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RESEARCH ARTICLE

Behavior of Micromobility User Towards Different Road Category

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ABSTRACT - The rise of micromobility solutions, particularly e-scooters and e-bikes, is reshaping urban mobility patterns in Malaysian cities. Despite their growing popularity, the behavioral dynamics and safety implications of micromobility users across various road categories remain insufficiently understood. This gap presents a challenge for developing responsive infrastructure and policies that ensure safe integration into existing transport systems. This study aims to examine the behavior, preferences, and safety concerns of micromobility users—focusing on their interaction with four distinct road types: expressways, federal roads, city centers, and residential areas. A mixed-method approach was adopted, comprising two main stages: (i) online surveys to capture user demographics, preferences, and risk perceptions, and (ii) on-site observational studies to assess user positioning, speed, helmet usage, and visibility practices across the selected road categories. The findings reveal notable behavioral differences based on road types. For instance, e-scooter usage was nearly non-existent on expressways, while bicycle users on federal roads and city centers showed a 67% rate of helmet use and a 74% compliance with lighting visibility standards during low-light conditions. In conclusion, the study highlights the urgent need for road-type-specific infrastructure enhancements, reinforced safety regulations, and awareness campaigns tailored to micromobility users. These insights are essential for urban planners and policymakers aiming to foster a safer, more inclusive micromobility ecosystem in Malaysia.

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1. INTRODUCTION

The rapid rise of micromobility solutions, such as e-scooters, e-bikes, and other compact electric vehicles, has revolutionized urban transportation systems across the globe. These modes of transport, characterized by their convenience, affordability, and environmental benefits, have become increasingly popular among city dwellers seeking alternatives to traditional motor vehicles. MIROS previous study showed that Malaysia logged almost 1.2 million micromobility rides in 2022, travelling a total of about 2.1 million kilometres and most of them use for leisure [1]. As cities continue to embrace these new forms of mobility, understanding how micromobility users interact with different road environments has become crucial for ensuring safety, efficiency, and overall user satisfaction. Unlike motor vehicles, micromobility users are highly sensitive to the physical characteristics, design, and traffic dynamics of the roads they use due to variations in speed limits, traffic density, infrastructure design, and enforcement practices [2].

Urban infrastructure encompasses a broad spectrum of road categories, each characterized by distinct design features, traffic volumes, and functional purposes, all of which significantly influence micromobility usage patterns and user behavior. On expressways and high-capacity arterial roads, the design prioritizes fast-moving vehicular traffic, often lacking dedicated micromobility infrastructure, thereby limiting access and posing safety concerns for users [3]. In contrast, federal and state roads, while still accommodating higher traffic volumes, may offer limited shoulder space or shared lanes, creating challenges for micromobility users due to speed differentials and reduced maneuverability [4]. City centers typically feature slower traffic, higher pedestrian activity, and more developed infrastructure such as bike lanes or shared paths, making them more conducive to micromobility use [5]. However, congestion and frequent intersections require heightened attention and adaptive behavior from users [6]. Lastly, residential areas, with lower traffic volumes and slower vehicle speeds, provide relatively safer environments for micromobility, though they may lack formal infrastructure like designated lanes [7] [8]. The interaction of micromobility users with these varying road types underscores the importance of context-specific planning and infrastructure design to enhance safety, accessibility, and efficiency [9].

In Malaysia, micromobility vehicles are currently banned from all roads. This prohibition was enacted under the Road Traffic (Prohibition of Use of Certain Micromobility Vehicles) Rules 2021 and is enforced through the Road Transport Act 1987. The primary reasons for this ban are centered around safety concerns [1]. However, exemptions are possible through sandbox project subject to Ministry of Transport approval, contingent on adherence to the Micromobility Sandbox Implementation Guidelines (GPPSM) developed by MIROS, effective January 24, 2024. These guidelines permit certain micromobility vehicles to operate on roads with speed limits of 50km/h or less, dedicated bicycle lanes, or shared pedestrian paths. This GPPSM may also be or will be amended from time to time. In addition, by the end of 2024, Majlis

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Bandaraya Shah Alam (MBSA), Majlis Bandaraya Pulau Pinang (MBPP), and UiTM Seri Iskandar had each received approval for their micromobility sandbox project implementation. The sandbox project will provide the government with the necessary information to determine the future of micromobility legislation in Malaysia.

1.1 Problem Statement

Despite the growing popularity of micromobility, limited research exists on how user behavior varies across different road categories—such as expressways, federal roads, arterial roads, city streets, and residential zones, which differ significantly in design, speed limits, traffic density, and interaction with other road users. Understanding these behavioral variations is critical, as micromobility users are more vulnerable to road design inconsistencies, lack of infrastructure, and vehicle conflicts than users of conventional motorized transport [10] [11] [12] [13]. For instance, arterial roads with high-speed traffic and limited shoulder width may discourage micromobility use due to safety concerns, whereas residential streets may foster more favorable conditions for shared or personal micromobility use [14] [15].

Behavioral insights can help identify infrastructure gaps, conflict points with other road users, and areas with non-compliant riding patterns. Without this contextual understanding, urban planners and policymakers may implement generalized infrastructure or regulatory measures that fail to address location-specific needs—ultimately compromising safety, efficiency, and user satisfaction [16] [17]. Moreover, existing studies tend to focus on aggregated urban-level usage patterns, neglecting how road typology influences route choice, risk perception, and compliance with road rules [18]. Thus, a detailed behavioral assessment by road category is essential to support evidence-based micromobility integration and ensure safer, more sustainable urban mobility ecosystems.

1.2 Objectives

The primary objective of this study is to investigate how micromobility user behavior—including preferences, safety concerns, and usage patterns—is influenced by different road categories, with the goal of informing infrastructure planning and policy decisions to support safer and more effective integration of micromobility into urban transport systems.

1.3 Significant of the study

This study is significant in that it addresses a critical gap in the understanding of micromobility user behavior across different road categories, the lack of empirical data and comparative analysis on how specific road characteristics such as traffic volume, speed limits and infrastructure provision influence micromobility usage, safety perception, and behavioral adaptation. Existing literature often examines micromobility use in general urban contexts or at isolated intersections but fails to distinguish how users interact differently with expressways, federal roads, urban commercial streets, and residential areas [19] [20].

This generalization overlooks the nuanced ways that road design and function affect route choices, risk exposure, and compliance with traffic rules. For instance, federal or arterial roads may lack designated micromobility lanes, leading to risky riding behavior, while residential areas, though lower in traffic, may not be designed with vulnerable road users in mind. Furthermore, the absence of disaggregated data prevents policymakers from making informed decisions on where and how to invest in safe micromobility infrastructure. By filling this research gap, the study contributes essential evidence to support targeted urban planning and safety strategies for diverse road environments.

The findings of this study will support the development of more effective infrastructure, safety measures, and policies to meet the growing demand for micromobility in cities. By identifying how users behave on different road types, the study can guide where to build dedicated lanes, improve crossings, or link micromobility routes to public transport. It also helps shape safety protocols—such as signage, speed control, and rider education—tailored to specific road environments. Additionally, the insights can inform clearer, evidence-based regulations that define where micromobility devices are allowed, ensuring safer and more organized integration into the urban transport system.

2. METHODS AND MATERIALS

This study employs a mixed-method approach, combining data from on-line surveys form and from on-site observational studies to explore the behavior of micromobility users across different road categories. The research design is cross-sectional, capturing data at a single point in time to provide a snapshot of user behavior in various urban settings.

2.1 Study Area

The study was conducted in selected areas in Kuala Lumpur and Selangor, a city recognized for its diverse urban infrastructure and growing adoption of micromobility. The selected study area includes a variety of road categories such as expressways, federal roads, city centers, and residential neighborhoods, providing a comprehensive environment for examining micromobility user behavior. Kuala Lumpur and Selangor were chosen due to its mixed-use development patterns, high traffic density, and the presence of both modern and aging infrastructure, which together reflect the real-world challenges of integrating micromobility into complex urban settings. Moreover, the city has seen increasing use of e-scooters and other micromobility devices, particularly around public transport hubs, commercial areas, and recreational zones—making it an ideal location for gathering relevant and varied user data.

2.2 On-line Survey

This survey aims to gather quantitative data on user preferences and usage patterns across different road categories through a structured questionnaire comprising both closed- and open-ended questions. Closed-ended questions will capture measurable aspects such as frequency of micromobility use, preferred road types, perceived safety, and availability of infrastructure—for example, asking how often users ride e-scooters per week, or whether they feel safe using them on federal roads. Meanwhile, open-ended questions will provide deeper insights into user experiences by inviting respondents to explain challenges faced on specific road types or describe reasons for avoiding certain routes. This combination allows for both statistical analysis and contextual understanding to better inform infrastructure planning and policy development. The survey will cover the following areas:

i. Road Category Preferences: Participants will choose their preferred road types for micromobility use—such as city center roads, residential streets, federal roads, and expressways—and provide reasons for their choices as guided by the questionnaire. These preferences will help identify which road environments users perceive as most suitable or safe for micromobility travel.

ii. Usage Patterns: Information on typical routes, speed, and duration of use on different road types.

The survey will be administered online and via mobile applications, with links shared through social media, micromobility platforms, and local community networks. The survey will be distributed online rather than through physical means to ensure broader reach, cost-efficiency, and ease of data collection. Online distribution allows the survey to be accessed by a diverse group of respondents across different locations and timeframes, particularly tech-savvy micromobility users who are more likely to engage through digital platforms. It also minimizes logistical challenges and reduces health risks associated with in-person interactions. Moreover, digital surveys facilitate quicker response collection and automated data processing, improving overall research efficiency. Micromobility users involved in this survey including rental and private users who own the micromobility device. Respondents will be selected through random sampling at various public locations in study areas, including transit stations, parks, and commercial areas, to ensure diverse demographic representation and capture a broad range of user experiences and perceptions

2.3 On-Site Observational Study

On-site observation was conducted to record the actual behavior of micromobility users across different road categories within Kuala Lumpur and Selangor. Key locations were strategically selected to represent expressways, federal roads, city centers, and residential areas across various regions of the city. For expressway proximity, observations took place near the LATAR, LEKAS and Guthrie, where informal micromobility crossings are occasionally observed. Federal road behavior was recorded along Kuala Selangor, a major arterial route with high traffic volume. In the city center, Jalan Bukit Bintang and Jalan Ampang were chosen due to their high micromobility activity and complex urban environment. Residential area observations were carried out in Melawati, Putra Height and Shah Alam. These diverse locations provide a comprehensive understanding of micromobility user behavior in real-world urban contexts. Observers will record data on the following variables:

i. Speed: Average speed of users on different road types.

ii. Lane Positioning: Whether users ride on the road, sidewalk, or bike lanes.

iii. Safety Behaviors: Helmet use, adherence to traffic signals, and interactions with other road users.

Observations will be conducted during different times of the day (peak and off-peak hours) to capture a range of traffic conditions. Data will be recorded using standardized observation sheets, and where possible, video recordings will be used to validate and supplement observations.

2.4 Data Analysis

2.4.1 Quantitative analysis

Descriptive Statistics: Basic statistics (mean, median, mode) will be used to summarize data, road preferences, and safety concerns.

2.4.2 Qualitative analysis

Thematic Analysis: Responses to open-ended survey questions will be coded and grouped into key themes related to user experiences and safety concerns. These responses will be categorized based on common topics such as perceived safety, quality of infrastructure, user behavior, enforcement issues, and environmental challenges. For example, comments about unsafe road conditions will be grouped under safety concerns, while suggestions for better lanes or signage will be categorized under infrastructure needs. This approach helps to clearly identify the main issues faced by micromobility users across different road types.

Behavioral Patterns: Observational data will be analyzed to identify patterns in lane positioning, speed, and rider behavior across different road categories. This includes examining whether users use sidewalks or vehicle lanes and their speed relative to surrounding traffic. The analysis will also note any risky behaviors such as sudden lane changes, riding against traffic flow, or use of unauthorized routes. These patterns will help assess how road design and traffic conditions influence micromobility user behavior in real-world settings.

3. RESULTS AND DISCUSSION

3.1 The Rise of Micromobility Vehicles

Figure 1 illustrates the prevalence of various micromobility vehicles in Malaysia, revealing clear user preferences. Electric scooters (e-scooters) are the most popular, accounting for 62% of users, followed by electric bicycles (e-bikes) at 44% and mountain bikes at 31%. The surge in e-scooter usage can be attributed to several factors—primarily convenience, portability, and environmental advantages. E-scooters are lightweight, foldable, and easy to store or carry, making them suitable for short urban trips and first- or last-mile connections [21] [22]. In terms of environmental benefits, e-scooters produce zero tailpipe emissions, helping to reduce air pollution and greenhouse gas emissions in dense urban areas. This aligns with growing public awareness of climate change and individual efforts to adopt greener travel habits. Cities experiencing high levels of traffic congestion and pollution have seen e-scooters as a sustainable alternative to private cars or motorcycles [23]. Furthermore, many e-scooters are powered by rechargeable batteries, which—when sourced from renewable energy—contribute further to carbon reduction. This environmental appeal, combined with affordability and increasing accessibility through shared micromobility platforms, has driven the rapid adoption of e-scooters in Malaysia's urban centers [24] [25] [26].

Other options, including mopeds (15%), folding bikes (8%), city bikes (5%), electric unicycles (4%), other bike types (6%), and hoverboards (2%), are used less frequently. This distribution highlights a growing shift in user preference toward electric micromobility options over traditional non-electric bicycles. The preference for electric vehicles can be attributed to their ability to reduce physical effort, offer faster travel times, and provide greater convenience for longer or uphill commutes. Additionally, electric micromobility options are increasingly viewed as practical alternatives to cars for short-distance urban travel, especially in congested areas [27] [28]. Their lower operational costs and contribution to reduced carbon emissions also appeal to environmentally conscious users, reinforcing the trend toward electrification in urban transport [1] [7] [14].

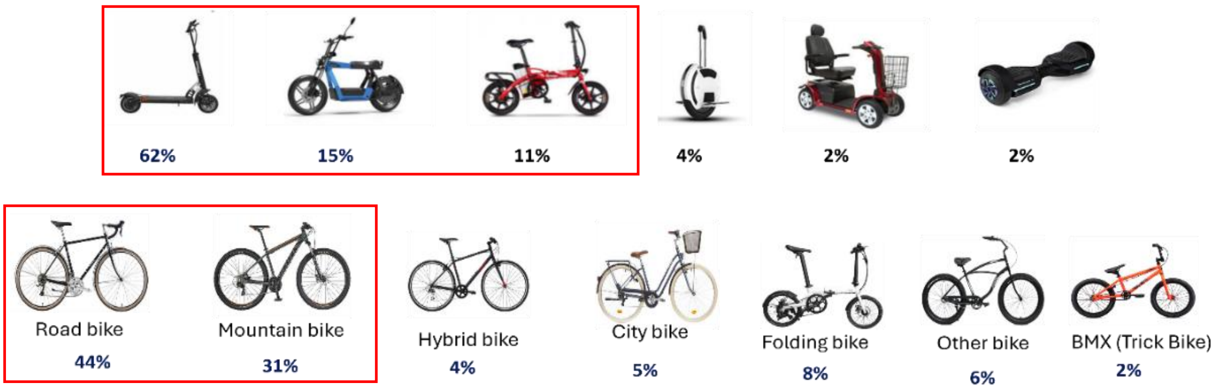

Figure 1. Common micromobility vehicles usage rates

3.2 Distribution of Micromobility Vehicles Usage Across Malaysia

Figure 2 illustrates the regional distribution of personal micromobility usage across Malaysia, with the central region (Selangor, Kuala Lumpur, Putrajaya, and Negeri Sembilan) showing the highest concentration at 70.8%. In contrast, the northern region (Perlis, Perak, Penang, and Kedah) and the eastern region (Kelantan, Terengganu, and Pahang) recorded the lowest usage, at 6.2% and 5.7% respectively. This disparity can be attributed to several key factors such as the central region is more urbanized and has better-developed transport infrastructure, including cycling lanes, pedestrian paths, and integration with public transport, which are crucial in supporting micromobility adoption [29].

Conversely, the other regions of Malaysia are predominantly rural or semi-urban, where dedicated infrastructure for micromobility is often limited or lacking. Furthermore, cultural preferences for motorcycles and cars, especially in rural areas, continue to dominate daily mobility patterns [30]. The lack of exposure to shared micromobility services and limited local government policies promoting sustainable urban transport further contribute to the lower adoption in these areas [31]. Micromobility offers a range of benefits that justify its expansion beyond high-demand urban areas. Environmentally, it contributes to lower carbon emissions and reduced air and noise pollution, especially through electric options such as e-scooters and e-bikes [32]. From a traffic perspective, micromobility helps alleviate congestion by reducing reliance on private cars, particularly for short trips and first- or last-mile connectivity to public transport. Economically, it presents a more affordable travel option compared to car ownership or ride-hailing, while also generating employment opportunities in maintenance, operations, and logistics. Socially, micromobility can enhance transport equity by improving access for underserved communities and promoting healthier lifestyles through active travel modes like cycling. Furthermore, in terms of urban planning, these vehicles are space-efficient and can be deployed rapidly compared to traditional infrastructure. These combined advantages explain why many cities are now extending micromobility services to semi-urban and lower-demand areas, aiming to promote inclusive and sustainable urban mobility. Recognizing micromobility's benefits, cities are extending services beyond areas [33] [34].

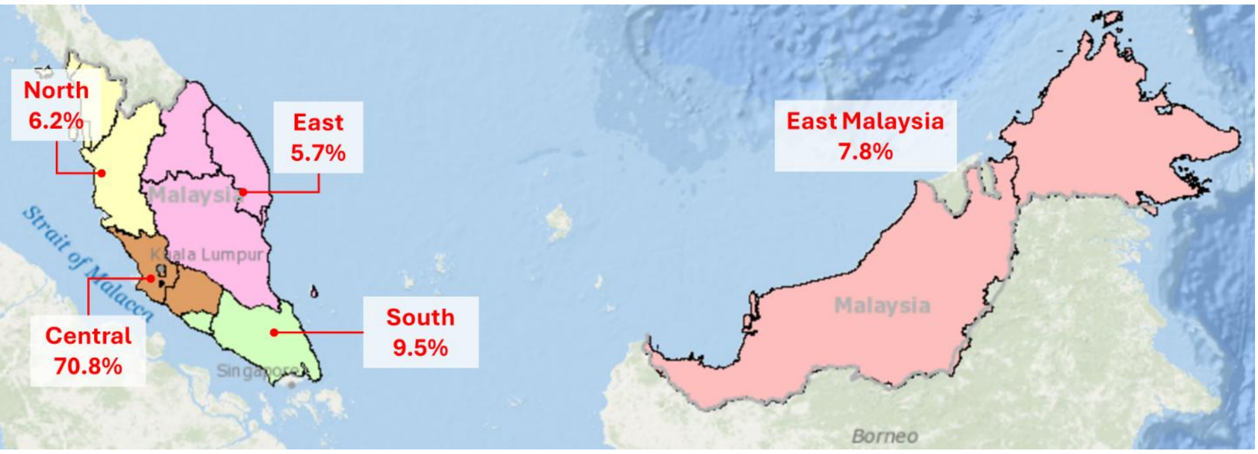

Figure 2. Regional distribution of micromobility usage across Malaysia

3.3 Micromobility User Preferable Position on Road: Doing vs Saying

This chapter reviews findings from observations, which show real-world actions, and surveys, which show perceptions and self-reported behavior based on road types. In addition, Malaysian roads categorized into four main types. Figure 3 to 5 shown an example of micromobility behavior on different road categories.

i. Highways/expressway - typically characterized by higher speeds and limited non-motorized traffic.

ii. Federal roads - main national road network connect major cities and towns across Malaysia, are roads fall under the jurisdiction of the Ministry of Works (MOW) and the Malaysian Public Works Department (JKR) is primarily responsible for the construction and maintenance of these roads.

iii. Municipal roads – also known as city roads or local roads, are roads that fall under the jurisdiction of local governments, such as city councils or municipalities.

iv. Other roads - any road that doesn't fall under the primary classifications of highways, federal roads, or municipal roads.

Figure 3. Example of micromobility behavior on expressway

Figure 4. Example of micromobility behavior on federal road

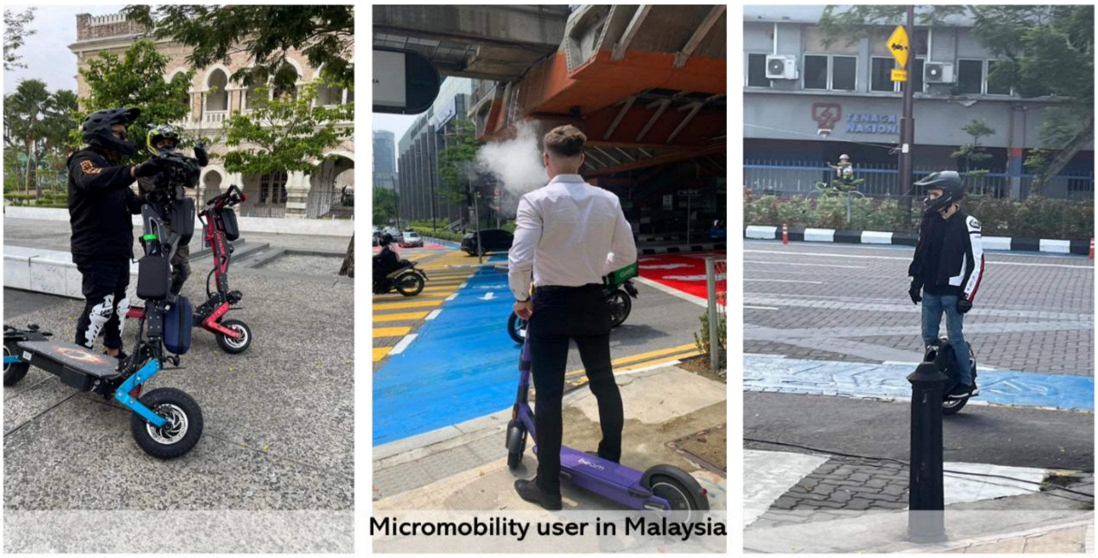

Figure 5. Example of micromobility behavior on municipal or cities road

3.4 Micromobility User Safety Awareness

Table 1 presents a comparative analysis of micromobility characteristics between cyclists and e-scooter users on roads, focusing on positioning, helmet wearing, device light usage, and speed. The data is categorized by road type (Expressway and Other Road) and includes the number of cyclists (1,451) and e-scooter users (757) observed. Notably, there were null numbers of e-scooter presence on the highway during the observation period. The absence of e-scooters on highways during the observation period can be attributed to a combination of legal, safety, and infrastructural factors. Highways in Malaysia prohibit the use of micromobility devices such as e-scooters due to their incompatibility with high-speed traffic and the lack of protective infrastructure

Helmet wearing is more prevalent among e-scooter users on other roads, with a significant portion of cyclists on expressways not wearing helmets [35]. Cyclists on expressways largely use device lights, with a mix of both, rear, and front lights on other roads, while e-scooter users predominantly use both lights on other roads. Speed data indicates that cyclists generally have higher average and maximum speeds compared to e-scooter users across different road types [36].

Different road types influence the speed of cyclists and e-scooter users due to variations in infrastructure, surface quality, and traffic conditions [37]. They generally achieve higher average and maximum speeds, particularly on dedicated bike lanes and low-traffic roads, where smoother surfaces and fewer obstacles allow for greater momentum and confidence. In contrast, e-scooter users tend to ride more cautiously and are often constrained by speed limits set on shared devices. On urban and arterial roads, cyclists maintain relatively higher speeds due to their ability to navigate traffic and use road shoulders, while e-scooter users typically reduce speed to ensure safety in mixed-use spaces [38]. More will discuss on sub chapter below.

Table 1. Micromobility characteristic on road

Attribute	Value	
	Cyclist (1,451)	E-scooter (757)
Positioning		
Expressway		
Bike Lane (BL)	NA	NA
Motorcycle Lane (McL)	456 (60.2%)	-
Emergency Lane (EL)	277 (36.6%)	-
Carriageway L1 (L1)	24 (3.2%)	-
Carriageway L2 (L2)	0	-
Other road		
Bike Lane (BL)	61 (4.2%)	88 (49.2%)
Motorcycle Lane (McL)	NA	NA
Emergency Lane (EL)	234 (16.1%)	4 (2.2%)
Carriageway L1 (L1)	1,006 (69.3%)	83 (46.4%)
Carriageway L2 (L2)	150 (10.3%)	4 (2.2%)
Helmet Wearing		
Expressway		
NA	0	-
Bright	360 (47.6%)	-
Dark	397 (52.4%)	-
Other road		
NA	132 (9.1%)	167 (93.3%)
Bright	544 (37.5%)	3 (1.7%)
Dark	775 (53.4%)	9 (5.0%)
Device Light		
Expressway		
NA	458 (60.5%)	-
Both	33 (4.4%)	-
Rear Only	264 (34.9%)	-
Front Only	2 (0.3%)	-
Othe road		
NA	686 (47.3%)	16 (8.9%)
Both	297 (20.5%)	122 (68.2%)
Rear Only	425 (29.3%)	20 (11.2%)
Front Only	43 (3.0%)	21 (11.7%)
Speed		
Expressway		
Motorcycle Lane (McL)		
Min	13km/h	-
Average	34km/h	-
Max	53km/h	-
Carriageway		
Min	14km/h	-
Average	32km/h	-
Max	76km/h	-
Other Road		
Min	5km/h	5km/h
Average	18km/h	14km/h
Max	39km/h	49km/h

3.4.1 Position preferable

This study reveals a stark contrast between the positioning of bicycles and e-scooters on roads based on on-road observation. The on-site observation revealed that e-scooter riders were not used on high-speed road (highways/expressways), while bicyclist (cyclist) were observed - show a clear predominance of cyclist, in specific at motorcycle lanes (MC L) and emergency lanes (EL). This aligns with the government's ban on certain micromobility vehicles on public roads since their speed, stability, and potential for serious injury in collisions with faster-moving vehicles raise safety issues. Furthermore, e-scooters are frequently not built or prepared to withstand the demands of high-speed traffic and using them on such routes might put the rider and other drivers at risk. This prohibition does not apply to bicycles and e-bicycles, subject to their adherence to prescribed specifications and guidelines [39]. In comparison to other road types, cyclist showed a tendency to utilize the main carriageway (L1), which is shared with motorcycles, cars, and lorries [40].

However, the presence of cyclists on high-speed roads is alarming to traffic enforcement due to significant safety concerns. Visibility issues further compound this danger, as drivers traveling at high speeds may struggle to detect cyclists, particularly in challenging conditions such as low lighting at dawn or dusk, heavy rain, fog, glare from oncoming headlights, or when cyclists wear dark clothing without reflective gear. These conditions reduce a driver’s reaction time and increase the likelihood of collisions, especially on roads lacking proper shoulders or designated cycling lanes [41]. Additionally, cyclists can disrupt the smooth flow of traffic, forcing drivers into potentially dangerous evasive manoeuvres. Legal and regulatory frameworks often prohibit cycling on such roads precisely because of these risks, necessitating strict enforcement to protect all road users [42].

Meanwhile, other studies reveal different types of road or path priorities for micromobility users (Figure 6). Each bar represents a different road or path type, and the segments within the bars are color-coded to represent priority levels, ranging from "First Priority" to "Last Priority”. In the context of micromobility infrastructure, user preferences for various types of roadways and paths highlight significant trends that are crucial for urban planning. Micromobility lanes emerge as the preferred option for users, with 57.8% of the responses indicating "First Priority." This suggests that when dedicated lanes are available, they are overwhelmingly favored by micromobility users, likely due to the safety and convenience they provide [43].

On the other hand, motor vehicle lanes are largely avoided, as reflected by the substantial portion of responses (4.4%) categorizing them as "Last Priority." This avoidance underscores the potential dangers and discomfort associated with sharing lanes with larger, faster vehicles. Surveys show micromobility users know high-speed roads are dangerous and avoid them if possible [44]. However, they are still seen on these roads, likely due to a lack of safe alternatives, misunderstanding of rules, or necessity. Several research-based improvements are suggested to reduce the dependence of micromobility users on high-speed roadways. To keep micromobility separate from fast-moving cars, road authorities are urged to designate protected lanes specifically for micromobility. It is also advised to improve road markings and signage to alert cars and provide users with advice. Another advocacy strategy is to educate the public on traffic laws and safe driving techniques. Adhere to current road laws to ensure safe behaviour. In the meanwhile, include micromobility infrastructure into overall transportation planning to provide safer and more connected travel options and lessen the need to use hazardous roadways [1] [14] [45].

The sidewalk or pedestrian path shows a mixed set of priorities, though it tends to be less favored, indicating that while micromobility users do utilize sidewalks, they are not the most desirable option [46] [47]. This is likely to be due to the need to navigate among pedestrians, which can be inconvenient and unsafe for both parties [48]. Similarly, the road shoulder or emergency lane is seen as an acceptable alternative, but it does not rank highly in user preferences. This suggests that while these lanes are usable, they are not ideal, possibly due to debris, uneven surfaces, or their intended use for emergency stops rather than continuous travel [46]. Lastly, unpaved roads or trails are the least preferred option, with 8.5% marking them as "Last Priority." This avoidance is likely due to the rough terrain, which is unsuitable for most micromobility devices, making them impractical and potentially hazardous for regular use. Overall, the data indicates a clear preference for dedicated micromobility infrastructure, while alternative routes like sidewalks, road shoulders, and especially unpaved paths, are less desirable, highlighting the need for urban environments to prioritize the development of specialized micromobility lanes [49] [50] [51].

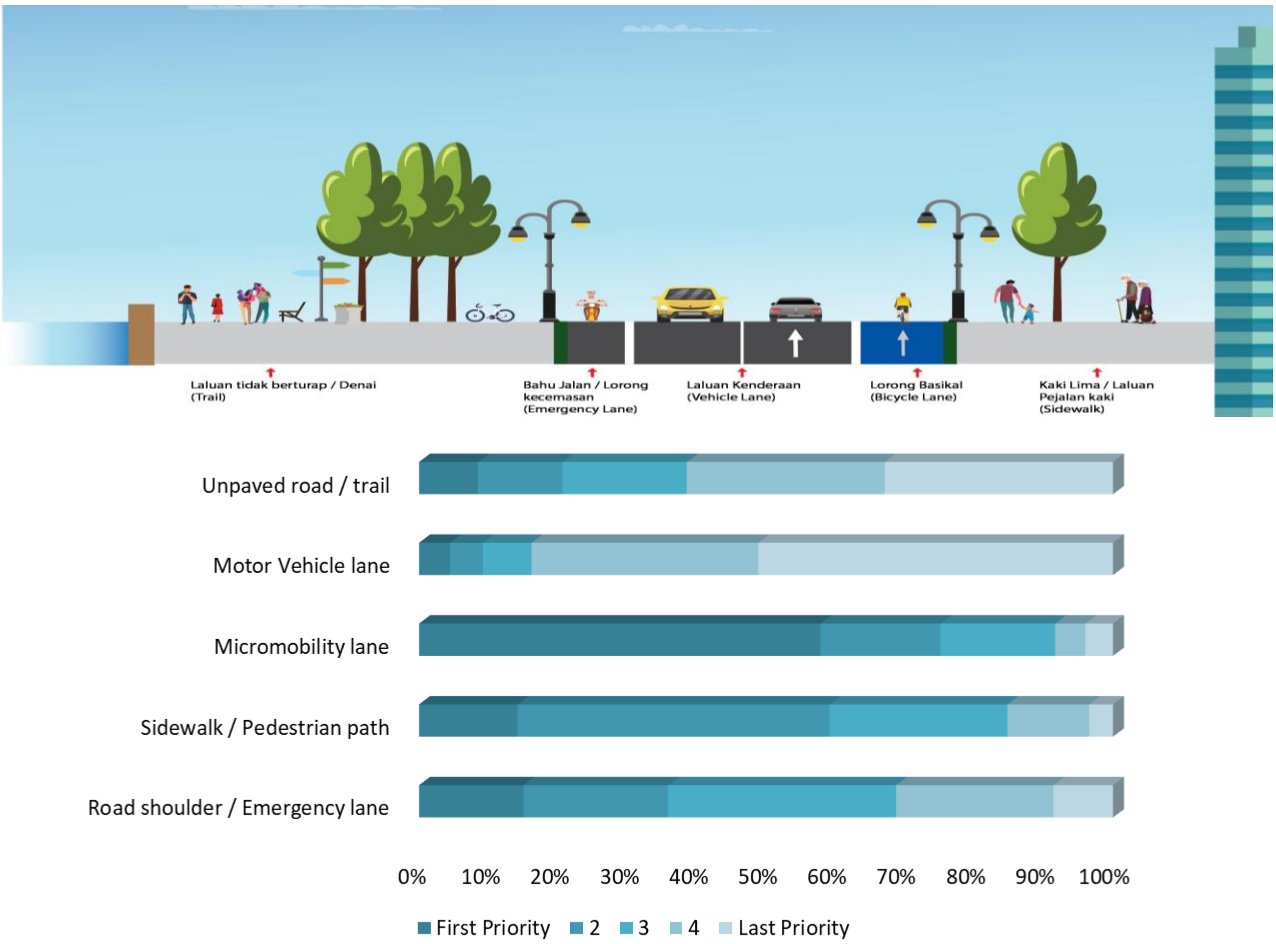

Figure 6. User priority for micromobility usage across different road types based on survey

3.4.2 Helmet wearing

This study shows that helmet-wearing rates among the e-scooters are relatively low. The figures indicate that cyclists have a higher helmet-wearing rate on the roads compared to e-scooter users. However, helmet-wearing rates on expressways for e-scooter users appear negligible, as indicated by the non-presence of e-scooters on the expressway. Meanwhile, cyclists have a consistently high helmet-wearing rate on the expressway, likely due to increased safety concerns on high-speed roads [52].

3.4.3 Visibility on the road

This study also indicates that e-scooter users on other roads have some level of device lighting, but the rates vary across different conditions or times. The result also suggests that cyclists are more consistent in using device lighting on other roads compared to e-scooter users. Under Malaysia's Road Traffic Rules (Rule 35), all bicycles ridden between sunset and sunrise must have a white front light and red rear light [53]. While both groups utilize lighting devices, cyclists exhibit a notably higher and more uniform usage rate, potentially due to the legal requirement for bicycle lights in Malaysia [39]. E-scooter users show very low use of device lighting, which can be dangerous, especially in dark or high-speed areas. This is likely because there are no clear rules requiring lights on e-scooters in Malaysia, and many users rely on built-in lights that may be weak or not working. On the other hand, cyclists are more likely to use lights on expressways because the law requires it, and they understand the higher risks. Since expressways have fast-moving traffic and low visibility, cyclists use lights to make themselves more visible and stay safe.

3.4.3 Speed profile

The speed data in Table 1 reveals a clear distinction in speed profiles between cyclists and e-scooter users based on site observation. A number of important elements, such as infrastructure design, vehicle performance, user behaviour, and safety considerations, affect how fast bikers and e-scooter users travel on different types of roads [54]. On expressways, where only cyclists were observed using motorcycle lanes, the relatively high speeds (average 34 km/h) reflect the smooth road surface, limited interruptions, and dedicated lanes that allow for continuous, unimpeded cycling. When cyclists use the main carriageway (EL), even higher speeds—up to 76 km/h—may occur, possibly due to surface and gradients or drafting effects, although this also introduces greater safety risks.

In contrast, both cyclists and e-scooter users exhibit slower speeds on "other roads," which typically include shared paths, local streets, and areas with more pedestrian activity. These environments often involve narrower lanes, uneven surfaces, intersections, and mixed traffic, all of which require more cautious navigation. E-scooter users, in particular, travel significantly slower than cyclists on average due to technical limitations such as smaller wheels, lower power output, and factory-set speed caps (usually around 20–25 km/h for shared scooters). Moreover, e-scooter users may be less experienced and more risk-averse, further contributing to their slower travel speeds. Overall, the combination of road type characteristics, vehicle performance, and user intent (e.g., commuting vs. leisure) shapes how fast each mode can and does travel. Infrastructure suitability and perceived safety are especially influential in determining micromobility speed behavior across different environments [55].

3.5 Implications for Urban Planning

The findings emphasize the need for targeted infrastructure improvements tailored to each road category. For example, high-risk areas like expressways require enhanced safety features, while city centers and residential areas benefit from expanded and well-maintained bike lanes.

3.6 Policy Development

The study highlights the importance of developing policies that address specific challenges associated with each road type. This includes implementing speed regulations, safety guidelines, and educational programs to improve user behavior and safety across various environments.

i. Speed Regulations: Develop and enforce speed limits specific to micromobility vehicles in high-traffic areas and shared spaces.
ii. User Education: Implement educational programs to inform users about safe practices, especially in high-risk environments like expressways.
iii. Regulatory Framework: Establish clear regulations for micromobility usage across different road categories, ensuring consistency and safety.

4. CONCLUSIONS AND RECOMMENDATIONS

This study offers important insights into micro-mobility user behavior across different road categories in Malaysia, addressing the study objectives of identifying key behavioral patterns, safety concerns, and infrastructure needs. Speed data revealed a clear distinction between cyclists and e-scooter users, with cyclists generally exhibiting higher average and maximum speeds, especially on expressways and main carriageways, while e-scooter users maintained significantly lower speeds, particularly on local and shared-use roads. These variations are influenced by road type characteristics, safety perceptions, and user-specific limitations. Positioning patterns and compliance behavior also varied across road types. E-scooters were predominantly observed in urban settings but were entirely absent on expressways due to legal and safety constraints. Cyclists, however, were present on expressways, primarily using motorcycle or emergency lanes—raising serious safety concerns due to limited visibility and significant speed differentials with motor vehicles. Helmet usage and lighting compliance were notably higher among cyclists, especially on high-speed roads, compared to e-scooter users.

To ensure safer integration of micromobility into the transportation network, this study recommends specific infrastructure improvements, including development of physically separated micromobility lanes along arterial roads and urban corridors to reduce conflicts with motor vehicles, dedicated micromobility crossings and buffer zones at intersections to enhance rider visibility and reduce crash risk, installation of adequate lighting, reflective road markings, and wayfinding signs on routes frequently used by micromobility users, and retrofit of underutilized motorcycle lanes to accommodate micromobility safely, especially where demand is high and alternative infrastructure is lacking. In addition to infrastructure, policy interventions are needed, such as establishing appropriate speed limits for micromobility vehicles based on road type, enforcing helmet and lighting regulations, and introducing education campaigns to encourage safe riding behavior. Overall, the study contributes empirical evidence that supports more targeted and data-driven planning for micromobility integration. Future research should examine how users adapt to new infrastructure and policy changes over time and evaluate the effectiveness of interventions aimed at reducing micromobility-related crashes and enhancing network connectivity.

5. LIMITATION

In the nutshell, the sample in this study is not representing the vast majority of the Malaysian population, thus the findings should be interpreted with care and be perceived as an initial exploration of the MMD’s user characteristics that may exists in Malaysia.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

A. Roslan, R. Hamidun, N. S. Mohd Zulkipli, Z. H. Zulkiffli, K. D. Wing and S. Z. Ishak: Conceptualization, Design, Draft manuscript preparation.

A. Roslan, R. Hamidun, N. S. Mohd Zulkipli, Z. H. Zulkiffli, K. D. Wing: Data collection, Data analysis, Interpretation of results, Reviewing and Editing.

All authors reviewed the results and approved the final version of the article.

AVAILABILITY OF DATA AND MATERIALS

The data used to support the findings of this study are included within the article. Data sharing is not applicable to this article.

ETHICS STATEMENT

Not applicable.

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