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Article

Investigation of modal integration for transit-access trips in motorcycle dependent cities—The case study of Hanoi, Vietnam

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Abstract: Micro-mobility has the potential to address first -mile challenges, improving transit accessibility and encouraging public transit usage. However, users' acceptability of modal integration between various micro-mobility options and public transit remains largely unexplored in the literature. Our study investigates the user behavior for first-mile options, focusing on four alternatives: walking, bicycling, motorcycling, and bus, to access urban mass rapid transit (UMRT) in Hanoi, Vietnam. Based on data collected from 1380 individuals, a Nested Logit Model (NLM) was proposed to analyze the determinants of users' acceptability under each access mode option as well as evaluate further impacts of shifts in access mode choice on vehicle-kilometer traveled and emissions. The analysis shows that the availability of access modes might increase UMRT use by 47.83%. While this increase further generates additional vehicle-kilometer traveled due to the increase in park-and-ride users, this is offset overall by the large number of motorcycle users shifting to UMRT. Under the most optimistic scenario, modal integration for transit-access trips leads to an average reduction of 17.7% in net vehicle-kilometer traveled or 14.5% in net CO_2 emissions or 10.9% in NO_x from private vehicles. Our findings also imply that the introduction of parking fees for bicycling- or motorcycling-access trips, while impactful, does not significantly change UMRT choice. Therefore, the pricing schemes should be a focus of parking planning surrounding stations. Finally, a number of policy suggestions for parking planning and first-mile vehicles are presented.

Keywords: first-mile mode; modal integration; transit-access trips; nested logit model; emissions; vehicle-kilometer travelled

1. Introduction

The rapid advancement of technology and the growing need for travel demand have resulted in increased use of private vehicles, which has, in turn, led to global challenges in terms of global warming and greenhouse gas emissions. Motor vehicles have become one of the major pollution problems because of the threats posed to the environment and human health (Lang et al., 2021; Levy et al., 2010; Luo et al., 2022).

Planners have long debated whether implementing public transit priority policies, such as large investments and financial support for the public transit system, constitutes an effective strategy for transitioning from private to public transit (Baum-Snow and Kahn, 2005). Instead, scholars argue that the complete door-to-door travel experience exhibits a positive and highly significant relationship with transit ridership (Susilo and Cats, 2014).

Providing facilities to support modal integration for transit-access trips is part of an effort to enhance public transit ridership (Duncan and Cook, 2014; Guerra and Cervero, 2011), in parallel with complementary public transit service modes such as bicycle sharing, car sharing, and carpooling. Access travel modes and facilities surrounding stations are able to bridge the gap between private vehicles and public transit, for example by encouraging private vehicle users to choose park-and-ride (P&R) options rather than origin-destination journeys. While this strategy has been employed to alleviate urban traffic congestion in several large cities in the United States, Europe, and Australia (Duncan and Cook, 2014), the approach has not been universally successful. Studies have found that Asian countries, including Singapore and China, have been unsuccessful in developing parking schemes combined with public transit services, with users demonstrating a reluctance to change from private to public transport modes (Zhang et al., 2018). The inconsistent findings highlight the need to further investigate whether facilities supporting micro-mobility options at public transport stations could significantly enhance ridership on public transit. This research direction is particularly salient in the context of cities that rely primarily on motorcycles for transport, thus far an under-explored area. Furthermore, the investigation of modal integration for transit-access trips in motorcycle-dependent cities is crucial for understanding urban mobility challenges, particularly in regions where motorcycles dominate transportation modes (Chiu, 2023; Nguyen et al., 2024; Zhou et al., 2023).

Enhancing modal integration for transit-access trips may also have the undesirable effect of increasing the vehicle-kilometer traveled (VKT) and emissions as a significant proportion of commuters may opt for motorized vehicles to access transit stations (Dickins, 1999; Parkhurst, 1995, 2002a). With this in mind, this empirical research aims to shed light on whether micro-mobility vehicles can bridge the gap between public and private modes of transport to reduce VKT and emissions in motorcycle-dependent cities, realms that have been underexplored.

This study aims to explore the role played by micro-mobility vehicles in the transition of a city’s population to public transport, with a particular focus on the benefits it offers for the achievement of sustainable transport objectives. We hereby address three questions: (1) Can micro-mobility vehicles successfully drive mode choice shift? (2) To what extend does availability of micro-mobility influence mode choice shift? (3) What are the indirect effects of micro-mobility vehicles on VKT and vehicle emissions? To answer these questions, we draw on the symbolic attributes that are considered the standard for the evaluation of mode choice (Boisjoly et al., 2018; Kim and Wang, 2015; Manville, 2017). Our investigation into the indirect effects of micro-mobility vehicles on VKT and vehicle emissions extends the current research on sustainable transport.

This study contributes through its empirical analysis of how the presence of micro-mobility vehicles influences users’ transport mode and vehicle emissions in cities characterized by mixed-traffic flow, a demographically diverse population of private vehicle users, and an imbalanced demand-supply infrastructure—a topic that has thus far remained under-explored. Our findings should facilitate a comparison of the important factors with cities possessing a more mature and developed infrastructure. In addition, we can offer quantitative input for policymakers in terms of urban land use development. To investigate how micro-mobility vehicles can increase public transport ridership and the consequent effects on transport and emissions, we selected Hanoi, the capital of Vietnam, as a case study. This choice was motivated by the following reasons. First, Hanoi was the first Vietnamese city to implement a UMRT line which began operations in 2021. As a result, we expect that our survey will more realistically reflect the mode preferences of the respondents. Second, the research team has extensive experience and knowledge of the city's socio-economic conditions, traffic engineering, and traffic characteristics, enhancing the quality of the survey. Third, as relevant information on micro-mobility vehicles and their usage in Hanoi is quite sparse, policymakers face difficulties in implementing strategies toward achieving sustainability and traffic goals; the outcomes of this study will assist them in their efforts.

The remaining paper is structured as follows: In Section 2 we provide a brief investigation of the determinants of mode choice, including access mode choice. In Section 3, we elaborate on the methodology and dataset. The main results are reported in Section 4 and then we provide a discussion in Section 5. Finally, we provide conclusions in Section 6.

2. Literature review on access mode choice determinants

Determinants of mode choice and access mode choice for public transit have been recognized in many studies. They can be summarized into two approaches: macro and micro level. Several studies at the macro level have focused on economic components such as per capita Gross Domestic Product (GDP), unemployment rate, fuel cost, and vehicle ownership (Boisjoly et al., 2018; Lee and Lee, 2013; Wang and Woo, 2017). Other researchers have identified factors at the micro level to understand how individuals choose modes based on their specific circumstances, such as income, occupation, trip characteristics, or the built environment (Creemers et al., 2012; Legrain et al., 2015). Our study identifies the determinants of public transport ridership at the micro level; thus, acknowledging the determinants of mode choice is crucial.

2.1. Socioeconomic factors

First, the effects of socioeconomic factors are highlighted by income. Income serves as a good predictor of mode choice (Creemers et al., 2012; Kim and Wang, 2015; Mercado et al., 2012). Giuliano (2015) found that the use of public transport was lower in high-income communities than in lower-income communities in the US, whereas Beimborn et al. (2003) reported that public transport captivity was common among low-income users. Moreover, income was significantly and positively associated with car use but negatively with public transport use (Hensher and Rose, 2007; Vasconcellos, 2005). In addition to agreement on the effects of income on mode choice, there was skepticism on the part of several researchers who found that income did not appear to influence mode choice for business journeys (Limtanakool et al., 2006), while others showed that high-income groups were more likely to use public transport than lower-income groups (Legrain et al., 2015). These contradictory findings prove that different approaches in research can lead to different, even conflicting, results.

Apart from income, gender and age were found to be significantly associated with mode choice (Henser and Rose, 2007). Using a dataset from Ohio (USA), Kim and Wang (2015) found that men had a lower probability of using cars than women, and older age and higher income increased the probability of choosing cars. Elders were more likely to use public transport (Cirillo and Axhausen, 2006). However, de Witte et al. (2013) reviewed the literature and concluded that "there seems to be no real consensus on the impact of age and gender in mode choice". They noted contradictory findings in various studies (for example, Cirillo and Axhausen, 2006; Kim and Ulfarsson, 2008; Nurul Habib et al., 2009). Several studies revealed the impact of vehicle ownership on reducing public transport use or increasing private vehicle use for travel (Boisjoly et al., 2018; Currie and Delbosc, 2011; Manville et al., 2018). Members of zero-car households seem to be captive public transport users (Cervero, 2002). A study on the impact of motorcycle ownership on public transport in Taiwan's cities proved that there was a significant and negative association between motorcycle ownership levels and the use of public transport (Hsu et al., 2007; Lai and Lu, 2007). Last but not least, household size and composition were considered in the modeling mode choice but no real consensus was reached among various empirical studies. Household type was found to have an insignificant effect in the mode choice model of Kim and Wang (2015) but was significant and correlative with cars in several studies (Cirillo and Axhausen, 2002; de Palma and Rochat, 2000). The probability of choosing a car was reported to increase in association with the presence of children (Cirillo and Axhausen, 2006; Limtanakool et al., 2006).

2.2. Trip characteristics

Trip characteristic indicators include distance, travel time, travel cost, and trip purpose. Distance was examined for its influence on mode choice, in that faster travel modes will be preferred for longer distances (De Witte et al., 2013). In an empirical study in the Netherlands, Rietveld (2000) found that depending on the trip start and trip end, walking was popular for distances of 1.2–2.2 km, cycling for distances of 1.2–3.7 km, and public transport for distances of 2.2–3.7 km. Travel time and travel cost were other key determinants of mode choice (Kajita et al., 2004; Van de Walle and Steenberghen, 2006). Public transport fares were found to have a strong impact on reducing ridership (Vega and Reynolds-Feighan, 2009; Vasconcello, 2005) and were more sensitive in terms of fewer choices for people; for example, de Witte et al. (2008) reported that fewer car drivers would want reduced fares in order to use public transport. However, this was not always the case. In the context of a motorcycle dependent city, Shimizu et al. (2005) found that citizens were less influenced by public transport policies like fare reduction or quality improvement.

2.3. Parking facilities surrounding stations

The importance of parking and mode choice has been well studied. Some scholars have argued that parking supply and parking subsidies in residential areas can have a strong influence on car ownership levels (Guo, 2013; Manville, 2017; Weinberger, 2012), especially in new urban development areas (Soltani and Somehalli, 2013). Others found that the demand for car parking would be reduced in areas with high-quality public transport service (Gruyter et al., 2020) or the amount of parking reduced in areas with good transport accessibility (Mississauga, 2019; Shoup, 2018). Recently, Thanh and Ngoc (2020) developed a multinomial logit model to explore the relationship between parking fees and mode choice in Hanoi, the targeted area of this study, and found that parking users are more sensitive to parking fees, they are more willing to shift to alternative modes if parking fees increase.

In terms of P&R facilities, a close correlation between P&R facilities and rail transit ridership has been reported by several investigators (Duncan, 2010; Guerra and Cervero, 2011; Lane et al., 2006). Some studies have used P&R as a dominant factor in mode choice (Bergman et al., 2011, Debrezion et al., 2009, Fan et al., 1993), while others have considered the aspect of accessibility (Chow et al., 2006; Cui et al., 2020; Owen and Levison, 2015).

3. Materials and methods

3.1. Methods

We developed a three-step methodology to address the key questions in Section 1. In the first step, we used discrete choice modeling to estimate the probability of choosing UMRT with the availability of access travel modes. In the second step, we setup a base scenario of transport conditions based on the survey responses. In the third step, we investigated the effect of modal shifts on traffic and emissions.

3.1.1. Step 1: Estimate the impact of access modes on UMRT

We applied a nested logit model to model the choice of mode for selected trips and access mode to UMRT. The nested structure places the choice of transportation mode in the upper level and the choice of access mode to UMRT in the lower level. The decision tree for this choice is depicted in **Figure 1**. A diagram of mode choice and its determinants is illustrated in **Figure 2**.

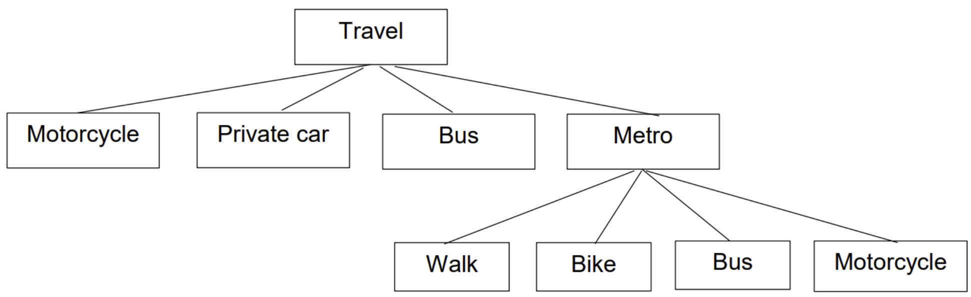

Figure 1. Choice decision tree.

The foundation of discrete choice models lies in the concept of utility. Utility represents the satisfaction or preference that an individual derives from choosing a particular alternative. In this study, the utility function is typically expressed as:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{1}$$

where:

U_{ij} is the total utility of mode i for individual j

V_{ij} is the systematic utility associated with mode i for individual j, often modeled as a linear combination of explanatory variables or attributes of the modes

ε_{ij} is the random utility component capturing unobserved factors affecting individual *j*'s choice of mode *i*.

Based on the above basic formula, the utility function for specific modes are highlighted as follows:

$$U_{Motorcycle} = V_{Motorcycle} + \varepsilon_{Motorcycle} \tag{2}$$

$$U_{Car} = V_{Car} + \varepsilon_{Car} \tag{3}$$

$$U_{Bus} = V_{Bus} + \varepsilon_{Bus} \tag{4}$$

$$U_{Metro} = V_{Metro} + \varepsilon_{Metro} \tag{5}$$

$$U_{Walk-Metro} = V_{Walk-Metro} + V_{Metro} + \varepsilon_{Walk-Metro} + \varepsilon_{Metro} \tag{6}$$

$$U_{Bike-Metro} = V_{Bike-Metro} + V_{Metro} + \varepsilon_{Bike-Metro} + \varepsilon_{Metro} \tag{7}$$

$$U_{Bus-Metro} = V_{Bus-Metro} + V_{Metro} + \varepsilon_{Bus-Metro+\varepsilon_{Metro}} \tag{8}$$

$$U_{Motorcycle-Metro} = V_{Motorcycle-Metro} + V_{Metro} + \varepsilon_{Motorcycle-Metro} + \varepsilon_{Metro} \tag{9}$$

In the nested logit model, the error terms for each choice ($\varepsilon_{Motorcycle}$, ε_{Car}, ε_{Bus}, $\varepsilon_{Walk-Metro} + \varepsilon_{Metro}$, $\varepsilon_{Bike-Metro} + \varepsilon_{Metro}$, $\varepsilon_{Bus-Metro} + \varepsilon_{Metro}$, *and* $\varepsilon_{Motorcycle-Metro} + \varepsilon_{Metro}$) are assumed to have Gumbel distribution (0,1) and the error terms for each branch ($\varepsilon_{Walk-Metro}$, $\varepsilon_{Bike-Metro}$, $\varepsilon_{Bus-Metro}$, and $\varepsilon_{Motorcycle-Metro}$) have independent Gumbel distribution (0, θ^1) (Ben-Akiva and Lerman, 1985).

The probability that an individual chooses a specific mode is determined by the relative utility of that mode compared to all other mode. In Nested Logit Model, conditional probability of choice for each brand n among the choice be equal to:

$$P_{n/Metro} = \frac{\exp\left(\frac{V_n}{\theta}\right)}{exp\left(\frac{V_{Walk-Metro}}{\theta}\right) + exp\left(\frac{V_{Bike-Metro}}{\theta}\right) + exp\left(\frac{V_{Bus-Metro}}{\theta}\right) + exp\left(\frac{V_{Motorcyle-Metro}}{\theta}\right)} \tag{10}$$

The marginal probability of each choice for the nest is:

$$P_{Motorcycle} = \frac{\exp(V_{Motorcycle})}{exp(V_{Motorcycle}) + exp(V_{Car}) + exp(V_{Bus}) + exp(V_{Metro} + \theta\Delta_{Metro})} \tag{11}$$

$$P_{Car} = \frac{\exp(V_{Car})}{exp(V_{Motorcycle}) + exp(V_{Car}) + exp(V_{Bus}) + exp(V_{Metro} + \theta\Delta_{Metro})} \tag{12}$$

$$P_{Bus} = \frac{\exp(V_{Bus})}{exp(V_{Motorcycle}) + exp(V_{Car}) + exp(V_{Bus}) + exp(V_{Metro} + \theta\Delta_{Metro})} \tag{13}$$

$$P_{Metro} = \frac{\exp(V_{Metro} + \theta\Delta_{Metro})}{exp(V_{Motorcycle}) + exp(V_{Car}) + exp(V_{Bus}) + exp(V_{Metro} + \theta\Delta_{Metro})} \tag{14}$$

where Δ_{Metro} measures the expected maximum utility among the nested alternatives and is given by the log sum of the exponents of the nested utilities:

$$\Delta_{Metro} = ln\left[exp\left(\frac{V_{Walk-Metro}}{\theta}\right) + exp\left(\frac{V_{Bike-Metro}}{\theta}\right) + exp\left(\frac{V_{Bus-Metro}}{\theta}\right) + exp\left(\frac{V_{Motorcycle-Metro}}{\theta}\right)\right] \tag{15}$$

where θ is the parameter of the log sum variable.

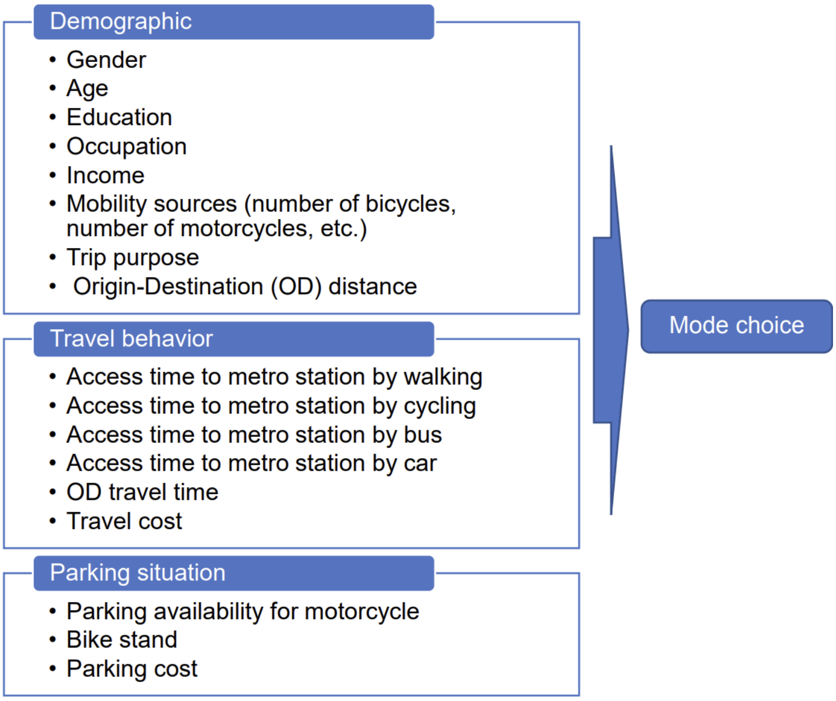

Figure 2. Mode choice determinants.

To provide an assessment of the factors that led respondents to choose UMRT for travel, a list of factors influencing their mode choice is given in **Table 1**.

Table 1. Descriptions of key variables.

Variable	Variable type	Variable assignment
Upper-level parameters		
Gender (independent variable)	Unordered	Male = 1, female = 0
Age (independent variable)	Ordered	Under 18 years old = 1, 18-24 years old = 2, 25-34 years old = 3, 35-50 years old = 4, above 50 years old = 5
Education (independent variable)	Ordered	High school and below = 1, junior college = 2, bachelor's degree = 3, master's degree and above = 4
Occupation (independent variable)	Ordered	Office worker/gov. officer = 1, worker = 2, self-employed = 3, student = 4, seasonal worker = 5, housewife/retired/jobless = 6, and others = 7
Monthly income (independent variable)	Ordered	Less than 6 mil. VND = 1, 6-10 mil. VND = 2, 10-20 mil. VND =3, 20-30 mil. VND = 4, above 30 mil. VND = 5
Bicycle ownership (independent variable)	Continuous	
Motorcycle ownership (independent variable)	Continuous	
Trip purpose	Ordered	To home = 1, to work = 2, to school = 3, at work/business = 4, private = 5, other = 6
Origin-destination distance	Continuous	
Lower-level parameter		
Walking-access time	Continuous	
Bicycling-access time	Continuous	
Bus-access time	Continuous	
Motorcycle-access time	Continuous	
Parking availability	Unordered	Parking = 1, no parking = 0

Table 1. (*Continued*).

Variable	Variable type	Variable assignment
Bike stand	Unordered	Parking = 1, no parking = 0
Parking cost	Continuous	78.4
Origin-destination travel time	Continuous	
Travel cost	Continuous	

3.1.2. Step 2: Setup scenarios of transport conditions

The base scenario measures the actual traffic volume and emissions generated by each transportation mode. Origin-destination (OD) survey data were used to estimate VKT. The OD survey provided the zone of the respondents. With this information, we determined zone-to-zone travel distance and estimated the number of kilometers that the respondents drove before the introduction of UMRT. Based on the mode choice model derived from step1, we differentiated the proportion of UMRT and access mode to UMRT stations. The specific UMRT stations were derived from the planning map and field surveys, then we assigned home-to-station and station-to-destination travel distances.

3.1.3. Step 3: Estimate emissions

In this study, we consider greenhouse gas emissions (GHGs) and local pollutants. GHGs are categorized into direct (tank-to-wheel or (TTW)) and indirect (well-to-tank or (WTW)) emissions. Local pollutants include particle matter ($PM_{2.5}$), NO_X, and SO_2.

- Direct greenhouse gas emissions.

The United Nations Framework Convention on Climate Change (UNFCCC, 2014) considered the components of transport-related GHGs including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). However, IPCC (2006) considered only CO_2 and CH_4 emissions and estimated the CO_2 emissions based on energy consumption.

- Local pollutants.

Local pollutants include $PM_{2.5}$, NO_x, and SO_2. Estimation of local pollutants in the transport sector only considers combustion-related emissions, not cover particle emissions caused by tires or brakes. $PM_{2.5}$ and NO_x pollutants were determined based on the Euro emission standard of the transportation mode, fuel type, vehicle speed, load factor, and gradient using the COPERT emission model (version 2018).

3.2. Data collection

3.2.1. Data limitation

Before describing our approach to addressing the research questions in Section 1, we must acknowledge that up to the survey period, the UMRT service was still not put into operation, and we do not have any information on how facilities supporting access modes will be provided along the UMRT corridor. Mode choices shift would be tracked in a hypothetical scenario with different access mode options by using a stated preference survey. One might argue that such kind of survey may not reflect actual behaviors. However, this kind of survey is relatively common in planning if planners or policymakers want to predict travel behavior in uncertain conditions (Ducan and Cook, 2014), hence we relied on this advantage in our analysis. Scenario analysis may provide us with the answers to our research question and draw some preliminary conclusions.

3.2.2. Data and descriptive analysis

A questionnaire-based survey was conducted from 1 August to 30 August 2018, focusing on the daily travel characteristics of residents living in Hanoi. Among 1610 questionnaires, 1380 samples were identified as valid for further analysis, resulting in a validity rate of 85.7%. Descriptive statistics of the sample are outlined in **Table 2**.

Table 2. Descriptive statistics of the sample.

Category	Sub-categories	Percentage
Gender	Male	57.8
	Female	42.2
Age (years old)	Under 18	1.0
	18–24	34.2
	25–34	31.5
	35–50	23.5
	Above 50	9.8
Education	High school and below	49.1
	Junior college	16.1
	Bachelor's degree	34.2
	Higher degree	0.6
Occupation	Office worker/gov. officer	17.5
	Worker	12.7
	Self-employed	28.1
	Student	24.1
	Seasonal worker	1.9
	Housewife/retired/jobless	4.8
	Others	10.5
Monthly income (VND)	Less than 6 mil.	78.4
	6–10 mil.	14.8
	10–20 mil.	5.6
	20–30 mil.	0.8
	Above 30 mil.	0.4

The overall proportion of respondents using motorcycles is significant, approximately 78.77%, followed by 11.42% of respondents using the bus system. Less than 2% of travel demand is met by walking and cycling; thus, accessibility by non-motorized vehicles can be considered to be not good in this city.

The distribution of travel distance between the origin and destination of motorcyclists is summarized in **Figure 3**. More than 77% of respondents traveled within 10 km by motorcycle, and of these 24% of respondents used motorcycles for distances less than 2 km. Approximately 11% of respondents took trips of 10 to 15 km, and the rest traveled 15 km or more. This summary suggests that most passengers prefer motorcycles whether the journey is long or short. For a comparison, the travel time between the origin and destination of survey respondents is depicted by a dotted line. There are large deviations in the reported responses for all travel distances, as can be determined from the minimum and maximum travel times. Based on the reported travel distances and times, the average driving time over distances up to 2 km was 6 minutes, between 2 and 5 km was 13 minutes, between 5 and 10 km was 22 minutes, between 10 and 15 km was 34 minutes, between 15 and 20 km was 43 km, between 20 and 30 km was 57 minutes, and above 30 km was 65 minutes.

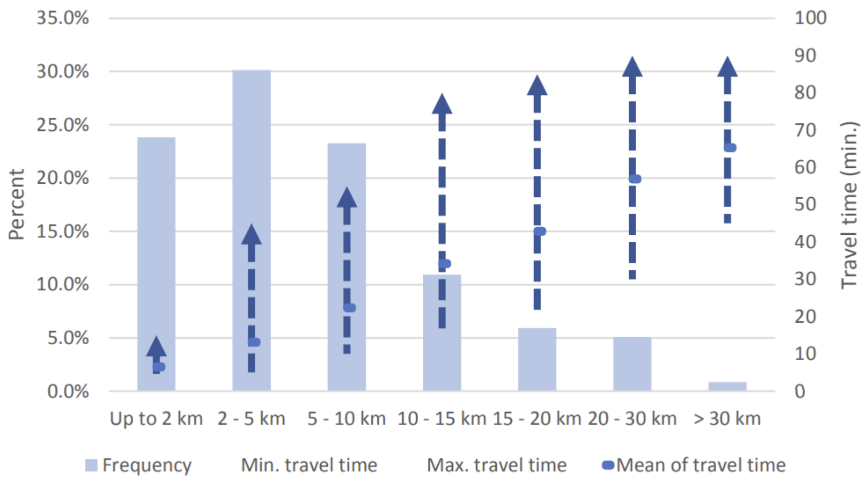

Figure 3. Distribution of travel distance and travel time between origin and destination by motorcycles

Modal shift before and after the introduction of UMRT service was explored using stated preference data. We assume that respondents' travel mode choice at the time of the survey would reflect their preference in the future. As shown in **Table 3**, the preference for motorcycles dropped from 78.77% before the introduction of the UMRT service to decrease to 41.88% after the introduction of modal integration for transit-access trips. The change in mode choice confirms that UMRT service would be well received by citizens in Hanoi when it goes into operation. On the other hand, it also reveals that people still prefer motorcycles even after the introduction of UMRT.

Table 3. Descriptive statistics of the sample.

Mode	Before the introduction of UMRT	After the introduction of modal integration for transit-access trips.
Non-motorized vehicles (NMV)	9.0	0
Motorcycle	78.77	41.88
Private car	0.82	0.36
Bus	11.42	9.93
UMRT	-	47.83

The preference of choosing mode for UMRT stations is summarized in **Table 4**. It shows that motorcycles would be the most preferred mode of access with 26.16%, followed by buses with 12.75%. Walking and cycling accounted for 5.87% and 3.04%, respectively. This summary implies that the development of facilities to support access to motorized vehicles at stations is crucial to integrating the use of motorcycles and public transit.

Table 4. Summary of the probability of access mode choice, $N = 1380$.

Access mode	Choice level (%)
Walk	5.87
Bicycle	3.04
Feeder bus	12.75
Motorcycle	26.16

4. Results

4.1. Determinants of mode choice

The model parameters were estimated using Stata software (http://www.stata.com) with the commonly used maximum likelihood estimation method (Louviere et al., 2000). This process creates a set of utility function parameter estimates that maximize the likelihood (or probability) function. In effect, a good estimation maximizes the ability of the model to replicate the observed data. The estimation results of the nested logit model discussed above are given in **Table 5**.

Table 5. Estimation results for mode choice—access mode decision nest.

Variables	Coefficient	*Z*-value	*P*-value	
Upper-level parameters				
Gender				
• Bus	–0.560	–2.49	0.013	**
• Private car	–0.632	–0.73	0.467	
• UMRT	–0.323	–2.42	0.015	**
Age				
• Bus	–0.597	–4.39	0.000	***
• Private car	–0.341	–0.78	0.438	
• UMRT	–0.111	–1.67	0.096	*
Education				
• Bus	0.338	2.79	0.005	**
• Private car	–0.617	–1.17	0.242	
• UMRT	–0.121	–1.67	0.095	*
Occupation				
• Bus	0.185	2.81	0.005	**
• Private car	–0.171	–0.65	0.515	
• UMRT	–0.007	–0.19	0.849	
Income				
• Bus	–0.703	–2.94	0.003	**
• Private car	–0.198	–0.29	0.773	
• UMRT	–0.407	–4.12	0.000	***

Table 5. (*Continued*).

Variables	Coefficient	*Z*-value	*P*-value	
Bike ownership				
● Bus	0.600	2.64	0.008	**
● Private car	0.154	0.17	0.861	
● UMRT	0.085	0.52	0.603	
Motorcycle ownership				
● Bus	–0.181	–2.00	0.045	*
● Private car	0.074	0.25	0.805	
● UMRT	–0.025	–0.49	0.624	
Origin–destination				
● Bus	0.078	5.65	0.000	***
● Private car	0.021	0.42	0.675	
● UMRT	0.050	5.42	0.000	***
Trip purpose				
● Bus	0.218	2.60	0.009	**
● Private car	–0.549	–1.25	0.212	
● UMRT	–0.105	–2.22	0.026	**
Lower-level parameters				
Walking-access time	–0.046	–2.72	0.006	**
Bicycling-access time	0.033	2.09	0.036	*
Bus-access time	–0.033	–2.46	0.014	*
Motorcycling-access time	0.039	2.60	0.014	*
Motorcycle parking	0.872	3.16	0.002	**
Bicycle stand	2.676	3.55	0.000	***
Parking cost	–0.0002	–5.00	0.000	***
Origin-destination travel time	–0.020	–8.65	0.000	***
Travel cost	0.0002	14.04	0.000	***

Note: Number of observations = 9,660; number of cases = 1380; base reference = motorcycle; log likelihood function = –1790.6; prob [χ^2 > value] = 0.0000. Significance indicated by the following: *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$.

The estimation results show that the availability of access travel modes had a significant influence on the choice of UMRT. For example, the odds of accessing UMRT by walking and bus would reduce by 4.4% ($e^{-0.046}$ –1) and 3.36% ($e^{-0.033}$ – 1) due to the influence of access time when using these modes. Conversely, other factors such as access time by bicycle and motorcycle were found to have a positive association with the choice of mode of access to UMRT stations. Indeed, a 1% increase in access time by bicycle and motorcycle has been associated with an increase in the odds of choosing a bicycle or motorcycle as the mode of access by 3.36% ($e^{0.033}$ – 1) and 3.98% ($e^{0.039}$ – 1), respectively.

In addition to access travel modes to UMRT, several other factors are also crucial in the choice of UMRT. Parking areas for motorcycles and bicycles had a positive and significant influence on the choice of accessing UMRT by these modes. The availability of motorcycle parking would increase the odds of choosing a motorcycle as the mode of access to a UMRT station by 139.1% ($e^{0.872} – 1$). Parking charges and travel costs, although having a negative effect, were almost negligible. The coefficient of parking cost was 0.0002, which suggests that if travelers have to pay a parking fee, the probability that they would choose UMRT instead of motorcycles was 0.02% lower than if there was no parking fee.

Furthermore, the demographic attributes of respondents, such as gender and income, and trip attributes, such as distance and trip purpose, affected UMRT choice. Specifically, men were less likely to choose UMRT; a one-unit increase in income or purpose level has been associated with a decreased probability of choosing UMRT over motorcycle by 33.03% and 9.5%, respectively. In addition, respondents were more likely to choose UMRT if the origin-destination distance was longer.

4.2. Development of scenarios

As mentioned in Section 3.1.2, to determine the transport and emission impacts of mode choice shift, we will setup two scenarios. The base scenario without the presence of UMRT and access travel modes, one mitigation scenario with the presence of UMRT, access travel modes and facilities to support access modes. Estimation of a mitigation scenario was developed from the output of the mode choice model.

The base scenario reflects the actual amount of VKT based on the daily trip diary of respondents. The survey team recorded all origin-destination (OD) trips and estimate the average distance by each mode. The respondents' average trip rate was 2.48 including walking and 2.27 excluding walking. The main characteristics are as follows:

a) The ratio of cycling is small—bicycles are used mainly within a 1.2 km distance;
b) Motorcycles travel an average distance of 8.01 km;
c) The average trip length of a private car is 13.14 km;
d) Buses are used for a distance of 12.13 km.

From the mode choice model estimates above, we recalculated the VKT that would be generated assuming travelers choose UMRT. As we did not consider last-mile modes, we consider that travelers will reach their destination on foot.

The fuel type used by vehicles is classified into the following categories: (i) diesel, (ii) CNG, (iii) petrol, and (d) biofuel. Data on fuel type and the average age of vehicles come from the Vietnam Register (Vietnam register is responsible for certifying the safety and technical standard of vehicles as well as vehicle roadworthiness).

4.3. Estimation of VKT and emissions

The estimates of VKT and vehicle emissions for the base scenario are presented in **Table 6**. Averages are provided for each mode and for all modes combined.

Within the presence of UMRT, the probability of taking motorcycles for OD trips was reduced from 78.77% to 41.88% but the probability of choosing motorcycles as the first mile mode increased by 26.16% (**Table 3**). However, due to the short access distance, this change would reduce the net motorcycle VKT by 36.1%. The results are presented in **Table 7**.

Table 6. Average VKT and emissions, base scenario, N = 1380.

Mode	Average daily VKT (km)	Annual tons CO_2 (WTW incl. BC)	Annual $PM_{2.5}$ (tons)	Annual NO_x (tons)
Non-motorized vehicles	1752	0	0	0
Motorcycle	22,155	598	0.04	1.86
Private car	355	34	0	0.03
Bus (*)	111	50	0.01	0.5
Total	**24,373**	**682**	**0.05**	**2.39**

Note: (*) Bus VKT was calculated based on travel demand, average bus occupancy rate, and average route length. Data of average bus occupancy rate and average route length were derived from public transport authority (TRAMOC, 2018).

Table 7. Changes in VKT and emissions within the presence of UMRT.

Scenario	Mode				
	NMV	Motorcycle	Private car	Bus	Total
Within presence of UMRT					
Daily VKT (km)	1752	14,166	123	111	16,152
Annual tons CO_2 (WTW incl. BC)	0	383	12	50	444
Annual $PM_{2.5}$ (tons)	0	0.03	0	0.01	0.04
Annual NO_x (tons)	0	1.19	0.01	0.5	1.70
Evaluation (% change compared to base scenario)					
% Change of VKT	0	–36.1%	–65.4%	0	–33.7%
% Change of CO_2	0	–36.0%	–64.7%	0	–34.9%
% Change of $PM_{2.5}$	0	–25.0%	0	0	–20.0%
% Change of NO_x	0	–36.0%	–66.7%	0	–28.9%

The above analysis highlights that the introduction of UMRT service with different access modes and facilities to support the availability of access modes would have a positive effect on the overall reduction of VKT and the associated vehicle emissions. This is mainly due to a significant shift from motorcycle to UMRT usage. Although extra motorcycle VKT is generated by accessing UMRT stations, the effect caused by users willing to switch to UMRT is higher, resulting in a net reduction of 36.1% VKT for motorcycles, or a total of 34.9% CO_2 WTW. The change in NO_x emission is also significant, with a reduction of 28.9%.

5. Discussions

5.1. Responses to research questions

This study addressed the abovementioned questions about the role of access travel modes on increasing UMRT ridership. Our results show that on average, travelers would drive motorcycles less if modal integration for transit-access trips were introduced than if they did not exist. As a result, the introduction of bicycling- and motorcycling-access modes should lead to a net decrease in VKT and vehicle emissions. These findings are similar to those of research carried out by Duncan and Cook (2014) in the US showing that the availability of facilities supporting car-access trips causes a decrease in VKT. However, these findings contrast with the previously discussed research results from Europe (Meek et al., 2011; Mingardo, 2013). The provision of facilities for access travel modes is more likely to attract people to public transit in Hanoi than in European or US cities. Furthermore, it also implies that both car-oriented cities (US) and motorcycle-oriented cities (Vietnam) should make policies for developing park-and-ride or kiss-and-ride a central point when setting transit-oriented policy goals.

5.2. General inferences

Previous research on transit-oriented development typically investigated the extent to which micro-mobility policies are able to yield an increase in public transit usage. This paper comprises work concerned with empirically analyzing how the availability of access travel modes can support increased UMRT ridership and therefore reduced transport and vehicle emissions. While the previous research is undertaken to study mainly the transit-oriented facilities for car users, this work specifically concentrates on investigation of the mode choice change with transit-oriented facilities of motorcycle users. We conducted a stated preference survey of residents living along a UMRT line in Hanoi City in 2018. At that time, that UMRT line was under construction and 90% of the workload was completed. The contribution to existing knowledge and research is mentioned under two key findings: (1) the possible effect of the introduction of access travel modes on public transit ridership, for which we have evidence to believe that if facilities for access travel modes are provided at UMRT stations, it would significantly improve public transit usage; and (2) effects of micro-mobility availability in terms of transport and environmental impact are transparent.

First, the key factors that affected respondents' choice of UMRT were identified, specifically "bike stand" and "parking for motorcycle". These refer to travelers who prefer to ride bikes or motorcycles to UMRT stations instead of walking. Well-established behavior of riding a motorcycle is a different experience in the rest of the world and is by means unique to Asian countries, particularly in Vietnam; therefore, it should not be underestimated. Motorcycles should be oriented to become feeder mode at UMRT stations or bus stops, if possible, with the support of a P&R system.

Next, the introduction of parking fees did not contribute significantly to the change in UMRT choice. Motorcyclists did not change their concerns about travel mode even with increased parking fees. Therefore, we can conclude that the policy for parking pricing might have positive supplement effects: parking fees supplement local government revenue, thus more financially supporting the provision of public transport, and some aspects are related to reduced pressure of finding parking in surrounding areas. The latter refers to drivers who use parking areas without using public transport; the time spent searching for parking might be reduced, which creates lower emissions and less traffic congestion.

The final finding from the work is important to understand the net impact of modal integration for transit-access trips on VKT and vehicle emissions: there appears to be a positive association between the presence of access travel modes with facilities and the reduction of total VKT and vehicle emissions as well. These expected outcomes come from the reason that the availability of access travel modes would change drivers' behaviors and many journeys formerly made by motorcycle would shift to UMRT. This means that the extent of the undesirable effects caused by extra VKT is compensated by the significant reduction in total motorcycle trips of some travelers using motorcycles for OD trips. In other words, with the introduction of motorcycle-access trips, the net reduction in motorcycle use has indeed proven to be efficient.

6. Conclusions

This context-specific study aimed to assess how the presence of access travel modes affects mode shift, urban transport, and vehicle emissions in an urban environment by building a nested logit model of Hanoi citizens' UMRT choice using the control variable of access time and travel cost in conjunction with other variables. Subsequently, we identify the positive and negative effects of users' mode choice shift on urban transport and vehicle emissions using an emissions model. Our results underline the cruciality of policies that emphasize access travel modes and facilities near public transport services to reap the benefits in terms of mode share, urban transport, and vehicle emissions.

First, our findings confirm that access time and travel cost strongly predict UMRT mode choice, in line with previous research (Bergman et al., 2011; Debrezion et al., 2009). Moreover, we show that the presence of motorcycle parking along UMRT leads to a net VKT decrease for users as a higher proportion of motorcycle users are encouraged to shift to public transport. Finally, this paper introduces a framework explaining the scenarios under which the presence of access travel modes can effectively reduce net VKT.

6.1. Policy implications

This work has several implications for policymakers. First, the findings indicate that modal integration for transit-access trips is vital to achieving the stated policy goals (i.e., reduced net VKT and emissions). Second, there is a need to modify the facility design by integrating an efficient parking fee scheme that can attract UMRT users while ensuring minimum usage by non-UMRT users. It should be noted that such a scheme does not need to cover the parking facility's operational costs but rather should help avoid unintended and improper use. As emphasized by Truong and Ngoc (2020), there is a clear need for a comprehensive policy regime for transit-oriented parking in Hanoi to tackle illegal parking. In addition, UMRT station parking facility fees should be lower than those of other facilities as motorcycle user may otherwise continue to use their vehicles within the city. Third, as the overall objective is reducing motorcycle use, parking should be made available at every station, rather than solely at terminal stations, for users whose journeys overlap the UMRT line by a single section. This is consistent with Mingardo's (2013) policy suggestions. Fourth, in light of the critical role played by last-mile vehicles in emissions reduction, we suggest that public bicycle rental services be established at UMRT stations to reduce motorized vehicle use. Although bicycles are slower than motorcycles, this effect is less emphatic over short distances, and they are also safer, making them a suitable alternative that can mitigate Hanoi's traffic jams.

The data mentioned play a vital role in various traffic segments. For instance, a comprehensive analysis and prediction of modal distribution can significantly impact road network planning, leading to cost reduction in construction (Simić et al., 2023) and improving traffic safety (Kodepogu et al., 2023; Trifunović et al., 2024), as well as mitigating pollution and offering numerous other benefits (Senturk et al., 2023).

6.2. Research limitations

This study is subject to some limitations. The first comprises the study's design and small sample size as our analysis of the impact on urban transport and vehicle emissions was limited to 1,380 respondents rather than the city's entire population. More large-scale research is needed to investigate in greater depth how modal integration at UMRT stations affect transport and emissions. The second limitation is that the survey data did not address all modes of transportation, especially motorcycle taxis, which experience high usage in Hanoi. As a result, the results calculated for VKT and vehicle emissions do not take all relevant modes of urban transport into account. Third, there is a need for more research on users' willingness to pay for parking at UMRT, ideally via a statistical analysis of the relationships among traffic, parking fees, and vehicle emissions as part of an effective parking policy.

Last but not least, we are not able to develop software for the automatic calculation of mobility impacts although new eco-assessment software is available and useful for the quantification of the environmental impacts, as mentioned in Spreafico and Russo (2021). The potential synergies need to be considered in further studies.

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