06 | Yes |
| 2 | 70/45 = 1.56 | 10/14 = 0.71 | 1.56x0.71=1.11 | Yes |
| 3 | 70/75 = 0.93 | 10/7 = 1.43 | 0.93x1.43=1.33 | Yes |
| 4 | 70/100=0.70 | 10/8 = 1.25 | 0.70x1.25=0.88 | No |

Figure 5 Example of transport choice set.

### *3.5 Spatial equity assessment*

#### *3.5.1 Corridor analysis*

Our first focus is on ensuring the equitable spatial distribution of time and money saving route choices within trade-off choice sets (i.e., choices with $\boldsymbol{O} \geq 1$). Spatial equity refers to the fair treatment of all individuals within a specific group, considering them as equals. In the context of transport, it advocates for the application of the same cost (e.g., public transport fare) to all citizens regardless of their place of residence. To assess the fairness of distribution, we visualise the maximum degree of time and money saving route choices available to a sample of commuting O-D pairs. This visualisation helps us identify the (uneven) distribution of these benefits across different areas of the city. By examining this spatial distribution, we can gain insights into the equity of access to time and money saving transport options for residents in various locations.

#### *3.5.2 Global analysis*

The following analysis aims to determine the extent to which making adjustments to redundant choices (i.e., choices with $\boldsymbol{O} < 1$) through service modifications can lead to more equitable transport services. To assess the overall impact of these adjustments, a global indicator is necessary for a before-and-after comparison. In our study, we utilise the Gini (1912) coefficient as a measure of spatial equity among citizens. The Gini coefficient, denoted as $\boldsymbol{G}$, quantifies the level of inequality in the distribution of a specific attribute. To calculate the Gini coefficient in our context, we employ the following equation, which provides an approximation of the mathematical calculation (Delbosc and Currie, 2011):

$$G = 1 - \sum_{k=1}^{n} (X_k - X_{k-1})(Y_k - Y_{k-1}) \tag{4}$$

where $X_k$ and $Y_k$ are the cumulative proportions of the population and the public transport service variable, respectively, for $k = 0, 1, 2, \ldots, n$, with $X_0$, $Y_0 = 0$ and $X_n$, $Y_n = 1$.

The Gini coefficient is a measure that ranges from 0 to 1, representing the degree of spatial equity. A value of 0 indicates perfect equity, where money/time saving is evenly distributed among all citizens. On the other hand, a value of 1 suggests extreme inequity, where one person bears all the costs. In our analysis, we calculate the Gini coefficients for all the factors mentioned earlier to investigate whether transport choices from different perspectives are distributed unequally among riders residing in different areas. Next, we examine the extent to which adapting redundant choices through service adjustments can contribute to more equitable transport services. To provide a comprehensive overview, we present the data and research framework in **Figure 6**, which illustrates the key elements of our study.

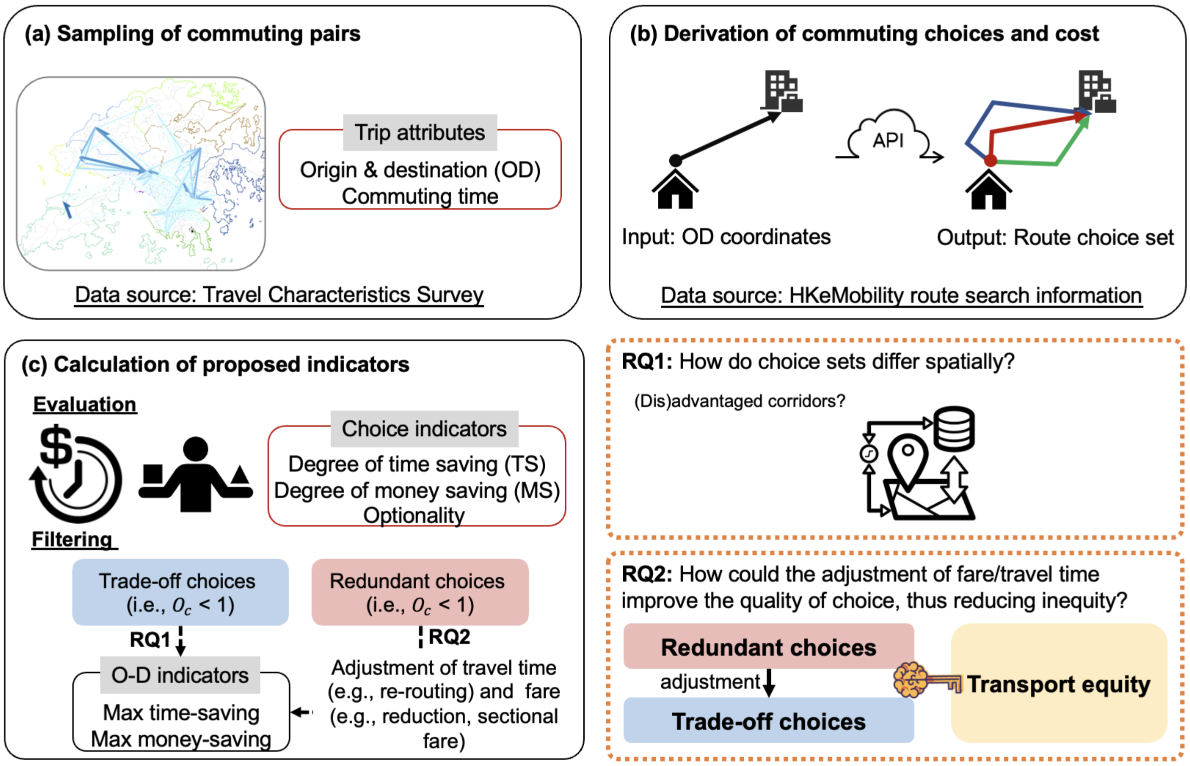



Figure 6 Data and research framework with an illustration

## 4 Results and discussions

### *4.1 Transport choice characteristics*

To illustrate the characteristics of the proposed metrics, we begin by examining the statistical distribution among various transport modes. **Table A1** in the appendix presents the distribution of choices with an optionality value $O_c$, revealing that the percentage of trade-off options varies for different transport modes. Choices with a single mode, such as buses, and modes classified as "other" (including light rail, trams, ferries, etc.), have a lower proportion of options for trade-off, ranging from 40% to 60%. When considering time-saving choices, the metro service stands out as an efficient mode, with approximately 29.38% of routes having a time-saving ***TS*** greater than 1. On the other hand, for money-saving choices, no particular mode stands out, with approximately 20% of routes offering trade-off options for saving money. This analysis provides insights into the distribution of options among different transport modes, highlighting the efficiency of metro services for time-saving choices and the absence of a dominant mode for money-saving choices.

### *4.2 Distribution of the horizontal equity of transport choice across spaces*

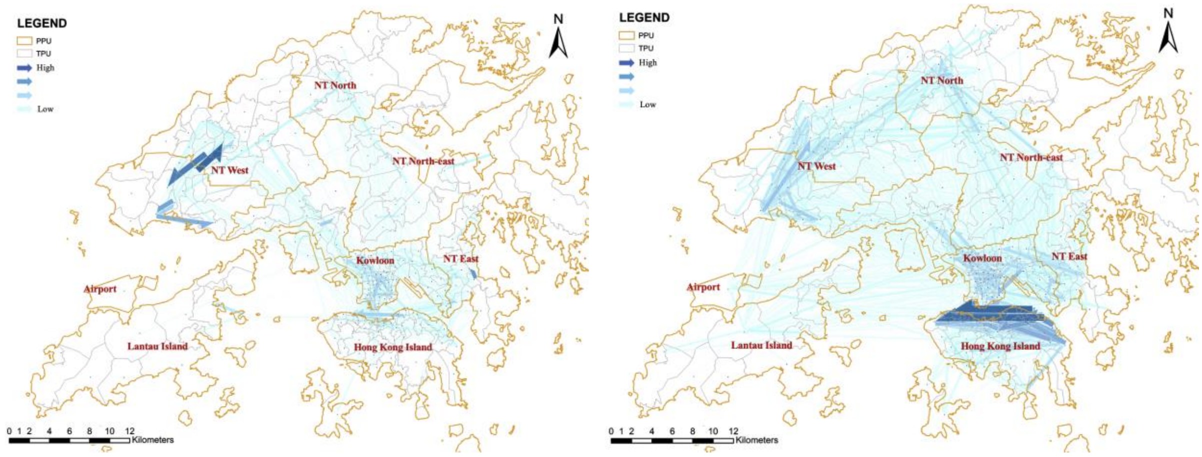
In order to examine the spatial equity implications of the proposed metrics for transport choices, we conducted a one-way analysis of variance (ANOVA) using the spatial classification system of primary planning units (PPUs) as factors. The goal was to determine if there were significant differences in the degree of money and time savings among PPUs. The results, as presented in **Table 3**, indicate statistically significant differences among the PPUs in terms of the proposed metrics. Specifically, transit services in Lantau Island were found to offer the lowest degree of savings. On the other hand, PPU5 (New Territories West) stood out with the highest degree of time savings. This can be attributed to the presence of express bus services that are faster but relatively more expensive. When it comes to money savings, transit services in Hong Kong Island emerged as providing the highest degree of savings. This can be attributed to the availability of low-priced tram services that facilitate connections between the eastern and western parts of the island along the north shore. These findings highlight the spatial variations in the degree of money and time savings among different PPUs, underscoring the potential inequities in access to transport choices across different regions within Hong Kong.

Table 2 Difference among primary planning units (PPUs).

| Geographic name | PPU | Degree of money-saving | | Degree of time-saving | |
|---|---|---|---|---|---|
| | | Mean | S.D. | Mean | S.D. |
| HK Island | 1 | *1.77* | 0.565 | 1.74 | 0.640 |
| Kowloon | 2 | 1.53 | 0.327 | 1.69 | 0.610 |
| NT West | 3 | 1.48 | 0.351 | 1.64 | 0.562 |
| | 4 | 1.65 | 0.707 | 1.63 | 0.864 |
| | 5 | 1.56 | 0.571 | *1.84* | 0.942 |
| NT North | 6 | 1.47 | 0.458 | 1.55 | 0.501 |
| NT Northeast | 7 | 1.49 | 0.362 | 1.52 | 0.508 |
| NT East | 8 | 1.50 | 0.355 | 1.74 | 0.636 |
| Lantau Island | 9 | *1.35* | 0.354 | *1.38* | 0.438 |
| | Overall | 1.57 | 0.463 | 1.67 | 0.650 |
| | Sig. | *** | | *** | |

"NT": New Territories.
*** One-way ANOVA, transport choice parameters differ significantly ($p < 0.001$).

In addition, the analysis of corridors (routes) based on the proposed classification reveals distinct patterns. **Figure 7a** illustrates the advantages for travellers in New Territories West in terms of time-saving choices. However, when we examine the actual demand for travellers from New Territories West, as depicted in **Figure 2**, we observe that only a few of these advantageous corridors experience high demand. This implies that the benefits provided by these corridors cannot reach a substantial number of travellers in the region. On the other hand, **Figure 7b** demonstrates that travellers along the north shore of Hong Kong Island benefit from affordable tram services. This indicates that a significant number of travellers in this area have access to low-cost transport options, contributing to their money-saving choices. These observations highlight the importance of considering both the advantages offered by specific corridors and their alignment with the actual demand patterns of travellers. It emphasises the need to ensure that the advantages provided by transport services are accessible to a larger proportion of the population and distributed more equitably across different regions.




(a) (b)

Figure 7 Spatial distribution of degree of (a) time and (b) money savings at O-D level. Arrows with higher colour intensity are O-D pairs with higher degree of savings.

### *4.3 How could adjustment of fare/travel time of current services improve the quality of choice and thus reduce inequity?*

#### *4.3.1 Gini coefficients change after redundant choice adaptation*

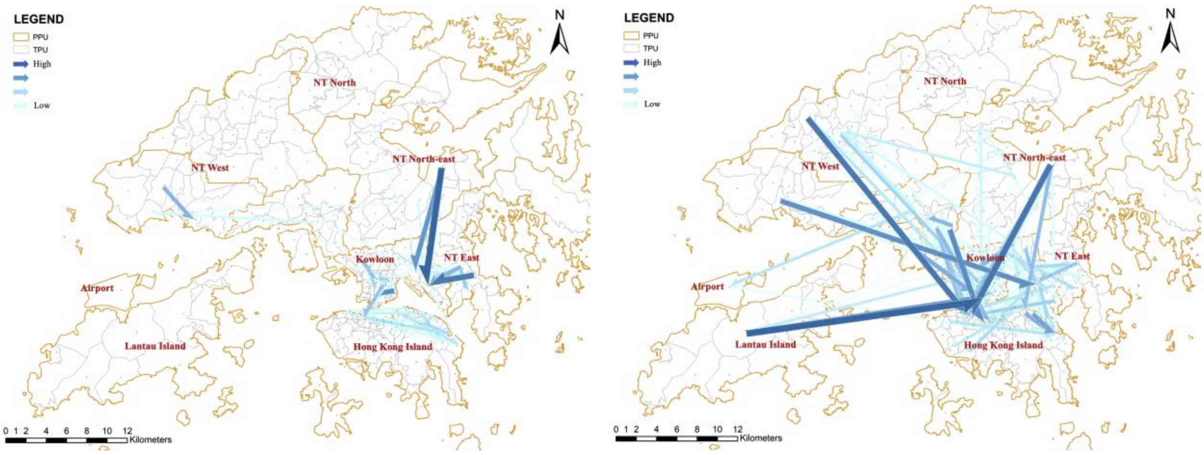
The subsequent analysis aims to investigate the potential of adapting redundant choices (i.e., $\boldsymbol{O_c} < 1$) through service adjustments to enhance the equity of transport services. **Table 3** showcases the changes in Gini coefficients for various aspects of transport choices before and after the adjustment of transport services. Initially, when considering the presence of the highest saving choices, the Gini coefficients for both time and money savings are low before the adjustment (0.197 and 0.167, respectively). These coefficients indicate that the current public transport services offer a relatively even distribution of choice sets across different areas. However, after the adjustment of transport services, there is a slight improvement in the Gini coefficients. This suggests that reevaluating and reconsidering redundant choices can have a positive impact on reducing the inequity of choices. The initial findings indicate that addressing redundant choices can serve as a starting point for enhancing the quality and equity of transport options. By improving the quality of redundant choices, it becomes possible to mitigate the existing disparities and create a more equitable distribution of transport services.

Table 3 Changes in Gini coefficients at the O-D level before and after adjustment (N = 24,609)

| Variable | Before adjustment | After adjustment |
|---|---|---|
| Max money-saving (2,121 O-D pairs improved) | 0.193 | 0.188 |
| Max time-saving (2,029 O-D pairs improved) | 0.167 | 0.165 |

### *4.3.2 Case studies of commuting corridors*

To gain a more in-depth understanding, we perform case studies focusing on specific corridors for both time- and money-saving aspects. The selection of these case studies is based on the visualisation of the spatial distribution of improved routes/corridors, as depicted in **Figure 8**. By examining these case studies, we can delve into the specific characteristics and implications of these corridors, shedding light on their role in enhancing time and money savings within the transport network.




(a) (b)

Figure 8 Spatial distribution of improvement in the degree of (a) time and (b) money savings at O-D level. Arrows with higher colour intensity are O-D pairs with a higher degree of savings

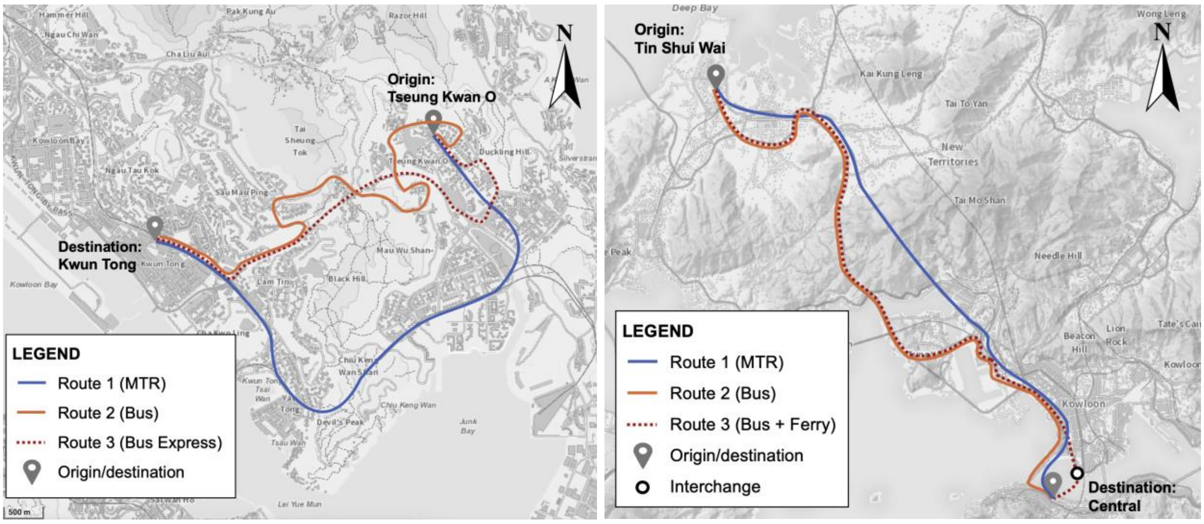
Regarding the improvements in the degree of time-saving, we observe enhancements in medium-distance trips, particularly along the corridors connecting NT North-east/East to and from eastern Kowloon. To illustrate this, we take the Tseung Kwan O-Kwun Tong corridor in NT East as an example. Tseung Kwan O is a residential new town, while Kwun Tong serves as a traditional industrial centre. Within this corridor, there are a total of 13 transit routes. **Figure 9a** displays the trajectories and detailed information of the routes with the highest optionality (Route 1 and 2), as well as the target route (Route 3). Although Route 3 exhibits a low optionality value (0.907), which falls below 1, it provides a significant degree of time-saving (3.577) compared to other options. The reason for its high fare and short travel time is that it serves as an expressway connecting the airport and the NT East residential area. To adapt Route 3 for commuting trips, we aim to increase its optionality to the average value of 1.414. By performing a back calculation as depicted in **Table 4**, we determine that a sectional fare of $27 would be appropriate, reducing it from the original full fare of $42. This adjustment allows for a more reasonable and equitable transport choice along this corridor.

In terms of the improvements in the degree of money-saving, we observe that the enhancements are spread across various areas in Hong Kong. However, these improvements are more prominent for long-distance commuting trips. As an example, we consider the Tin Shui Wai-Central corridor. Tin Shui Wai is a residential new town, while Central serves as the traditional central business district (CBD). Within this corridor, there are a total of 20 transit routes. **Figure 9b** illustrates the trajectories and detailed information of the routes with the highest optionality (Route 1 and 2), as well as the target route (Route 3). Despite Route 3 having a low optionality value (0.957), falling below 1, it provides a significant degree of money-saving

(1.292) compared to other options. The reason for its low fare is that it is a multi-modal route, with the ferry providing a low-priced cross-harbour service. To adapt Route 3 for commuting trips, similar to our approach for time-saving choices, we aim to increase its optionality to the average value of 1.124. By performing a back calculation as depicted in **Table 4**, we determine that a fare reduction of $19.6 can be provided, reducing it from the original full fare of $23. This can be practically achieved by waiving the fare for the ferry component ($3.2 for adults on weekdays). This adjustment allows for a more reasonable and equitable transport choice along this corridor.

Table 4 Fare adjustment of transport choices in selected corridors

| Route | Fare ($) | Travel time (min) | Degree of money-saving | Degree of time-saving | Optionality |
|---|---|---|---|---|---|
| **(a) Time-saving choice in the choice set from Tseung Kwan O to Kwun Tong** | | | | | |
| 1 | 8.3 | 35 | 1.284 | 1.022 | 1.312 |
| 2 | 6.5 | 20 | 1.639 | 1.789 | 2.931 |
| *3* | *42* | *10* | *0.254* | *3.577* | *0.907* |
| Average (N = 13) | 10.7 | 35.8 | 1.276 | 1.246 | 1.414 |
| **Selected route: 3** | | | | | |
| Step 1: Target value of optionality | | | | | 1.414 |
| Step 2: Target value of MS | | | 1.414/3.577 = 0.395 | | |
| Step 3: Fare adjustment | 10.7/0.395 = $27.0 | | | | |
| **(b) Money-saving choice in the choice set from Tin Shui Wai to Central** | | | | | |
| 1 | 26.8 | 50 | 1.109 | 1.555 | 1.724 |
| 2 | 24.6 | 70 | 1.208 | 1.111 | 1.342 |
| *3* | *23* | *105* | *1.292* | *0.740* | *0.957* |
| Average (N = 20) | 29.72 | 77.75 | 1.051 | 1.076 | 1.124 |
| **Selected route: 3** | | | | | |
| Step 1: Target value of optionality | | | | | 1.124 |
| Step 2: Target value of MS | | | 1.124/0.740 = 1.518 | | |
| Step 3: Fare adjustment | 29.72/1.518 = $19.6 | | | | |




(a) (b)

Figure 9 Selected corridors for fare adjustment for increasing optionality of (a) time-saving choice and (b) money-saving choice

## 5 Discussion

### *5.1 Time-saving choices: turning into more affordable choices?*

The presence of time-saving choices highlights the potential for travellers to reduce their travel time by paying a higher fare. As transport planners, it is important for us to delve into the disaggregated level to identify the most suitable solutions that align with local circumstances. In our study, the proposed metrics provide more detailed information on the inequities within transport services. In fact, just prior to the time of writing, the bus company (KMB, 2020) announced the implementation of a two-way sectional fare scheme for 17 bus routes serving the Northwest New Territories, marking Hong Kong's first regional two-way sectional fare initiative. As part of this scheme, the bus company has installed smart card readers at bus stops, allowing passengers on relevant routes to tap their smart cards upon alighting and receive a fare rebate. This new sectional fare practice aims to provide riders with greater flexibility, particularly for those with lower incomes, who previously faced the dilemma of "high cost, high reward" choices. The metrics proposed in our paper can potentially guide fare adjustments from an equity perspective. While the design of an optimal and equitable fare system is beyond the scope of this article, it would be valuable for future studies to re-evaluate the utilisation of these transport choices and assess the feasibility of fare adjustments to achieve a more equitable outcome for actual riders. By considering the insights provided by our metrics, researchers can explore the potential for creating a fare structure that better aligns with the principles of equity and meets the needs of diverse commuters.

### *5.2 Redundant choices: to keep or not?*

The planning and operation of public transport services in Hong Kong are regulated and overseen by the government, specifically the Transport Department (2017). They adopt an "area" approach, where bus services are reviewed and evaluated for a district as a whole rather than on a route-by-route basis. The department has the authority to rationalise bus and minibus routes, which may include terminating existing services if necessary. Various factors are taken into consideration during this process, including the nature of the services, availability of alternative options, fares of alternative services, operational considerations, job opportunities, and environmental benefits. However, implementing a rationalisation plan that involves cutting existing routes can be challenging due to administrative complexities and potential opposition from stakeholders.

In this study, we adopt a “route/corridor” approach, focusing on transit services at the origin-destination (O-D) level. We propose metrics to classify transit routes into trade-off and redundant choices and demonstrate how these metrics can be put into practice through case studies. The results obtained can help redefine and quantify the nature of services, which is a crucial criterion for route rationalization, particularly in the context of Hong Kong. For example, routes with consistently low utilisation rates, indicating unattractive trade-off choices or redundant options, can be identified. Transport planners can then explore alternative strategies to improve service performance, such as using smaller capacity vehicles or adjusting fares. Additionally, the route approach enables the identification of potential issues at a more granular level, from areas to corridors, providing valuable information for assessing service quality and spatial equity. By considering these insights, transport planners can make more informed decisions regarding route optimisation and enhancing equity in public transport services.

### *5.3 Situating the findings within the equity literature*

Our proposed methods are based on the working hypothesis that having more choices is desirable from an equity perspective. This perspective emphasises the need for a framework to redefine, quantify, visualise, and characterise transport choices based on their trade-off between costs, such as time and monetary expenses. We introduce optionality as an indicator to classify choices into reasonable options (providing better utility for the trade-off between money and time) and redundant choices (offering poor utility for the trade-off between money and time) by employing a benchmark line. Our classifications help identify unattractive choices, and we demonstrate how adapting redundant choices through fare and travel time adjustments can enhance the quality of choices and reduce inequity. While we assume the benchmark to be equal to one, future studies can explore empirical values for the benchmark through questionnaire surveys, taking into account travellers’ perceptions and acceptance of transport choices (Xu et al., 2022b). To improve the accuracy of spatial trip distributions and identify important corridors, future research should rely on more up-to-date travel surveys.

We also acknowledge Marten and Golub (2012)’s discussions on the use of utility-based measures for equity analysis. They argue that it is unfair to treat individuals with different preferences differently, particularly when it involves imposing constraints or requiring more resources. Although it may not always be possible to disentangle the inequality in travel behavior arising from individual preferences (voluntary choice) and contextual constraints beyond individual control (forced choice), our analysis provides initial evidence in a relatively simpler case that considers the trade-off between money and time based on travellers’ varying needs arising from their budgets. As illustrated in the case studies, a sectional fare scheme implemented on longer-distance bus routes offers a time-saving choice, particularly beneficial for individuals with limited time availability. However, it is important to consider the potential congestion issues and negative impacts on original longer-distance travellers resulting from induced demand. Therefore, further research is necessary to develop a more comprehensive equity measure that is conceptually consistent with different ethical frameworks (Pereira et al., 2017). Additionally, practical discussions are needed to address the challenges of building more equitable transport systems that go beyond the limitations imposed by conventional data used in transport surveys.

## 6 Conclusion

We examine transport equity and justice from an overlooked perspective of choice and present an empirical study focused on Hong Kong's multimodal transport services. We classify public transport route choices into trade-off choices and redundant choices based on fare and travel time. In terms of spatial equity, we find that travellers in the New Territories have a distinct advantage in accessing a wider range of trade-off choices, likely due to the availability of various transport modes and routes. Our case studies demonstrate how the proposed metrics can be implemented in practical applications. For future research and applications, we recommend adopting the route approach, which provides more detailed information about the specific needs of different user groups.

However, our study has some limitations. We acknowledge that the proposed methods for time and money trade-off are currently limited to public transport mode choices and require further modifications before being applied to choices between car, cycling, and walking. Additionally, considering only the time-money trade-off may not be sufficient, as choices are influenced by other factors such as attitudes, habits, and satisfaction (Hoffmann et al., 2017), which form a continuous travel mode choice cycle (De Vos et al., 2022). Furthermore, external environmental factors like the quality of walking environments (Chan et al., 2022c, 2022a) and weather conditions (Zhu et al., 2023) should be considered due to spatial disparities. It is important to note that our proposed methods are somewhat limited to transit-oriented cities like Hong Kong, where public transport accounts for over 90% of trips. We also acknowledge that the observed trip data used in our study is relatively old, although it is based on the most recent regional travel survey in Hong Kong, which is still commonly utilised in current literature (see a review by Chan et al. (2022c)).

Nonetheless, these limitations do not undermine the illustrations of our proposed methodology and its potential for real-life applications, as demonstrated in the case studies. We recognise that redundancy can be desirable to mitigate system disruptions, as highlighted in previous studies (Chan et al., 2023, 2022b; Xu et al., 2018). Moreover, analysing choices solely based on the trade-off between money and time is limited in scenarios involving disruptions, considering the complexity of adaptive transit services (e.g., bus bridging services (Kepaptsoglou and Karlaftis, 2009)) and the dynamic value of time for passengers, as well as the availability of traffic and transit information during disruptions (Kenyon and Lyons, 2003). These aspects are worth further investigation.

## Appendix

Table A1 Statistical distribution of transport choices with different transport modes

| Transport Choice | Trade-off choice $O_c \geq 1$ | | | Redundant choice $O_c < 1$ | | |
|---|---|---|---|---|---|---|
| | $MS_c > 1$ | $TS_c > 1$ | $MS_c, TS_c > 1$ | $MS_c > 1$ | $TS_c > 1$ | $MS_c, TS_c < 1$ |
| *Single modal* | | | | | | |
| Bus | | 90578 (36.55) | | | 157270 (63.45) | |
| | 43793 (17.66) | 28609 (11.54) | 18176 (7.33) | 64396 (25.98) | 79670 (32.14) | 13203 (5.33) |
| Metro | | 1083 (50.58) | | | 1058 (49.42) | |
| | 250 (11.68) | 629 (29.38) | 204 (9.53) | 606 (28.30) | 238 (11.11) | 214 (10.00) |
| PLB | | 4751 (47.57) | | | 5236 (52.43) | |
| | 2040 (20.43) | 1422 (14.24) | 1289 (12.91) | 1760 (17.62) | 2385 (23.88) | 1091 (10.92) |
| Others | | 224 (39.86) | | | 338 (60.14) | |
| | 1 (0.18) | 125 (22.24) | 98 (17.44) | 61 (10.85) | 3 (0.53) | 274 (48.75) |
| *Multimodal* | | | | | | |
| Bus + metro | | 19385 (40.87) | | | 28048 (59.13) | |
| | 9521 (20.07) | 7315 (15.42) | 2549 (5.37) | 11808 (24.89) | 13724 (28.93) | 2516 (5.53) |
| Bus + PLB | | 20668 (45.26) | | | 24995 (54.74) | |
| | 11067 (24.24) | 7025 (15.38) | 2576 (5.64) | 9181 (20.11) | 13306 (29.14) | 2508 (5.49) |
| Bus + others | | 53138 (45.16) | | | 64526 (54.84) | |
| | 23481 (19.96) | 20077 (17.06) | 9580 (8.14) | 26110 (22.19) | 28551 (24.26) | 9865 (8.38) |
| Rail + PLB | | 8498 (43.32) | | | 11117 (56.68) | |
| | 4092 (20.86) | 3214 (16.39) | 1192 (6.08) | 4232 (21.58) | 5713 (29.13) | 1172 (5.98) |
| Rail + others | | 30578 (38.41) | | | 49023 (61.59) | |
| | 15137 (19.02) | 11495 (14.44) | 3946 (4.96) | 20417 (25.65) | 24896 (31.28) | 3710 (4.66) |
| PLB + others | | 34530 (47.03) | | | 38885 (52.97) | |
| | 14711 (20.04) | 13550 (18.46) | 6269 (8.54) | 15446 (21.04) | 17640 (24.03) | 5799 (7.90) |
| Bus + metro + PLB | | 1114 (45.88) | | | 1314 (54.12) | |
| | 630 (25.94) | 388 (15.98) | 96 (3.95) | 466 (19.19) | 758 (31.22) | 90 (3.71) |

"PLB": public light bus
Note: Numbers in brackets are the percentage of shares within a mode

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