Metro-related transfers: A review of recent literature

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Abstract:

Metro constitutes an important form of public transport in large cities throughout the world. As metro transport encompasses long distances and large areas, many metro passengers have to transfer to other transport modes to complete their journeys. This paper reviews recent literature on metro-related transfers, and summarises and discusses key findings and issues regarding transfers between metro and other transport modes. A considerable number of studies in different countries explored transfer behaviour, influencing factors related to metro-related transfers, and travellers' perceptions of and satisfaction with these transfers. The paper discusses characteristics of travel behaviour associated to metro-related transfers and provides important implications for improving travellers' perceptions of and satisfaction with these transfers. It also offers recommendations on aspects of the

built environment that could facilitate transfers between metro and other travel modes. The paper is significant in providing policy guidance for the integration of public transit and active and private transport, and is valuable in directing future research in this field.

Keywords:

Metro; Transfer; Travel behaviour; Traveller's perception; Built environment

1. Introduction

Metro constitutes an important form of public transport in large cities throughout the world. For many people, metro provides a convenient, reliable, comfortable, fast and affordable transport option for daily trips. In 2017, about 168 million passengers travelled by metro systems per day in 182 cities in 56 countries in the world. Among these metro systems, over 70% started operations within the last two decades. An unprecedented pace of metro development and operation in recent years in a small number of Asian countries contributed greatly to this rapid growth (UITP, 2018). Metro, that has been serving numerous residents for their mobility needs for more than a century, has become an important component of public transport systems. For example, metro accounted for 41% of total daily trips made by public transport modes in the Hong Kong Special Administration Region, China (Transport Department, The Government of the Hong Kong Special Administrative Region, 2020), and about 35% of total daily trips in London, United Kingdom (UK) (Transport of London, 2020). In large dense cities with road traffic congestion, metro transport, which is more reliable than buses and yields greater time-savings, constitutes a large proportion of long-distance trips made by public transit (Zhao & Li, 2017). Metro systems are predominantly located underground, constituting an important part of city underground infrastructure and providing key infrastructure services to urban society (ITA Working Group Number 13, 2004; Bobylev et al., 2012; Cui & Nelson, 2019). Complex underground structures, such as metro, motor car garages, and pedestrian passages with access to shopping facilities, are important inter-modal transfer infrastructure, especially in densely built city central areas (Bobylev, 2016; Cui et al., 2020). In addition, many metro travellers use above-ground transfer infrastructure (e.g. bus stations, taxi depots, park and ride facilities for cycling and driving) when they exit metro stations.

Undoubtedly, as metro transport encompasses long distances and large areas, many metro passengers have to transfer to other transport modes to complete their journeys. Transfers are an essential component of a public transit network. In London, 69% of metro trips involved one or more transfers, and in Santiago, Chile, 47% involved one or more transfers (Raveau et al., 2014). Transfers can significantly influence the attractiveness of public transit when travellers choose this travel mode. For example, the number of transfers disadvantages metro use when travellers have a choice between metro and taxi (Li et al., 2018). Therefore, improved design and operation of transfer facilities can increase the attractiveness of public transport, including metro (Zhao et al., 2019). Compactness and shortening walking distances is also important to inter-modal transfer hubs. In addition, connectivity is still a common challenge in developing public transit systems. The provision of varied feeder modes (e.g. cycling, bus, car, walking and taxi) and high-quality feeder transit services connecting to metro systems is a possible solution for the challenge and would increase both the attractiveness of metro transport and passenger satisfaction (Guo & He, 2020; Lin et al., 2019). The integration of various transport modes to improve access and egress trips related to metro stations has drawn global attention.

In metro cities, travellers use various modes, such as bus, rail, car, walking, bicycle, and taxi, to access or egress metro stations. Commuting by transferring within the public transit network (including metro, rail and bus) is a green and sustainable travel choice compared to private car use, and needs to be promoted when direct transit lines are unavailable to the travellers to reach their destinations (Ye et al., 2018). Walking is a primary transport mode to access or egress metro, and has healthy benefits and environmentally friendly features that meet sustainable development goals (Bivina et al., 2020). In the urban periphery, where bus services are less developed and metro stations are not accessible by walking, bicycles and taxis become important transfer modes. Residents living in suburban areas use bicycles or taxis to the nearest metro station, and then travel by metro to maximise travel efficiency and cost-effectiveness (Ni & Chen, 2020). Cycling as a transfer mode for short-distance trips to and from transit stations is regarded as an important solution to the “first and last mile” problem for metro services (Zhao & Li, 2017). In addition to traditional bicycles, to increase the use of bikes as a feeder mode for metro, many cities have developed station-based bike-sharing systems or dockless bike sharing (DBS, also called free-floating bike sharing systems) systems. These systems encourage bike use by travellers without the worry of costs associated with purchase and maintenance of private bicycles, and reduce car travel via

77 driving or taxi. In particular, DBS features flexible pick-up and drop-off anywhere and is used on demand via
78 apps on smart phones for locating the nearest bike (Ni & Chen, 2020), enhancing the convenience and
79 affordability of bike use for metro transfers.

80 Metro systems, as the backbone of urban transport systems, are planned holistically, with transport, economic,
81 environmental, social, and technical considerations playing equally important roles (Volchko et al., 2020). Clear
82 understanding of transfer options and public perceptions is important not only for transport planning, but also
83 for urban strategic planning. Intermodal transfer acceptance and convenience for passengers are important
84 elements in urban transport mode policy, and urban sustainability strategy in general. Given the importance of
85 metro transport, the rapid development of metro systems in recent years, and the complex situation of metro-
86 related transfers involving various transport modes, empirical studies on metro-related transfers have been
87 plentiful in recent years. This provides an opportunity to conduct a literature review to synthesise the current
88 status of knowledge about transfers between metro and other travel modes, identify key arguments and aspects
89 of existing studies, and suggest future research directions. This paper reviews the literature on transfers between
90 metro and other transport modes. It explores issues surrounding metro-related transfers using public, private
91 and active transport modes, examining the role of metro-related transfers in transport networks. Transfers
92 included in this review are metro-metro, metro-bus, metro-rail, metro-taxi, metro-bike, metro-walking and
93 metro-car transfers. The research aims to answer the following questions: (1) what is the travel behaviour of
94 travellers transferring between metro and other transport modes, and do they have characteristic transfer
95 behaviours?; (2) how do they perceive their transfer experiences, and are they satisfied with transfer facilities
96 and services?; and (3) what are the factors influencing metro-related transfer behaviour?

97 ## 2. Methodology

98 This paper reviews articles derived from searches of major databases, including Science Direct and Google
99 Scholar. Search terms were identified from existing literature and through the expertise of the research team.
100 The search terms included “metro”, “subway”, “underground railway”, “transfer”, “travel behaviour”, “travel
101 behavior”, “perception”, “satisfaction”, “metro-metro”, “metro-bus”, “metro-rail”, “metro-taxi”, “metro-bike”,
102 “metro-walking”, “metro-car” and “park & ride” (P&R). We focused on transport studies, travel behaviour,
103 transport and environment, and planning and design aspects. Since the purpose of this paper is to review the

recent literature, synthesise the current status of knowledge about metro-related transfers, and identify evidence to answer research questions, we focused on empirical studies since the year 2000. Only English articles were selected. In the abstract and full-text screening processes, studies were excluded if they do not discuss transfers involving metro or do not provide empirical evidence about the research topic. Articles were cited according to the relevance and value of the articles to the research questions.

The framework of this review paper on metro-related transfers is shown in Figure 1. In line with the research questions, this review mainly focuses on three aspects of metro-related transfers: travel (transfer) behaviour, influencing factors of metro-related transfers, and travellers' perceptions and satisfaction. Specifically, travel behaviour studies include those that investigated passengers' transfer behaviour (e.g. mode choice, travel time, travel distance, origin and destination, and travel purpose); studies on influencing factors of metro-related transfers include those that examined socio-economic (e.g. income, education, and employment) and demographic (e.g. gender and age) factors, the built environment (e.g. land use, and transport infrastructure and service), the natural environment (e.g. weather), and other factors (e.g. technology); and studies on travellers' perceptions and satisfaction include those assessing transferring conditions and quality (e.g. safety, accessibility, comfort, convenience, and amenities). The framework of the review is shown in Figure 1.

It is unsurprising that the majority of the literature identified and reviewed comprises studies from Asia. The reason is that Asian cities have contributed significantly to the rapid growth of metro development and operation in the last two decades (UITP, 2018). A summary of the literature reviewed (40 publications) is shown in Table 1. Studies focus on transfer behaviour (21 publications), the influence of the built environment on transfer behaviour (19 publications), the influence of other factors on transfer behaviour (17 publications), and travellers' perceptions and satisfaction (15 publications). Existing studies employed different types of data (e.g. smart card data, big data, questionnaire survey data, and household travel survey data) to investigate metro-related transfers. Generally, questionnaire survey data and household travel survey data have individual and trip attributes, but sample size is small compared with smart card data, which generally have no personal attributes. Smart card data can be used to explore the spatial (e.g. orientation of connections, and core area vs suburban area) and temporal (e.g. seasonal, monthly and daily) variations in transfer behaviour. Different research methods were applied by previous studies. Most studies conducted descriptive statistical analysis that is appropriate for

describing the actual transfer behaviour. Some studies used different models (e.g. route choice models, mixed logit models and multinomial logit models) to analyse the mode or route choice behaviour in detail. Perception and satisfaction were analysed overwhelmingly by regression analysis of questionnaire survey data. The following sections discuss findings from the review to answer the research questions of this paper. The discussion is organised into three main sections: (1) metro-related transfer behaviour and its influencing factors, (2) travellers' perceptions and satisfaction, and (3) the built environment and transfer behaviour.

3. Metro-related transfer behaviour and influencing factors

This section discusses findings from 21 publications on metro-related transfer behaviour and its influencing factors (except for the built environment). A summary of travel behaviour literature is shown in Table 2.

3.1 Transfers between metro and active transport

Sun et al. (2016) conducted a case study on metro-walking transfers in Beijing, China and found that the mean walking time from a metro station to a destination was 8 min., with the walking time consistent for different types of destinations (e.g. recreational, office, and residential destinations). Walking was found to be the most important egress mode of metro transfer trips in Nanjing, China (Wu et al., 2018; Yang et al., 2014), and is particularly suitable for short egress trips within 1 km, and somewhat suitable for trips between 1 and 3 km. Travel time considerably influenced walking as the metro egress mode, for both males and females (Wu et al., 2018).

Metro-bike(share) transfer has been a focus of recent metro-related transfer research. One possible reason is that recent metro development occurred primarily in Asian countries where cycling is used as a major transport mode to access or egress metro stations. An increase in bike sharing also contributes to using cycling for metro transfers. When used as a metro transfer mode, cycling is characterised by short travel distance and time, used for trips with purposes that are not time-sensitive or moderately time-sensitive, and used particularly in morning peak "first-mile" transfer trips. Most passengers completed bikeshare rides within 2 km in Nanjing and Shanghai (Ji et al., 2018; Lin et al., 2019). An access distance between 1 and 3 km is positively associated with cycling to metro stations in Nanjing, while for electric bikes, commuters were more likely to ride 1-5 km for metro access trips (Wu et al., 2018). Riding distance was negatively related to metro-bikeshare transfer demand (Ji et

al., 2018). However, it is worth noting that the link between bike transfer choice and travel distance to metro stations is not linear: if travel distance is within a reasonable cycling range (about 1-5 km in Beijing's case), cycling is chosen; if the travel distance is above 5 km, motorised transfer modes are chosen; and if the travel distance is below 1 km, walking is chosen (Zhao & Li, 2017). The average travel time to ride a bike to or from a metro station was 8.2 min. with 77% of the trips being less than 10 min. in Shanghai (Lin et al., 2019). This is consistent with the finding in a Nanjing study that commuters preferred to use bikeshare as a feeder mode to transfer to or from metro when the cycling time was below 10 min. (Liu et al., 2020). Very few passengers (5%) ride a bikeshare bike for 30 min. or more for metro transfers in Nanjing (Ma et al., 2018). Cycling, as a transfer mode to access or egress metro stations, tended to be chosen for trips with purposes that are not time-sensitive (e.g. visiting friends and shopping) and moderately time-sensitive (e.g. school and work) rather than trips with purposes that are highly time-sensitive (e.g. business) in Nanjing, China (Chen et al., 2012).

Spatial and temporal characteristics can impact metro-bike transfer behaviour. In Shanghai, DBS was widely used for commuting purposes during morning and evening peaks, particularly in the morning, possibly because after work, more free time is available for travellers to choose alternative ways, such as walking, for metro transfers (Lin et al., 2019). There were relatively fewer bikeshare transfer trips in Nanjing on weekends than on weekdays (Ma et al., 2018). The trip duration using DBS for metro transfers in the morning travel peak on weekdays is shorter than that in the evening peak and on weekends in Shenzhen, China (Li et al., 2020).

The majority of DBS transfer trips in Shanghai were generated in the dense urban area, suggesting the locations of metro users (Lin et al., 2019). In Shenzhen, the core area had more and denser metro-DBS transfer trips, and a higher share of short-duration trips (up to 7 min.) of all metro-DBS transfer trips, compared to suburban areas. One possible reason is that the distribution density of DBS and the density of metro stations in the core area are much higher than those in suburban area. In addition, compared with suburban areas, the land use and intensity of developments in metro station areas in the core area better facilitate metro-DBS integration (Li et al., 2020). Most bikes were parked at bike-metro transfer facilities in the late morning or early afternoon for half a day (4-6 hours) for a metro station in a commercial district, or in the morning for the whole working time period (8 hours and over) for a metro station in a residential district. This possibly relates to work, school, or shopping trip purposes (Chen et al., 2012).

184 The influences of demographic and socioeconomic factors on metro-bike transfers have been given great
185 attention. Wu et al. (2018) found that with ageing, the likelihood of choosing cycling to access metro decreased.
186 Men were less likely to choose cycling to metro stations rather than driving than women (Zhao & Li, 2017).
187 This is somewhat inconsistent with the finding of Wu et al. (2018) that males were statistically more likely to
188 cycle as a metro access mode. Females were positively associated with using electric bikes to access metro
189 stations, while high education was negatively associated with electric bike as an access mode choice (Wu et al.,
190 2018). Middle- and high-income travellers were more likely to cycle than take a bus to metro stations. Those
191 who own cars were less likely to ride bicycles and more likely to drive to metro stations (Zhao & Li, 2017). Wu
192 et al. (2018) found that household electric bike ownership was negatively related to using cycling to access
193 metro stations in Nanjing. Chen et al. (2012) found that between walking and cycling, age, gender, income and
194 bike ownership were not significant determinants of transfer mode choice; and between bus and bike, age,
195 gender, and bike ownership were not significant determinants.

196 Social differences with regard to metro-bikeshare transfers have been examined. There were no significant
197 differences in travel distance and time between males and females, locals and non-locals, and various age groups
198 in a Nanjing study (Ma et al., 2018). Gender (females) did not have a significant influence on DBS use for metro
199 transfers in Beijing (Ni & Chen, 2020). Private bike ownership affected metro-bikeshare use by young
200 commuters: the higher the private bike ownership, the higher the likelihood for them to frequently choose metro-
201 bikeshare for metro transfers. A possible reason is that bike owners mostly have a positive attitude towards bike
202 use, and thus are more likely to choose metro-bikeshare as a travel mode (Liu et al., 2020). An experiment in
203 Kaohsiung, Taiwan examined hypothetical bikeshare services and found that low-income earners, the middle-
204 aged, and local residents owning more than one motor vehicle were less likely to use bikeshare after exiting a
205 metro station, while those who were employed in industry and commerce, and who had bikeshare experience
206 were more likely to use bikeshare to exit from a metro station (Cheng & Lin, 2018).

207 Travellers' attitudes and preferences can also impact metro-bike transfers. In Beijing, travellers with a
208 preference for low-cost travel were more likely to cycle to metro stations, after controlling for socio-economic
209 variables. Travellers who like driving were more likely to travel to metro stations by cars than bicycles (Zhao
210 & Li, 2017). The natural environment (e.g. meteorological conditions) influences metro-bike transfer behaviour.

Compared with cloudy weather, bad weather conditions (e.g. foggy and rainy weather) reduced the trip duration of metro-bike transfers in suburban areas in Shenzhen. It is likely that travellers gave up long-distance metro-bike transfer trips due to bad weather conditions. Compared with sunny weather, cloudy weather increased the trip duration of metro-bike transfers in the core area. It is likely that travellers undertook longer metro-bike transfer trips because cycling is comfortable in cloudy weather conditions (Li et al., 2020) because of Shenzhen's subtropical climate.

3.2 Transfers between public transport modes

The median intermodal transfer time between metro and bus varied in different cities. In Rennes, France, the transfer time from bus to metro was very low, with the median time between 2 and 3 min. while it increased to 12-13 min. from metro to bus (Richer et al., 2019). The average intermodal transfer time between metro and bus was also low in Seoul, Korea, about 8 min., consisting of walking time (5 min.) and waiting time (3 min.) (Lee et al., 2019) while the median transfer time from metro to bus was below 20 min. in Nanjing, China (Zhao et al., 2019). Bus was the dominant mode for comparatively long metro transfer trips exceeding 3 km in Nanjing. Increased travel time significantly decreased the likelihood of commuters selecting bus to access metro stations, possibly due to the comparatively low reliability of bus services (Wu et al., 2018). Females and older commuters were positively associated with using bus for accessing metro stations, while high income was negatively associated with bus access mode. For egress trips, age was positively associated with bus transfer mode (Wu et al., 2018).

A few studies investigated metro-rail and metro-metro transfers. Guo and Wilson (2007) compared metro-rail and metro-metro transfers in Boston, US and found high transfer penalties (longer transfer times) of the two types of transfers (between 8.5 and 17 min. of walking), while a higher transfer penalty was found in metro-rail transfers than metro-metro transfers. The higher transfer penalty for metro-rail transfers was caused by poor connection and design of transport infrastructure. Pass holders, who enjoy free access to metro, had 3.7-3.8 minutes' lower transfer penalties compared with cash payers (Guo & Wilson, 2007). For metro-metro transfers, the average transfer penalties in London metro and in Santiago metro were 7.0 min. and 10.2 min. respectively. The larger metro system in London resulted in more transfer possibilities and travellers in London were more used to transferring (Raveau et al., 2014). Moreover, overcrowding is a severe problem in many parts of London

metro, causing many metro users to use transfers to avoid overcrowding, although the decisions may be unreasonable in the context of minimising transfer time (Guo & Wilson, 2011).

For taxi as a metro transfer mode, there were no obvious differences with regard to transfer proportion and trip direction (from or to metro) during morning and evening peaks in Beijing, China. The majority of metro stations with high ridership of taxi as a metro transfer mode were located in residential and employment areas. The direction of the trip (to or from the metro) did not influence taxi transfer ridership. Females in Beijing were more willing to ride a taxi to metro transfer than males (Ni & Chen, 2020).

3.3 Transfers between metro and private transport modes

A Nanjing study found that long distance (3-5 km and 5+ km) was positively associated with car use for accessing metro stations. Car commuters were highly sensitive to travel time for accessing metro stations, and travel time was negatively related to car use, possibly because drivers value time more highly than other mode users (Wu et al., 2018). Transit station choice for P&R users was primarily determined by access distance and the relative station direction (from their homes to their workplaces) in Greater Toronto and Hamilton Area, Canada. Among the two factors, the influence of changes in station access distance was more significant than changes in the relative station direction to their workplaces. Regional P&R users were more sensitive to access distance than local P&R users (Mahmoud et al., 2014). Being male and having driving licenses were positively associated with car use for metro access (Wu et al., 2018). Technology such as Smartphone multimodal traveller information systems (SMTIS), significantly affected commuter drivers' decisions on changing from driving to P&R in Shanghai, China. Demographic and socio-economic factors (e.g. gender, age, education level, income), and P&R use experience influence the impacts of SMTIS (Gan & Ye, 2018).

3.4 Comparing different transfer modes of metro users

Zhao and Li (2017) compared metro transfer trips using various travel modes in Beijing and found that, with an increase of distance to metro stations, the likelihood of driving or travelling by bus increased compared with cycling. This suggests that when people live or work within a feasible cycling distance from metro stations, cycling is an attractive transfer mode. Yang et al. (2014) found for all metro travellers, averagely, more than a half of the total trip duration (metro travel duration and transfer trip duration) spent on transfer trips. The average

duration of a trip accessing metro stations (14.1 min.) was slightly longer than that of a trip exiting metro stations (12.1 min.). Bus users had longer commuting times and spent a higher proportion of commuting times on transfers than other mode users. Most metro commuters who used various transport modes for accessing and egressing metro stations were young adults, commuters with college/bachelor degrees, travellers living in the suburban areas, and those working in central locations.

4. Travellers' perception and satisfaction

Many studies examined travellers' perceptions of and satisfaction with metro-related transfers, since these types of information are significant for identifying the merits and shortcomings of existing transport networks and their planning, design and management, and therefore, finding appropriate approaches to improve the environment and services of metro-related transfers to enhance travellers' transfer experiences. Interestingly, most studies focused on cities in developing countries and regions. One possible reason is that compared to developed countries and regions, transport infrastructure and services of developing countries and regions are still under development, particularly in the context of rapid urbanisation, motorisation, and population growth. Depending on the types of transfer modes, passengers' perceptions and satisfaction have been investigated with regard to cost (e.g. ticket fare and time cost), safety and security, accessibility, connectivity, comfort (e.g. walking environment), performance/service (e.g. waiting time), infrastructure and facilities, design (e.g. accessible design, signage, and aesthetic appeal), amenities, and the impacts of demographic and socio-economic characteristics on travellers' perceptions and satisfaction. A summary of studies on travellers' perceptions of and satisfaction with metro-related transfers is shown in Table 3.

4.1 Transfers between public transport modes

Safety and security around metro stations, bus stop accessibility, connectivity between the subway station and the bus stop, and the reliability and performance of bus services were reported to be the most important conditions that significantly affected commuters' overall transfer experience in Bangkok, Thailand (Cherry & Townsend, 2012). This finding is consistent with Cheng and Tseng's (2016) finding in Kaohsiung, Taiwan that the enhancement of perceived value (e.g. convenience, accessibility, and high-quality service) was a priority for travellers during their metro-bus transfers. In addition to perceived values, perceived transfer penalties (e.g. due

to poor connectivity and service, low comfort level and high time cost) and free bus transfer were also important influencing factors on passenger transfer intentions (Cheng & Tseng, 2016). Comparatively, physical amenities (e.g. signage, bus shelter, and sidewalk quality) were less important (Cherry & Townsend, 2012).

In Santiago, Chile, commuters reported disutility of intermodal station transfers, since the few intermodal stations that were available in the city had very crowded transfer environments and long waiting and walking times during rush hours (Navarrete & Ortuzar, 2013). After the city launched a new metro line, comparatively negative perceptions of intermodality and transfers were reported by metro users, possibly due to the depth of new metro tunnels and platforms, since they were constructed below the existing metro network. Therefore, passengers must spend considerable time using stairs, escalators or elevators in their transfers (Pineda & Lira, 2019). Commuters valued the availability of an escalator, particularly when their transfers involved station-level changes. For both males and females, the more transfers travellers have to make, the higher the valuation of escalator availability; females more preferred the availability of escalators than males. Among different transit transfer combinations, metro to metro and metro to bus were preferred, compared with bus to metro and bus to bus, indicating that metro, as a superior mode, was preferred as the main component of the journey (Navarrete & Ortuzar, 2013).

4.2 Transfers between metro and active and private transport modes

Research on travellers' perceptions of and satisfaction with transfer metro and active transport focuses on metro and walking transfers. A high-quality walking environment that enhanced comfort, security and pleasure could offset the negative effects of longer walking times in Xi'an, China (Li et al., 2017). This is consistent with a study in Delhi, India, that travellers' perception of walking accessibility to metro stations can be better explained by their satisfaction with various factors of the built environment than walking distance to metro stations (Bivina et al., 2020). In addition, the built environment factors at the microscale (e.g. comfortable walking environments, high-quality walking infrastructure and facilities, and accessible design) had more significant impacts on perceived walking accessibility, compared with the built environment factors at the mesoscale (e.g. population and employment densities and land use diversity) (Bivina et al., 2020).

315 In a case study of Kolkata, India, Sadhukhan et al. (2015) found that pedestrian environment and visual
316 communication were perceived to be more important than the ticket fare or direct cost, an interesting finding
317 that is inconsistent with the common belief that the ticket fare (cost) is the primary concern of public transport
318 systems in developing countries like India. A possible reason for this perception is that aggressive vendor
319 activities occupied pedestrian walkways near metro stations, resulting in a poor pedestrian environment and low
320 level of comfort of walking to and from metro stations. Signage to direct passengers to other transport mode
321 stops in some metro stations were missing. A Beijing study indicated that perceived greater visual connectivity
322 was related to shorter walking time. Perceived barriers to crossing the street (e.g. extreme street width, bridges
323 or stairs to underground passageways, and wide intersections often lacking medians) negatively impacted on
324 walking access to metro stations. Aesthetic appeal of the pedestrian realm affected walking time, and better
325 design of the walking environment related to better walking access (Sun et al. 2016). Car ownership influenced
326 metro commuters' perceptions with regard to the importance of transfer facility attributes at metro stations in
327 Kolkata city, while gender did not show this influence (Sadhukhan et al., 2018). Age and vehicle ownership
328 moderately and positively affected perceived walking accessibility, while trip purpose had a negative influence.
329 Income positively impacted on perceived walking accessibility (Bivina et al., 2020).

330 Travellers' perceptions about the choice of P&R for metro transfers (car-metro and bike-metro transfers) was
331 examined. Generally, commuters tended to use P&R to pay less in Shanghai, China. If commuters believed the
332 cost of P&R exceeded the cost of driving, most of them would not use P&R; if commuters believed the travel
333 time of using P&R was the same as or just little more than that of driving a car, most tended to use P&R. Income
334 and age were negatively related to using P&R; people with lower income and younger travellers were more
335 likely to choose P&R. Time sensitivity had significant impact on the use of P&R, and travellers with urgent
336 time schedules preferred P&R. Comparatively, the impact of cost sensitivity was not very significant. Therefore,
337 reducing travelling time was more effective in attracting more P&R users than reducing travelling costs (Liu et
338 al., 2012).

339 ### 4.3 Comparing different transport modes of metro users

340 Yang et al. (2014) found that facility service qualities, as the primary factors in both access and egress, influence
341 the overall satisfaction of metro-related transfers in Nanjing. Escalators were highlighted as important transfer

facilities in Beijing. The installation of escalators, adding more escalators and better management of escalator use were listed as the top three requirements from travellers (Ji et al., 2013). This is possibly because of Beijing metro's long operation history of more than half a century; escalators are not always available or convenient to use at old metro stations. Commuters' perceptions differed with regard to influencing factors on transfers with the same access or egress mode (Wu et al., 2018; Yang et al., 2014). For example, bike-metro-bus users had low average perceptions of bike parking safety, while bike-metro-walk users valued parking spaces near metro stations. Bus-metro-bus users reported a negative perception about crowded spaces on buses (comfort) in the access stage, while bus-metro-walk users valued the reliability of bus services (Yang et al., 2014). Compared with commuters using other transport modes, commuters using metro always have a higher time sensitivity and have a lower perceived transfer disutility (Ye et al., 2018).

5. The built environment and metro-related transfers

The impact of the built environment of the metro station area on metro-related transfers is examined by many studies. Studies focused on built environment factors including density (e.g. population density, job density and car density), diversity (e.g. mixed land use and job-housing balance), design (e.g. accessible design), destination accessibility or transfer distance (time), connectivity, land use (e.g. type, number and percent), transport infrastructure and facilities, and transport service. A summary of studies on the impacts of the built environment on metro-related transfers is shown in Table 4.

5.1 Transfers between metro and active transport

Existing studies examined accessibility and connectivity impacts on metro-walk transfers. Physical obstacles to crossing streets increased walking time, while greater connectivity decreased walking time. Greater connectivity and pedestrian-friendly designs in metro station areas may facilitate walking access to metro stations (Sun et al. 2016). How the built environment impacts on metro-bike transfers is the focus in research on the built environment and metro-related transfers. Accessibility was believed to be a key determinant of metro-bike transfer behaviour. The frequency of bicycle-metro trips was positively related to a trip distance of no more than 500 m and was negatively related to a trip distance of more than 500 m (Wu et al., 2019b). Transfer distances

were negatively associated with DBS use in Shenzhen (Guo & He, 2020) and bikeshare use in Beijing, Taipei and Tokyo (Lin et al., 2018) for metro transfers.

Land use (e.g. type, number, percent) was found to be an influencing factor on metro-bike transfer behaviour. Mixed land use was positively associated with the use of bikes for metro transfers in Shenzhen. Residential land use encouraged the use of bikes to access metro stations during the morning peak. Industrial land use had a positive association with metro-bike integration. Parks and public squares increased the likelihood of use of DBS for both metro access and egress trips during peak times (Guo & He, 2020). This finding is consistent with another study in Beijing that found that the number of public parks was positively associated with the use of bikes to and from stations. The friendly cycling environment provided by parks (e.g. less traffic and fewer car-cycling conflicts, and no waiting for traffic lights) encouraged cycling behaviour (Zhao & Li, 2017).

Recreational land use encouraged metro-bikeshare transfers since travellers whose trip origin or destination was recreational land were more likely to use bikeshare for metro transfers in Nanjing. Although traffic congestion might be a problem around recreational locations for cyclists, the relatively higher density of bikeshare stations allowed easy access to bikeshare by travellers, particularly for those who preferred cheap and time-saving modes (Ji et al., 2018). This finding is inconsistent with that of a Beijing study that found the number of shopping destinations was negatively associated with the likelihood of cycling to or from the metro station by commuters (Zhao & Li, 2017). One major reason might be that the concentration of shopping destinations decreased land use heterogeneity in metro station areas, discouraging cycling activities. Meanwhile, a concentration of shopping malls in the metro station area encouraged walking (and shopping) behaviour. In the suburbs with a large number of shopping malls in the metro station area, a large number of free parking spaces were usually available and thus encouraged the use of cars (Zhao & Li, 2017).

Metro stations that were closer to the city centre and used by a higher number of passengers had more use of DBS for metro transfers (Guo & He, 2020). Commuters whose home or workplace was close to a suburban metro station, compared with those whose home or workplace was close to a metro station in the city centre, were more likely to drive or travel by buses than cycle for metro transfer trips in Beijing. A possible reason was that compared with the city centre, in suburbs the distances to metro stations were usually longer, and the cycling facilities and services were fewer (Zhao & Li, 2017).

Density impacts on metro-bike transfers. The population density of the metro station areas significantly influenced travellers' intentions of using bikeshare for metro egress trips (Cheng & Lin, 2018). Compared with Taipei, population density and student density had more positive associations with bikeshare use, and transfer distance had fewer positive associations with bikeshare use in Beijing; population density had more negative associations with bikeshare use in Tokyo (Lin et al., 2018). On weekends, the population density in the suburbs was positively associated with access duration, due to insufficient metro facilities, resulting in longer access duration in Shenzhen (Li et al., 2020).

Transport infrastructure and facilities in metro station areas also considerably affect the choice of cycling for metro transfers. The length of local roads was positively associated with the likelihood of using cars rather than bikes in a Beijing study, possibly because many local roads in the station area encouraged motorised travel (Zhao & Li, 2017). The length of branch roads was negatively related to cycling access duration; the impacts were significant in the core area for weekdays, weak in the suburb for weekdays, and weak on weekends (Li et al., 2020). Dedicated bike lanes were positively associated with DBS use for metro transfers in Shenzhen (Guo & He, 2020). This is inconsistent with another study in Beijing that found the length of exclusive cycling lanes was not associated with using cycling for metro transfers, an unexpected finding possibly due to the fact that exclusive bicycle lanes were often occupied by cars as parking spaces in Beijing, particularly near metro stations (Zhao & Li, 2017). The length of bicycle lanes did not significantly reduce access duration of DBS (Li et al., 2020). Areas with dense metro distribution and main streets with many intersections were negatively associated with DBS use for metro transfers (Guo & He, 2020). On weekends, the number of road intersections was positively related to access duration, and the impacts were less significant on weekends due to less congested roads. On weekdays, the number of major roads was positively associated with access duration (Li et al., 2020). The availability of motorcycle parking spaces significantly impacted on travellers' intentions of using bikeshare for metro egress trips (Cheng & Lin, 2018). Bike P&R spaces significantly impacted on metro station ridership (Zhao et al., 2013).

Transport services in metro station areas are found to be a vital determinant of cycling for metro transfers as well. The number of public bikes in the station area was positively associated with commuters' use of cycling for metro transfers in Beijing (Zhao & Li, 2017). Bus stops was positively associated with bike use for metro

transfers in Shenzhen (Guo & He, 2020). This is inconsistent with the findings of Zhao and Li's (2017) study in Beijing and Ji et al.'s (2018) study in Nanjing which found that the availability of many bus lines (bus density) increased the likelihood of using bus rather than cycling (Zhao & Li, 2017). The density of other metro stations in a metro station area was negatively associated with the transfer demand of bikeshare at the metro station. The possible reason is that the density of metro stations was significantly and positively related to local development level and high density, which often indicate heavy road traffic and potential high risk of injury for cyclists, therefore, discouraging bikeshare use (Ji et al., 2018). The density of bikeshare stations in the metro station area was positively associated with bikeshare use for metro transfers (Ji et al., 2018). Larger bike catchment areas were related to better metro service, more frequent morning trips, more diverse users, and larger distances to the city centre and terminal stations, but less dense metro stations (Lin et al., 2019). The road congestion level was positively related to access duration on weekdays, and impacts were less significant on weekends due to less congested intersections on weekends. The number of metro entrances and exits was significantly and negatively related to access duration in the suburbs (Li et al., 2020).

5.2 Transfers between metro and other transport modes

Population density positively affected metro-bus transfer efficiency while the density of companies negatively affected transfer efficiency between metro and bus in Seoul, Korea (Lee et al., 2019). Case studies in Nanjing (Zhao et al., 2013), Shanghai (An et al., 2019) and Taipei (Lin & Shin, 2008) indicated that the numbers of feeder bus lines and bus stops significantly and positively impacted on metro ridership, suggesting that convenient metro-bus transfer promotes metro use. More edges between the access bus points within the walkable area of a metro station entrance and other bus stops increased the level of accessibility of the metro station areas and metro-to-bus intermodal transfers (Wu et al., 2019a).

With regard to metro-metro transfers, the length of the transfer passage negatively impacted on metro-metro transfer efficiency and reduced the likelihood of metro use in Seoul. The new metro lines connected to existing transfer stations that were not designed for such expansion resulted in longer transfer passage and reduced transfer efficiency (Kim et al., 2017). For London Underground, the oldest metro system in the world that has operated since 1863, the availability of an escalator, the longer ramps, and transferring at the same level improved travellers' transfer experience in such an extensive network (Guo & Wilson, 2011).

With regard to P&R, the number of parking lots negatively affected metro ridership on weekends, indicating that convenient parking facilities discourage public transit usage (An et al., 2019). Access distance significantly affected transit station choice for P&R users in Greater Toronto and Hamilton Area, Canada (Mahmoud et al., 2014). With regard to taxi, population density, the number of residences and offices, and economically developed areas (measured by housing prices) positively influenced taxi use, and the number of nearby metro stations negatively impacted on taxi transfer ridership. Commuters in the central areas with high housing prices and well-developed arterial road network preferred taxi, especially during the evening peak (Ni & Chen, 2020).

6. Discussion and conclusion

This paper reviews recent literature on metro-related transfers, and summarises and discusses key findings and issues regarding transfer behaviour, influencing factors related to metro-related transfers, and travellers' perceptions of and satisfaction with these transfers. The review findings and the recommendations from the review are summarised in Figure 2 and discussed below.

This research identified the characteristics of travel behaviour of metro-related transfers. Metro-bike(share) transfer has been a focus in recent metro-related transfer behaviour research. When used as a metro transfer mode, cycling is characterised by short travel distance and time, used for trips with purposes that are not time-sensitive or moderately time-sensitive, and used particularly in morning peak "first-mile" transfer trips. Walking is an important travel mode for metro transfers and most suitable for short trips (e.g. within 1 km walking distance or around 8 min. walking time) to different types of destinations. Travel time significantly influenced walking as a metro egress mode. The median intermodal transfer time between metro and bus varied in different cities, ranging from 2 min. to 20 min., and bus was the dominant mode for comparatively long metro transfer trips exceeding 3 km. However, existing studies rarely discussed weekday, holiday and time-of-year differences in metro-related transfers. Considering that people's travel behaviour (e.g. trip purpose, travel time and duration, and trip destinations) on holidays may be very different from that on weekdays, and people may have different travel patterns at different times of the year, these issues may form the basis of future research topics. In addition, existing studies mainly focused on the influence of socio-economic and demographic factors on metro-related transfers, but few studies examined other factors such as the natural environment (Li et al., 2020) and technology

(Gan & Ye, 2018). Future studies are needed to further investigate additional factors and comprehensively consider the impacts of different types of influencing factors on metro-related transfers.

With regard to travellers' perceptions of and satisfaction with metro-bus transfers, safety and security around metro stations, bus stop accessibility, connectivity between the subway station and the bus stop, and the reliability and performance of the bus service significantly affected commuters' overall transfer experience. Perceived values, perceived transfer penalties and free bus transfer are also important influencing factors on passenger transfer intentions, while physical amenities are less important. Crowed transfer environments, long waiting and walking times, and deep metro platforms result in negative perceptions of transit transfers. With regard to transfers between metro and active transport modes, comfortable walking environments, visual connectivity, high-quality walking infrastructure and facilities, and accessible design significantly impact on walking accessibility. Age, income and vehicle ownership affect metro commuters' perceptions about metro-walking transfers. Commuters tend to use P&R due to affordability. Income and age are negatively related to using P&R. Time sensitivity significantly impacted the use of P&R, while cost sensitivity was not very significant.

There are important implications for improving travellers' perceptions of and satisfaction with these transfers. For example, research indicates that reducing travelling time was more effective in attracting P&R users than reducing travelling costs. Policies or initiatives focusing on reducing P&R users' travelling time can facilitate the switch from driving to more sustainable transport modes for parts of commuters' journeys. Obviously, many metro passengers will have to transfer to other transport modes to complete their journeys after exiting metro stations. Across different transport modes, generally, safety and security around metro stations have been highlighted as significantly impacting on travellers' perceptions of and satisfaction with metro-related transfers, particularly in developing countries like India. Facility service quality (e.g. escalators, comfort, accessibility and reliability of feeder modes) influence overall satisfaction with metro-related transfers. Comparatively, the ticket fare/ direct cost and physical amenities (e.g. signage, shelter, and sidewalk) are less important. There are many potential planning and design strategies that may improve travellers' perceptions of and satisfaction with metro-related transfers. For example, metro station areas can be treated as public realms, designing the physical form of these areas for public space use, considering the urban context and how the station areas fit together

with other elements of the urban form, and developing metro station areas to meet the desired planning and design objectives that are preferred by commuters. The service quality of infrastructure and facilities for metro-related transfers is an important research topic. Questions regarding how to increase time efficiency, safety and security, thus improving travellers' perceptions of and satisfaction with these transfers, require further investigation. Existing studies mainly focused on performing cross-sectional studies and presenting short-term results related to commuters' perceptions and satisfaction, as well as factors that influence metro-related transfer behaviour. Future research using longitudinal studies is needed to better understand metro-related transfers.

This review also shed light on factors that affect metro-related transfers. Commuters' demographic and socio-economic characteristics were associated with bus access and egress travel. Females and older commuters were positively associated with using bus for accessing metro stations, while high income was negatively associated with bus access mode. For egress trips, age was positively associated with bus transfer mode. High transfer penalties exist in metro-rail and metro-metro transfers. The ownership of transit passes decreased transfer penalties. Metro stations located in residential and work areas have high ridership of taxi as a metro transfer mode. Gender difference exists with regard to using taxi for metro transfers. For example, females in Beijing were more willing to ride a taxi to metro transfer than males. Long distance is positively related to car use for accessing metro stations, while travel time is negatively associated with car use. Gender and technology influence the use of cars for metro transfers.

Built environment affect metro-related transfers. Accessibility and connectivity impact on metro-walk transfers. Great connectivity and pedestrian-friendly designs in metro station areas facilitate walking access to metro stations while physical obstacles to crossing streets increase walking time. Accessibility, land use, density, transport infrastructure and facilities, and transport services are key determinants of metro-bike transfer behaviour. Density and bus infrastructure and service affected metro-bus transfer. The types of metro stations, the length of the transfer passage, the availability of an escalator, longer ramps, and transferring at the same level impact on metro-metro transfers. With regard to taxi, population density, the number of residences and offices, and economically developed areas positively influenced taxi use and the number of nearby metro stations negatively impacted on taxi transfer ridership.

These findings also offer policy recommendations on aspects of the built environment that could facilitate transfers between metro and other travel modes. For example, to encourage cycling and walking – both cheap, healthy, convenient, and sustainable transport modes – for metro transfers, the focus needs to be on the areas in close proximity to metro stations. Transit-oriented development (TOD) policies are promising approaches for promoting mixed land use, high-density developments and good connectivity, resulting in short distances between metro stations and residential or job locations, facilitating the use of walking and cycling for metro transfers; TOD has been implemented in many cities with emerging metro services. The study of metro-related transfers in TOD precincts would be a useful future research direction. In addition, an obvious substitution effect between cycling and bus use have been found at metro station areas with regard to metro-related transfers. Considering the characteristics of cycling and walking as metro transfer modes, the distribution of bus stations/stops at metro station areas may play an important role in affecting travellers' choice of transfer mode. An improvement in feeder bus services at station areas may have the result of decreasing metro-cycling transfers. This is a dilemma facing policy-makers, particularly in cities where bike-transit integration may be an approach to the "last mile" problem for metro and rail services. The effects of various metro-related transfer modes on other transfer modes require future investigation. In addition, comparative studies involving two or more cities would provide significant insight into metro-related transfers.

This review contributes to the planning of metro transport, a key public transport mode (especially in mega cities), with emphasis on the integration of metro with the whole transport network via promoting smooth transfers between metro and other transport modes. This study contributes to a better understanding of metro-related transfers and the value of promoting metro transport and public transit towards sustainable development goals. The paper provides important policy guidance for the integration of public transit and active and private transport, and is valuable in directing future research in this field.

Data Availability Statement

No data, models, or code were generated or used during the study.

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