Impact of On-street Wireless Charging Systems at Intersections on Route Choices behavior of Electric Motorcycle Users in Phnom Penh

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Abstract: Air pollution in Phnom Penh, Cambodia, is a growing public health concern due to the rise in motorcycles. The government promotes electric motorcycles (EMs) for sustainability, but adoption remains low due to limited charging infrastructure. Wireless charging at intersections offers a potential solution by allowing EMs to charge while waiting at traffic lights, turning congestion into a charging opportunity. This study examines how charging infrastructure influences EM riders' route choices, comparing shorter urban routes with wireless charging to longer suburban routes with traditional stations. A stated preference survey (239 respondents, 1,434 observations) analyzed with a mixed binary logit model shows that wireless charging significantly increases the preference for shorter routes, while traditional stations have no effect. Higher costs and longer travel times discourage route choice. These findings suggest policymakers should assess wireless charging feasibility, optimize battery stations, and introduce cost incentives to boost EM adoption.

Keywords: Route Choice Behavior, Electric Motorcycle, Battery Charging Station, Wireless Charging System

1. INTRODUCTION

The global transportation sector is undergoing a significant transition toward electric vehicles (EVs), driven by growing concerns over fossil fuel scarcity, increasing operational costs, and the environmental impact of climate change. Among EVs, electric motorcycles (EMs) have gained considerable attention, particularly in developing countries, as a sustainable alternative to conventional gasoline-powered motorcycles. In Cambodia, especially in the capital city of Phnom Penh, rapid urbanization and economic growth have contributed to a dramatic rise in the number of gasoline motorcycles, leading to worsening traffic congestion and air pollution. In response to these challenges, the Cambodian government has been actively promoting the adoption of EMs as part of its broader efforts toward sustainable urban mobility.

Despite these efforts, the widespread adoption of EMs remains limited, primarily due to the lack of adequate charging infrastructure. Existing charging options include on-street wired charging stations, battery-swapping systems, and the recently emerging wireless charging technology. Wireless charging, particularly dynamic charging systems installed at intersections, has been rapidly advancing in recent years and offers a promising solution for improving urban mobility. Unlike conventional charging stations that require vehicles to stop and connect physically, wireless charging enables EMs to recharge while waiting at intersections, effectively transforming traffic congestion into a charging opportunity. This innovation has the potential to reshape conventional route choice behavior, as intersections—traditionally viewed as delay points—could become strategic locations for both stopping and recharging.

Given this evolving landscape, this study aims to explore how future charging infrastructure developments, particularly the introduction of wireless charging systems at intersections, could influence EM riders' route choice behavior. Specifically, it examines the trade-offs between shorter urban routes equipped with wireless charging and longer suburban routes featuring traditional charging stations. The study is based on the assumption of a near-future road network where such advanced infrastructure is implemented.

The key objectives of this research are as follows:

- To compare the influence of wireless charging at intersections with conventional wired charging stations on EM riders' route choices.
- To assess riders' preferences, perceptions of convenience, and behavioral adaptations in response to different charging infrastructures.
- To provide evidence-based policy recommendations for the effective development of charging infrastructure to support EM adoption in Phnom Penh and beyond.

This study hypothesizes that wireless charging at intersections will enhance route efficiency, reduce overall travel time, and be more cost-effective than wired charging stations. If successfully implemented, this technology has the potential to transform the way EMs are used, alleviate concerns over battery range limitations, and contribute to a more sustainable urban transport system. The findings of this research are expected to provide valuable insights for policymakers, urban planners, and transport authorities as they work toward creating a more efficient and environmentally friendly transportation network.

2. Literature Review

As Phnom Penh's economy and population expand, gasoline-powered motorcycles (GMs) continue to dominate the transport system, exacerbating congestion and pollution. Although electric motorcycles (EMs) offer environmental and economic advantages, adoption remains low due to insufficient charging infrastructure (Chakraborty & Chakravarty, 2022; Truong et al., 2024). Establishing an efficient charging network and implementing cost-effective policies are crucial for a successful transition (Asian Development Bank, 2022; Huu & Ngoc, 2021). A well-planned charging system is essential to building rider confidence and facilitating Cambodia's shift to EMs (ESCAP, 2023). However, obstacles such as high electricity costs, a lack of investment incentives, and limited infrastructure must be addressed to encourage widespread EM adoption. The three primary charging methods available for EMs in Cambodia—conductive charging, inductive charging, and battery swapping (Figure 1) — highlight the need for diverse charging solutions (Aghajan-Eshkevari et al., 2022). This study focuses on two critical charging solutions: battery charging stations and wireless charging at intersections, both of which significantly impact EM riders' route choices.

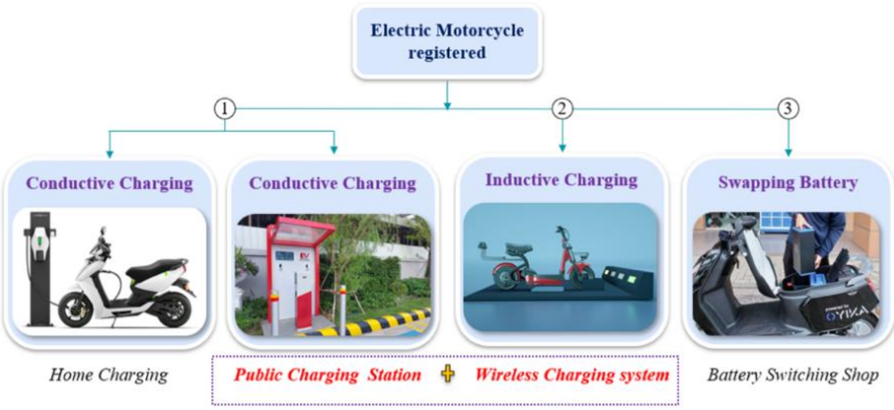

Figure 1: Charging options for electric motorcycles

2.1 Battery Charging Stations

Battery charging stations offer a reliable means of recharging EMs but require long charging times and stationary periods, which may discourage usage (Mishra et al., 2021; Zhang et al., 2021). Research emphasizes the need for an extensive and accessible charging infrastructure to ensure rider convenience and confidence (Ashkrof et al., 2019; Istiqomah et al., 2022). However, the trade-off between accessibility and charging duration remains a significant challenge, as riders may be reluctant to choose longer routes solely based on the availability of battery charging stations.

2.2 Dynamic Wireless Charging Systems

To reduce wait times at charging stations, dynamic wireless charging systems enable vehicles to charge while in motion, extending their driving range and improving travel efficiency (He et al., 2018; Sun et al., 2018). Wireless charging systems are safe, reliable, and require minimal maintenance due to the absence of physical connectors (Aydin et al., 2022). Studies suggest that real-time charging availability significantly influences route selection, as riders prioritize convenience and shorter travel times over detours to fixed charging points (Aydin et al., 2022; Mohrehkesh & Nadeem, 2011).

2.3 Optimal Placement of Charging Systems

Strategic placement of wireless charging systems at intersections and battery charging stations is key to enhancing EM adoption. Wireless charging at signalized intersections allows riders to charge while waiting at traffic lights, making it particularly effective in dense urban settings (Tan et al., 2022; Zhang et al., 2020). Research indicates that integrating wireless charging into urban road networks improves travel efficiency and reduces the need for frequent charging stops (Yang et al., 2017; Mohrehkesh & Nadeem, 2011). Conversely, placing battery charging stations in suburban areas ensures secure and predictable charging access while alleviating congestion in urban centers (Chen et al., 2013; Zhang et al., 2021). Optimized station placement based on traffic patterns and rider demographics improves accessibility and fosters EM adoption (Alanazi et al., 2023).

2.4 Modeling Route Choice Behavior

A mixed binary logit model effectively predicts EM riders' route choices by incorporating factors such as demographics, mobility patterns, and environmental conditions (Phun & Yai, 2022; Ashkrof et al., 2020). Prior studies confirm that riders tend to prefer routes with convenient charging points, particularly when their battery levels are low (Karakitsiou et al., 2018). Additionally, suburban charging stations can alleviate congestion by serving commuters before they reach densely populated urban centers (Mahmoud et al., 2021; Almatar, 2023). The ability to charge on the go with wireless technology further alters route preferences, making dynamic charging a crucial factor in route choice analysis.

2.5 Research Gaps

Despite growing interest in EM adoption, limited research has focused on EM riders' charging preferences in Phnom Penh. Comparative studies examining the impact of wireless charging versus battery charging stations on rider behavior and route choices are particularly scarce. Understanding these influences is essential for optimizing charging infrastructure placement, promoting EM adoption, and enhancing urban mobility. This study seeks to address these gaps by investigating how different charging infrastructures shape EM riders' route choices, thereby informing future transportation policies and urban planning strategies in Cambodia.

3. Methodology

Because electric bicycles are not yet widespread in Cambodia, this study uses the SP survey methodology, which is powerful in forecasting demand for non-existent transportation alternatives. A stated preference survey with a hypothetical scenario was carried out to understand the factors that influence EM riders' route choices. This scenario was designed to reflect real-world situations. Respondents were asked to choose between a shorter 5km urban route and a longer 10km suburban route, both starting and ending at the same points, simulating the options for traveling from home to work or school. Each alternative was described with five specific attributes at different levels to develop a trade-off between the routes. Additionally, two common attributes were included to give respondents a more complete understanding of their options. This careful research approach ensures that the findings are valid and reliable.

3.1 Route Choice Context

Two different types of commuting routs are assumed in the SP survey.

- Route A: Congested, shorter 5km route in urban areas with wireless battery charging at traffic intersections but no battery charging station.

- Route B: Less congested, longer 10km route in suburban areas with battery charging stations but no wireless charging system.

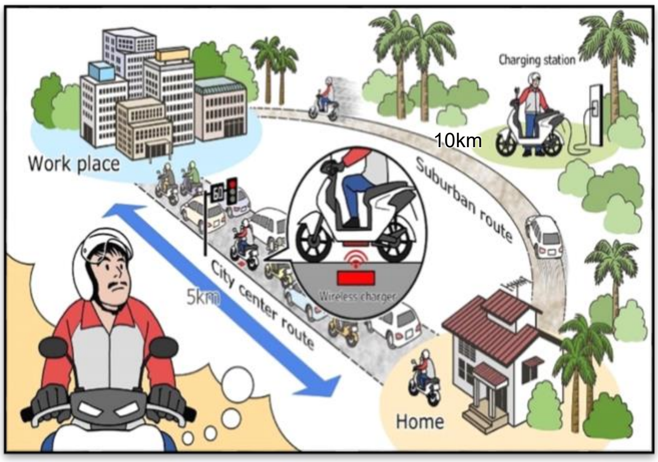

Figure 2: Route options for electric motorcycles in a hypothetical choice context

The stated preference (SP) experiment examines the impact of wireless charging systems and battery charging stations on electric motorcycle (EM) riders' route choices. Given the higher density and shorter travel distances in urban areas compared to suburban areas, this study assumes that urban routes are generally shorter.

To analyze these choices, two route options were presented:

- Route A (Shorter Route): Travel times were set at 12 minutes, 17 minutes, and 22 minutes.
- Route B (Longer Route): Travel times were set at 24 minutes, 29 minutes, and 34 minutes.

This setup aligns with previous research on route choice behavior under varying traffic conditions (Fadilah et al., 2022).

Cost assumptions were based on current charging rates at battery charging stations, where 1 kWh costs 1,600 riel ($0.4) (GGGI, 2021). Since wireless charging technology is new and in need of promotion, one of the cost levels in the scenario was set to be free, as shown in Table 1.

Table 1: Characteristics of Stated Choice Experiments

	Levels for Route A (Shorter)			Levels for Route B (Longer)		
Common Attributes						
Distance		5 km			10 km	
Energy Remaining at Start	80%	50%	30%	80%	50%	30%
Battery Charging Station at Destination	No		Yes	No		Yes
Specific Attributes						
Battery Charging Station on Route	No		Yes	No		Yes
Wireless Charging at Intersections	No		Yes	No		Yes
Travel Time (min)	12	17	22	24	29	34
Battery Charging Cost (Riel/kWh)	800	1,600	2,400	800	1,600	2,400
Wireless Charging Cost (Riel/kWh)	Free	1,600	3,200	Free	1,600	3,200

The experimental design considered seven attributes with multiple levels. A full factorial design would result in $2^2 \times 3^3$ different combinations, making direct testing impractical. To handle this complexity, the Statistical Analysis System (SAS) was used to generate an orthogonal fractional factorial design (Han et al., 2022). This method:

- Reduced the number of choice sets while maintaining the ability to estimate main effects and interactions of the attributes.
- Generated 36 choice sets, which were divided into six blocks to reduce respondent burden.
- Each respondent was randomly assigned to one block, making six route choices during the survey.

At the end of each choice set, respondents chose between Route A and Route B, as illustrated in Figure 2 (SP choice example). More details are provided in the appendix of this paper.

3.2 Questionnaire Structure

The survey consists of four sections, beginning with a brief introduction outlining the purpose of the study.

- Section 1: Demographic and Socioeconomic Information
    - Collects basic demographic details (e.g., age, gender, education level)
    - Gathers socioeconomic data (e.g., employment status, income level)
- Section 2: Individual Mobility and Environmental Concerns
    - Captures daily travel patterns and transportation preferences
    - Assesses environmental awareness and concerns related to electric motorcycles (EMs)
- Section 3: Stated Choice Experiments
    - Presents respondents with six choice tasks (randomly selected from 36 choice sets)
    - Asks respondents to choose between Route A (shorter route) or Route B (longer route) based on the provided attributes (e.g., charging availability, travel time, cost)
- Section 4: Feedback and Future Expectations
    - Collects respondent feedback on the survey experience
    - Gathers insights on future expectations for EM infrastructure and policies

3.3 Target city and Data Collection

Phnom Penh, the capital city of Cambodia was chosen as the study area because it offers a diverse and representative respondent demographic, including government officers, private sector employees, students, and individuals from various professions. Additionally, the city's urban intersections align well with the study's research objectives.

Due to the limited number of electric motorcycle (EM) riders in the country, obtaining sufficient responses solely from EM users was challenging. To ensure an adequate sample size, the study included both EM and gasoline motorcycle (GM) riders aged 15 and above.

A total of 250 participants took part in the survey. However, 11 responses were excluded due to missing data and incomplete submissions. As each respondent completed six choice tasks, the final dataset consisted of 1,434 valid responses for analysis.

Obtaining permission and informed consent for the survey was both essential and challenging. To reach potential respondents, Telegram and Messenger were used for initial contact and appointment scheduling. Face-to-face interviews were conducted in convenient locations, such as neighborhood meeting spots or coffee shops that served as temporary offices.

To ensure respondent privacy, no personal information was collected. Additionally, survey samples were provided in advance, allowing participants to familiarize themselves with the questionnaire before the interview.

4. Route Choice Modeling

To analyze electric motorcycle (EM) riders' route choice behavior, a discrete choice model was employed to examine their preferences between alternative routes. The stated preference (SP) survey presented respondents with two route options:

- Route A (Shorter Route)
- Route B (Longer Route)

A mixed binary logit model was used to describe the decision-making process of EM riders, incorporating random variations in utility functions for the two routes. This model extends the traditional binary logit model by allowing for heterogeneity in individual preferences, ensuring a more flexible and realistic estimation of route choice behavior. This approach aligns with Fadilah et al. (2022), who utilized a mixed binary logit model to analyze motorcyclists' route choices based on traffic conditions and policy interventions.

4.1 Model Specification

The probability of selecting Route A or B is formulated as follows:

$$P_{(A)} = \int \frac{e^{(V_A+\eta_A)}}{e^{(V_A+\eta_A)}+e^{(V_B+\eta_B)}} f(\eta_A, \eta_B) d\eta_A d\eta_B \quad (1)$$

$$P_{(B)} = \int \frac{e^{(V_B+\eta_B)}}{e^{(V_A+\eta_A)}+e^{(V_B+\eta_B)}} f(\eta_A, \eta_B) d\eta_A d\eta_B \quad (2)$$

where,

$P_{(A)}$ and $P_{(B)}$ represent the choice probability of Route A or Route B respectively,

V_A and V_B are the deterministic utility functions for the respective routes,

η_A and η_B capture unobserved heterogeneity, assumed to follow a normal distribution,

4.2 Utility Functions

The utility functions for each route incorporate both common and specific attributes affecting EM riders' decisions:

$$V_A = \beta_0 + \beta_1 \times X_{A1} + (\beta_2 + \sigma \times \eta) T_{A2} + \beta_3 (X_{A1} \times C_{A3}) + \beta_4 \times X_{A4} + \beta_5 \times X_{A5} + \eta_A \quad (3)$$

$$V_B = \beta_0 + \beta_1 \times X_{B1} + (\beta_2 + \sigma \times \eta) T_{B2} + \beta_3 (X_{B1} \times C_{B3}) + \eta_B \quad (4)$$

where,

V_A and V_B are the utility of Route A and Route B,

β_1, β_2, β_n are the parameters to be estimated,

X_{A1}: dummy variable for wireless charging system at traffic intersections on Route A

X_{B1}: dummy variable for battery charging station availability on Route B,

T: travel time for each route,

C: charging cost for wireless and battery charging system

X_{A4} is energy remaining at start

X_{A5} is battery recharging station availability at destination

η_A and η_B are random error terms to capture unobserved heterogeneity,

4.3 Interpretation

- Wireless charging at intersections (X_{A1}) is expected to positively influence route choice, as it provides a convenient charging opportunity without stopping.
- Battery charging station availability (X_{B1}) may have a weaker effect if charging stations are inconveniently located or time-consuming to use.
- Travel time (T) and charging cost (C) are expected to negatively influence utility, as longer travel durations and higher costs reduce route attractiveness.
- The interaction term ($X \times C$) accounts for how cost sensitivity varies depending on charging availability.

This mixed binary logit model allows for heterogeneity in individual route preferences and provides insights into the factors influencing EM riders' decisions. The model findings will help policymakers optimize charging infrastructure placement and enhance EM adoption by improving user convenience and reducing cost barriers.

5. Sample Characteristics

5.1 Demographic Factors

A total of 250 respondents were randomly selected for the survey, ensuring representation of individuals aged 15 years and older in accordance with Cambodian traffic laws. After data cleaning, 239 valid responses were analyzed, reflecting a diverse range of demographic and economic characteristics.

- Age and Gender: The sample is concentrated in the 19-30 and 31-40 age groups, with a higher proportion of female respondents than male.
- Employment Status: The majority of respondents are office workers, followed by government officials, while others include students and unemployed individuals.
- Education Level: Most respondents hold a bachelor’s or graduate degree, with smaller groups having high school education, vocational training, or less.
- Income Level: A significant portion earns less than $204, which aligns with Cambodia’s minimum wage (MoLVT, 2024).
- Living Area: Respondents from urban areas are nearly half as common as those from suburban areas.

Table 2 Demographic and economic information of respondents

Characteristics	Category	Number	Percentage
Age	15-18	21	8.8%
	19-30	103	43.1%
	31-40	85	35.6%
	41-50	20	8.4%
	51-60	8	3.3%
	60+	2	0.8%
Gender	female	146	61.1%
	male	93	38.9%
Employment	government officer	63	26.4%
	office worker	101	42.3%
	unemployment	5	2.1%
	student	57	23.8%
	other	13	5.4%

Education	graduate degree	63	26.4%
	bachelor's degree	145	60.7%
	high school or lower	25	10.5%
	vocational training	5	2.1%
	none	1	0.4%
Income	-204	50	20.9%
	$204-799	128	53.6%
	$800-1600	40	16.7%
	$1061-3000	16	6.7%
	$3000+	5	2.1%
Residence	urban	154	64.4%
	suburban	94	39.3%

5.2 Individual Mobility Behavior and Environment

This section explores respondents' travel habits, experience with electric motorcycles (EMs), and environmental attitudes (Table 3).

- Travel Frequency & Distance**:** Most respondents commute daily, with the majority covering distances greater than 10 km.
- Primary Trip Purpose: The main reasons for travel include commuting to school or work, while others travel for business, errands, or professional activities.
- Riding Experience: Many respondents have over 10 years of motorcycle riding experience.
- Awareness of EV Trends: Awareness of global EV adoption is high, with some respondents being moderately aware, while others are very aware.
- Environmental Concerns:
    - Strong agreement that EMs reduce greenhouse gas (GHG) emissions compared to gasoline motorcycles.
    - High importance placed on EVs improving air quality.
    - Environmental factors are considered the most influential reason for using EMs.

Table 3 Individual mobility and environmental awareness of respondents

Travel Frequency	daily	199	83.3%
	3-5 time a week	19	7.9%
	weekly	4	1.7%
	monthly	11	4.6%
	rarely	6	2.5%
Trip Distance	lee than 3.6 km	2	0.8%
	3.6-5.0 km	146	61.1%
	5.1-6.4 km	93	38.9%
	6.4-10.0 km	63	26.4%
	more than 10.0 km	101	42.3%
Trip Purpose	commuting	203	84.9%
	shopping/personal business	21	8.8%
	leisure/visit someone	5	2.1%
	business/professional reason	2	0.8%
	other	8	3.3%
Riding Experience	less than 1 year	32	13.4%
	1-3 years	9	3.8%
	3-5 years	25	10.5%

	5-10 years	59	24.7%
	more than 10 years	114	47.7%
Awareness of EV Trends	don't know at all	27	11.3%
	know very little about it	102	42.7%
	can't say either way	21	8.8%
	know a little	69	28.9%
	know a lot about it	20	8.4%
Opinion on EVs	strongly disagree	2	0.8%
	disagree	8	3.3%
	neither agree or disagree	20	8.4%
	agree	163	68.2%
	strongly agree	46	19.2%
Importance of EVs in improving air quality	very unimportant	0	0.0%
	unimportant	5	2.1%
	neither agree or disagree	18	7.5%
	important	144	60.3%
	very important	72	30.1%
Important factors in EVs use	environment	147	61.5%
	changing infrastructure	32	13.4%
	travel range	17	7.1%
	price	40	16.7%
	other	3	1.3%

6. Influence of Wireless Charging System on Route Choice Behavior

6.1 Estimation of Route Choice Models

A survey conducted in Phnom Penh, Cambodia, analyzed factors influencing electric motorcycle (EM) riders' route choices using a mixed binary logit model. The study examined 1,434 valid observations from 239 respondents, comparing urban Route A (with a wireless charging system) and suburban Route B (with a battery charging station).

Key findings in Table 4 indicate that younger riders (ages 15–30) had no significant route preference, while middle-aged riders were less likely to choose Route A. Gender showed minimal influence, with males displaying a slight but statistically insignificant preference for wireless charging. Lower- and middle-income riders favored Route A, likely due to cost considerations. Conversely, those with vocational training or less education preferred Route B, possibly reflecting lower awareness of wireless charging technology.

The analysis revealed that employment status did not significantly affect route choice, but students and others showed a strong preference for Route B over Route A (student and other = -0.927, t-ratio: -2.03). Riders from suburban areas were more likely to choose the longer Route B with a battery charging station (residential area = -0.321, t-ratio: -2.18), while urban residents preferred Route A.

In terms of mobility and environmental factors, both moderate (moderate travel = 1.330, t-ratio: 2.41) and frequent travelers (frequent travel = 0.988, t-ratio: 2.07) significantly favored Route A. However, long-distance travelers did not show a strong preference, indicating that practical factors such as charging availability and cost play a more critical role. Shopping and leisure travelers preferred urban routes, but awareness of EVs, GHGs, and environmental benefits did not significantly influence choice. Price and travel range remained key considerations (travel factors = -0.411, t-ratio: -1.85).

Regarding route attributes, a significant preference was observed for Route A with a wireless charging system at intersections (estimate = 0.343, t-ratio: 2.89), highlighting the appeal of charging while waiting at traffic signals. In contrast, battery charging stations influenced preference for Route B but were not statistically significant. Riders with higher initial battery levels were more likely to choose Route A (estimate = 0.227, t-ratio: 4.04). However, battery charging stations at the destination had a negative effect on route choice (estimate = -0.281, t-ratio: -4.39), suggesting that riders prefer charging along the route rather than at their final stop. Higher charging costs for both battery (estimate = -0.538, t-ratio: -4.07) and wireless charging systems (estimate = -0.427, t-ratio: -3.81) reduced the likelihood of choosing either route, emphasizing the need for affordable charging solutions to support EM adoption.

Table 4 Estimation result of mixed binary logit model

Parameter	Estimate	Std.err.	t-ratio(0)
Socio-demographic characteristics			
age 15-30	-0.016	0.163	-0.10
age 31-50	-0.500	0.366	-1.36
male	0.197	0.139	1.41
low-income	0.840	0.427	1.96*
middle-income	0.881	0.425	2.07*
vocational training/no education	-0.335	0.455	-0.73
bachelor/high school	-0.185	0.166	-1.11
office/government worker	-0.846	0.424	-1.99*
student/other	-0.927	0.428	-2.16*
residential area	-0.321	0.140	-2.29*
Mobility and environmental factors			
moderate travel	1.330	0.469	2.83**
frequent travel	0.988	0.400	2.46*
medium distance	-0.151	0.242	-0.62
long distance	0.185	0.234	0.79
shopping/leisure activity	0.543	0.251	2.15*
business/other	0.181	0.340	0.53
less experience	-0.994	0.215	-4.60**
moderate experience	-0.162	0.179	-0.90
low awareness	-0.226	0.229	-0.98
high awareness	-0.239	0.246	-0.97
negative opinion	-0.279	0.393	-0.70
positive opinion	-0.425	0.257	-1.65
not importance	0.059	0.563	0.10
importance	0.405	0.260	1.55
travel factors	-0.411	0.200	-2.05*
environment factors	-0.193	0.227	-0.85
Route attributes			
Energy remain at start	0.227	0.059	3.80**
Battery charging station at destination	-0.281	0.064	-4.39**
Battery charging station on Route B	0.150	0.145	1.03
Wireless charging system on Route A	0.343	0.118	2.89**
Battery charging cost	-0.538	0.132	-4.07**
Wireless charging cost	-0.427	0.112	-3.81**
μ	-3.755	0.499	-7.52**
σ	0.969	0.408	2.36*
Number of Individuals	239		
Number of Observations	1434		
LL (final)	-889.3		
Rho-squared	0.105		

6.2 Segmentation analysis

Segmentation analysis was conducted to address the low Rho-squared value in the full model, which indicated a relatively poor fit. The results show a notable improvement in Rho-squared values within segmented models. For instance, the value increased from 0.105 in the full model to 0.156 for males and 0.130 for urban riders. However, segmentation also led to significant changes in the significance of route characteristics due to the reduced number of observations in each segment.

As shown in Table 5, the preference for wireless charging systems at intersections, initially significant in the full model, remained significant only for males and suburban riders. This suggests that these groups place a higher value on wireless charging. Conversely, the significance of this parameter diminished for female and urban riders, likely due to the smaller sample sizes. Additionally, residential area, with a negative coefficient of -2.180, indicated that suburban riders strongly preferred Route B, reflecting their tendency for longer-distance travel. These findings highlight the importance of considering sample size and demographic differences when interpreting segmented analyses to ensure robust and meaningful conclusions.

Table 5 Segmentation analysis of mixed binary logit model

Significant Parameter in Segmented Models					
Parameter		Sex		Living Area	
	Full Model	Male	Female	Urban	Sub-Urban
Energy remain at the start	sig.	sig.	sig.	sig.	sig.
Battery charging station at destination	sig.	sig.	sig.	sig.	sig.
Battery charging station on Route B	non-sig.	non-sig.	non-sig.	non-sig.	non-sig.
Wireless charging System on Route A	sig.	sig.	non-sig.	non-sig.	sig.
Battery Charging Cost	sig.	sig.	sig.	sig.	sig.
Wireless Charging Cost	sig.	sig.	sig.	sig.	sig.
mu_log_b_Travel_different	sig.	sig.	sig.	non-sig.	sig.
sigma_log_b_Travel_different	sig.	non-sig.	non-sig.	non-sig.	non-sig.
Rho-squared	0.105	0.156	0.101	0.130	0.121
Number of Observations	1434	558	876	870	564

6.3 Discussion

This study provides a comprehensive understanding of the factors influencing the route choice behavior of EM riders in Phnom Penh, Cambodia. The preference for shorter urban routes with wireless charging systems at intersections over longer suburban routes with battery charging stations highlights key insights for policymakers in planning future charging infrastructure development.

6.3.1 Wireless Charging System

A key finding is the strong preference for routes with wireless charging systems at intersections. This suggests that riders prioritize the convenience of charging while in motion, reducing overall travel time. Wireless charging also alleviates range anxiety, eliminating the need to search for a charging station—especially in congested urban areas where frequent stops and limited space make charging access critical. This system enables riders to maintain their travel schedules without detours for charging.

However, cost remains a crucial factor. Riders sensitive to high costs may be deterred from using wireless charging, reducing its benefits. Keeping charging costs affordable is essential for broader adoption of Route A. Segmentation analysis further reveals that suburban residents, who typically travel longer distances, highly value the reduced travel time and charging benefits offered by wireless systems. Addressing cost concerns will be key to maximizing adoption and ensuring the success of wireless charging infrastructure.

6.3.2 Battery Charging Stations and Cost

The insignificant estimate for charging station availability on Route B suggests that simply having a charging station along the route is not enough to motivate riders to choose the longer route. Instead, factors such as travel time and cost have a greater impact. The high sensitivity to battery charging costs indicates that riders on Route B are strongly influenced by charging expenses. Any increase in cost could significantly deter riders from choosing this route.

Additionally, while charging stations are necessary, their presence alone is insufficient to attract riders. Cost savings remain a top priority, and high charging fees can diminish the benefits of convenient charging locations. To encourage riders to use Route B, it is essential to keep charging costs low while ensuring sufficient infrastructure. Other factors, such as additional charging time and extended travel time, may also discourage riders from selecting Route B.

6.3.3 Battery Charging Stations at the Destination

The presence of a battery charging station at the destination reduces the preference for choosing the shorter Route A while increasing the appeal of Route B.

For Route A, this suggests that riders may prefer charging along the route rather than arriving at their destination with a low battery and the uncertainty of waiting for a charger. The inconvenience of reaching a destination with insufficient battery power can deter riders from choosing this route.

Conversely, Route B, which already has charging stations along the way, becomes even more attractive when a charging station is available at the destination. This combination of en-route and destination charging provides a comprehensive solution, reducing range anxiety and ensuring riders can start their return journey or next trip with a full charge. Destination charging is particularly valuable for longer trips where the initial energy level may not be enough to complete the journey without recharging. Thus, having a charging station at the destination makes Route B a more reliable and practical choice.

6.3.4 Travel Time

Travel time is the most influential factor in route choice, as indicated by its strong negative estimate. The greater the difference in travel time between the longer Route B and the shorter Route A, the less likely riders are to choose Route B. Longer travel times lead to higher energy consumption and rider fatigue, making Route B less appealing.

Minimizing the travel time difference could increase the attractiveness of Route B. Additionally, charging time affects travel decisions—while Route A allows riders to recharge energy passively during waiting times at intersections, Route B requires extra time for battery charging, making it less convenient. The ability to recharge while waiting reduces the perceived burden of charging for Route A users, while Route B users must account for additional time lost at charging stations.

6.3.5 Energy Remaining at the Start

Riders with higher initial energy levels might consider taking longer routes like Route B. However, they still prefer Route A due to its wireless charging system, which continuously recharges the battery while driving. This continuous charging provides a sense of security and convenience, eliminating the need for unexpected charging stops. Even with sufficient initial energy, the assurance of maintaining consistent battery levels makes Route A more attractive. This underscores the value of wireless charging in ensuring uninterrupted travel and reducing the dependency on battery charging stations, making Route A the preferred choice despite its shorter distance.

7. Conclusion

This study provides valuable insights into the factors influencing electric motorcycle (EM) riders' route choices in Phnom Penh, Cambodia. However, several challenges and limitations must be acknowledged. Wireless charging systems, though promising, are still in their early stages globally. Their implementation at intersections may face significant delays due to technological, financial, and safety concerns, particularly in developing countries like Cambodia. Potential exposure to electromagnetic radiation is another factor that requires further investigation, especially for motorcyclists who lack the shielding available in cars.

Additionally, this study relied on a stated preference (SP) survey, which, while useful for analyzing potential rider preferences, may not fully reflect actual behavior. Future research could combine SP data with revealed preference (RP) data to enhance accuracy. Another challenge was the limited number of EM users in Cambodia, leading to the inclusion of gasoline motorcycle riders in the study. Future studies should focus exclusively on EM users for a more targeted analysis.

7.1 Policy Recommendations

To support the efficient development of EM charging infrastructure in Phnom Penh, policymakers should consider the following recommendations based on rider preferences, charging infrastructure needs, and cost considerations:

1. Pilot Wireless Charging Systems at Urban Intersections
    - Seek technical assistance from developed countries such as Japan, which has successfully tested wireless charging technology.
    - Conduct pilot projects at key intersections to evaluate safety, technological feasibility, and rider acceptance before large-scale deployment.
    - Provide subsidies or incentives to make wireless charging affordable for riders. Given Cambodia's high electricity costs, support from international development agencies, private investors, and EM suppliers is crucial.
2. Expand Battery Charging Stations in Suburban Areas
    - Increase the number of fast-charging stations along suburban routes to support longer travel distances.
    - Strategically place charging stations in high-traffic locations such as restaurants and convenience stores.
    - Maintain low charging costs to encourage adoption and reduce financial barriers for riders.
3. Develop a Hybrid Charging Infrastructure
    - Establish a mix of wireless charging systems and battery charging stations to meet the needs of both urban and suburban riders.
    - Strategically locate charging points based on travel patterns and rider cost sensitivity to ensure maximum convenience.
4. Increase Public Awareness and Accessibility
    - Conduct public awareness campaigns to educate riders on the benefits and proper usage of wireless and battery charging systems.

- Develop a mobile app or digital platform to provide real-time updates on charging station locations, pricing, and availability.
- Highlight cost-saving incentives and government subsidies to encourage EM adoption.

By implementing these policies, the Cambodian government can build a robust and efficient EM charging network that supports both urban and suburban travel needs. A diverse and adaptable charging system will ensure greater adoption of EMs and contribute to sustainable transport development. Whether riders prioritize wireless charging for reduced travel time or prefer cost-effective battery charging stations, a flexible infrastructure will accommodate their needs while promoting environmental sustainability and reducing urban congestion.

5.2 Limitation and Future Works

The wireless charging system envisioned in this study still faces challenges related to institutional design, technological development, and industry collaboration.

To ensure the safe installation and operation of wireless charging systems, institutional frameworks must comply with various regulations, including the Road Act, Radio Act, and Electricity Business Act. Specific conditions such as the depth of charger burial beneath the road surface and the maximum output of charging units must be clearly defined. Additionally, standards for power-receiving coil installations in vehicles must be established, considering factors like crash safety and electromagnetic compatibility. A well-defined regulatory framework is crucial to ensure smooth implementation.

For the practical implementation of wireless charging systems, several technological advancements are necessary. First, it is crucial to develop higher output power capabilities to ensure efficient wireless charging, enabling vehicles to charge effectively without prolonged delays. Additionally, the system must be compatible with high-speed driving to support continuous charging while in motion, which is essential for maintaining smooth and uninterrupted travel. Cost reduction is another critical factor, as making wireless charging technology more affordable will facilitate widespread adoption and encourage investment in necessary infrastructure.

Furthermore, achieving high-efficiency, high-speed power transmission is essential to minimize energy loss and improve overall system performance. The charging system must also demonstrate environmental adaptability, ensuring stable and reliable operation under various road and weather conditions. To enhance integration into vehicles, charging components should be compact, lightweight, and thin, allowing for seamless installation without compromising vehicle design or performance. Lastly, addressing health and safety concerns is imperative, particularly for electric motorcycle (EM) users, by developing measures to mitigate potential risks associated with electromagnetic exposure. These technological advancements will be fundamental in realizing a practical and efficient wireless charging infrastructure for sustainable transportation.

By fostering cross-sectoral collaboration and aligning technological advancements with regulatory frameworks, wireless charging for EMs can be successfully implemented as a key component of sustainable urban mobility.

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