

Article

Determining the Location of Shared Electric Micro-Mobility Stations in Urban Environment

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Abstract: Locating shared electric micro-mobility stations in urban environments involves balancing multiple objectives, including accessibility, profitability, sustainability, operational costs, and social considerations. This study investigates traveler preferences regarding shared electric micro-mobility stations, focusing on factors influencing their location decisions. The study used the Analytic Hierarchy Process (AHP) model to analyze the criteria and determine their relative importance in influencing the location decisions of shared electric micro-mobility stations as evaluated by experts in transportation fields. The examined criteria are proximity to public transportation, accessibility to key destinations, demographics (e.g., age, and income), safety, land use, and pedestrian and cyclist infrastructure. Using the AHP model, the importance and ranking of each criterion were established. Results indicate that the availability and quality of sidewalks and bike lanes in the vicinity, along with the proximity to popular destinations like shopping centers and tourist attractions, emerge as the most influential criteria. The least important criteria were the demographics such as the young age percentage in the area and the average income of the surrounding population. These findings underscore the critical importance of well-maintained infrastructure for pedestrian and cyclist mobility, as well as the need for convenient access to high-traffic areas. Such insights provide valuable guidance for informed decision making regarding the optimal placement of shared electric micro-mobility stations.

Keywords: analytic hierarchy process; shared electric mobility; micro-mobility; location optimization



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1. Introduction

Cities all over the world have experienced rapid urbanization and population growth, leading to an increase in traffic congestion. Shared electric micro-mobility has emerged in recent years because it is eco-friendly, affordable, and easy to use [1]. Micro-mobility solutions can reduce private vehicle use, especially for short trips, and signify a shift to more ecologically friendly transportation. Accordingly, the adverse effects of traffic congestion, such as air pollution and high land use could be mitigated by shared electric micro-mobility services. Moreover, their utilization may promote physical activity and contribute to improved public health outcomes. Micro-mobility sharing allows people to use different forms of transportation on demand [2]. Furthermore, the convenience of electric-assisted micro-mobility broadens the shared mobility market. Therefore, shared mobility and electrification are two of the most promising transportation trends. However, enhanced accessibility for shared micro-mobility services could amplify their benefits, making them more recognizable and impactful.

The location and layout of the stations where customers can pick up and drop off electric bikes or electric scooters are essential in terms of accessibility [3]. Finding optimal locations for shared electric micro-mobility stations is a challenging problem due to the many spatial aspects [4–6]. Several solutions, from straightforward heuristics to complex mathematical models, have been offered to optimize shared electric micro-mobility stations [7]. Prior to discussing the identification and mapping of charging stations in shared electric micro-mobility systems, it is crucial to acknowledge the limitations of micro-mobility initiatives. These include concerns such as range anxiety, infrastructure accessibility, safety, regulatory barriers, and conflicts with other modes of transportation. Understanding these challenges is essential for optimizing the performance of micro-mobility systems. The identification and mapping of charging stations in shared electric micro-mobility systems hold significant scientific importance due to several key reasons. Firstly, information on the exact location of charging stations enables efficient planning and optimization of the micro-mobility system, ensuring adequate coverage and availability of charging infrastructure [8]. This determination of the station location helps alleviate the electric micro-mobility limitations, promoting overall reliability and accessibility. Secondly, mapping charging stations facilitates the analysis and modeling of charging patterns and energy demand, enabling the development of intelligent charging strategies and infrastructure expansion plans. Additionally, such data aid in evaluating the environmental impact and sustainability of electric micro-mobility systems by assessing energy consumption, which indirectly influences carbon emissions through electricity generation which is approximately higher than 100 CO₂eq/pkt [9–11]. This evaluation also includes the potential integration of renewable energy sources to mitigate environmental impacts. Lastly, the availability and visibility of charging station locations play a crucial role in enhancing user experience and promoting the adoption of shared electric micro-mobility, fostering a seamless transition toward cleaner and more sustainable urban transportation systems [12,13].

The contributions of this study are that we identify and examine several criteria essential for determining the optimal locations for charging stations in shared electric micro-mobility systems, encompassing aspects such as proximity to public transportation, key destinations, demographics, safety, land use, and pedestrian and cyclist infrastructure. Utilizing the Analytic Hierarchy Process (AHP) model, our systematic approach prioritizes these criteria, contributing to the efficiency, accessibility, and sustainability of electric micro-mobility systems in urban environments. Additionally, our research informs urban planning decisions, guiding the development of more sustainable and accessible transportation systems.

2. Literature Review

With the increasing public acceptability of shared mobility, it becomes critical to integrate these services into sustainable urban mobility. For instance, the research by An et al. [14] emphasizes the importance of understanding stereotypes surrounding shared mobility and identifying dimensions such as competence that influence public perceptions. Additionally, Neifer et al. [15] underscore the need to address performance expectations and collective environmental impact to enhance user acceptance of electric micro-mobility. Furthermore, Jaber et al. [16] highlight the preferences of micro-mobility users in urban areas, indicating factors such as trip time, trip cost, and parking characteristics that influence mode choice. Overall, these studies contribute to the theoretical understanding of shared mobility acceptance and offer valuable insights for policymakers and planners aiming to promote sustainable transportation options.

Previous research has investigated various factors influencing the location of shared electric micro-mobility stations in cities. These factors can be broadly categorized into physical, economic, social, and policy-related factors [1,5]. Understanding these factors and how they interact with each other and with urban mobility patterns is crucial for optimizing the location of shared electric micro-mobility stations [17,18].

The proximity of shared electric micro-mobility stations to public transportation has been one of the most studied factors in the literature. The idea is that shared electric micro-mobility services can supplement conventional public transportation by providing last-mile service. Because of this, studies have recommended placing shared electric micro-mobility stations close to major train, bus, and subway stations [19,20]. This may promote multi-modal transportation and improve the user experience. Additionally, public transportation can shorten travelers' commuting time and travel distance. In addition, locating shared electric micro-mobility stations near major transit nodes can expand the service's potential user base and encourage more people to incorporate it into their daily trips [21].

Besides public transportation services, safety and security are also being frequently considered. Users' feelings of protection and security have been shown to have a major impact on how frequently they use a service [22]. It is also crucial to establish the necessary facilities to guarantee customers' privacy and safety while using the service. Additionally, placing the micro-mobility station near a safe area regarding road and micro-mobility accidents is preferred [23]. Kalakoni et al. [24] provided a thorough framework for assessing safety and security in micro-mobility systems. By considering factors such as accidents, network infrastructure, separation from traffic, street lighting, and security measures, decision-makers can prioritize locations that ensure user safety. Additionally, Altintasi and Yalcinkaya [25] highlighted the need for safe and secure environment to establish an electric micro-mobility routes and stations. When deciding where to put shared electric micro-mobility stations and making sure they are around for a long time, security is paramount.

It is crucial to choose places that are both affordable and practical for station placement due to the scarcity of land in urban areas [1,26]. Despite the higher land cost, research suggests that stations should be placed in densely populated locations near businesses and homes to maximize usage [27]. As a result, creative approaches may be required to address this issue, including the reuse of old buildings and public areas.

Another important criterion is proximity to key destinations [28]. The users of shared electric micro-mobility services typically travel to common destinations including offices, malls, and transportation hubs. Therefore, it is crucial to identify areas that are close to these major destinations achieving a high penetration rate. Accessibility is directly linked to the closeness to important places. The term "accessibility" refers to how convenient it is for people to travel to a specific location utilizing a variety of transit options [29]. However, station placement options may be constrained in places with heavy traffic and inadequate parking.

The availability of safe cycling and walking routes is another important aspect of placing shared electric micro-mobility stations in urban areas. Researchers have observed that the accessibility and quality of cycling and pedestrian infrastructure affect the number of shared electric micro-mobility service customers and their sense of security [30,31]. By offering convenient and secure routes to destinations, well-designed cycling and pedestrian infrastructure can also increase demand for shared electric micro-mobility services [32]. Additionally, it can help the city's sustainability and quality of life by decreasing traffic, encouraging exercise, and cutting down on greenhouse gas emissions.

Finally, demographics is a key factor. Studies have identified notable differences in shared micro-mobility service utilization across age, gender, income, and level of education [19,33]. Research has shown that those with higher levels of education and younger ages are more likely to use shared micro-mobility services [34]. Individuals with lesser incomes may be unable to use the service due to the associated costs, which can affect the program's accessibility and popularity [35].

In general, the Analytic Hierarchy Process (AHP) methodology, employed in this study, offers several advantages that contribute to its widespread use in decision-making processes. These benefits include its ability to systematically structure complex decision problems, facilitate the consideration of multiple criteria and sub-criteria, and provide a framework for quantitative analysis of subjective judgments [36,37]. Moreover, AHP enables the integration of expert opinions and preferences into decision models, enhancing

their robustness and transparency [38]. Additionally, AHP supports sensitivity analysis, allowing decision-makers to assess the impact of changes in criteria weights on overall outcomes [39,40].

While previous research has shed light on various factors influencing the location of shared electric micro-mobility stations, there remains a need to address several gaps and limitations in the existing literature. These include a lack of comprehensive examination of the interrelationships between criteria factors, and a limited consideration of economic and demographic influences. In our manuscript, we aim to bridge these gaps by employing the Analytic Hierarchy Process (AHP) method to systematically assess and prioritize the criteria and sub-criteria influencing micro-mobility station location. By offering a more integrated and nuanced approach, our study contributes to advancing the understanding of optimal micro-mobility station placement in urban environments.

3. Methods

Based on the literature review, we identified the following important aspects of shared electric micro-mobility station localization: proximity to public transportation hubs and key destinations, demographics, land use, cycling infrastructure, safety, and security. By carefully evaluating these factors, it is possible to establish a network of micro-mobility stations that meets the needs of the community and supports the city's sustainable mobility goals. Unlike traditional empirical studies focused on specific areas, AHP enables the systematic analysis of criteria and sub-criteria relevant to the research objective, applicable across various urban contexts. Thus, the factors considered serve as a comprehensive baseline applicable to diverse environments, ensuring the generalizability and relevance of the findings.

The survey methodology employed in this study involved a structured questionnaire format to collect data on participants' perceptions of the criteria and sub-criteria for the location optimization of shared electric micro-mobility stations. It consisted of two parts:

Rating of Criteria: The experts were asked to rate the importance of six criteria on a scale from 1 to 100 for the location optimization of shared electric micro-mobility stations. The criteria included proximity to public transportation, accessibility to key destinations, population density, safety, land use, and pedestrian and cyclist infrastructure.

Weighting of Criteria and Sub-criteria: The experts were presented with a list of criteria and corresponding sub-criteria related to the location optimization of shared electric micro-mobility stations. They were instructed to compare the importance of each sub-criterion relative to its parent criterion using the Analytic Hierarchy Process (AHP) scale developed by Saaty. This scale allows participants to assign values based on their perceived level of importance, ranging from 1 (equal importance) to 9 (absolutely more important), with intermediate values in between.

3.1. Criteria Description and Selection

The selection and prioritization of criteria are essential. After carefully considering the literature and expert opinions, six criteria were chosen and assigned different levels in order to apply the AHP model. These six primary criteria were further subdivided into 16 sub-criteria, each labeled according to its corresponding primary criterion from C1.1 to C6.3. To ensure the validity of the criteria and their sub-criteria, a panel of 35 experts comprised individuals from diverse backgrounds, including academics, professionals, Ph.D. students, and policymakers, all of whom have expertise in transportation-related fields. Their selection was based on their qualifications, experience, and contributions to the field, making them suitable candidates to provide informed opinions on the relative importance of the criteria and sub-criteria. Their input in the study, providing opinions and judgments on AHP-modeled criteria, was crucial. It guided the assignment of weights to criteria, shaping the decision making on shared electric micro-mobility station locations, and aligning with AHP principles. Table 1 presents the criteria and sub-criteria.

Table 1. Criteria and sub-criteria for location optimization of shared electric micro-mobility stations.

Criteria	Sub-Criteria
Criterion 1: Proximity to Public Transportation	C1.1: Distance to the nearest bus or train stop C1.2: Frequency and reliability of public transportation services C1.3: Availability of transfer options to other modes of transportation
Criterion 2: Accessibility to Key Destinations	C2.1: Distance to major employment centers, such as business districts or universities C2.2: Distance to popular destinations, such as shopping centers and tourist attractions C2.3: Distance to residential areas and other potential user populations
Criterion 3: Demographics	C3.1: Population density of the surrounding area C3.2: Average income of the surrounding population in the area C3.3: Young age percentage of the surrounding population in the area
Criterion 4: Safety	C4.1: Crime rate and safety concerns in the surrounding area C4.2: Improvements for micro-mobility environment needed to reduce accidents
Criterion 5: Land use	C5.1: Green space and vegetation in the surrounding area C5.2: Cost of land acquisition or lease for the station site
Criteria 6: Pedestrian and Cyclist Infrastructure	C6.1: Availability and quality of sidewalks and bike lanes in the surrounding area C6.2: Accessibility of pedestrian/cycling crossings and intersections C6.3: Proximity to the nearest micro-mobility station

3.2. Analytic Hierarchy Process (AHP)

In the 1980s, Saaty introduced the AHP model, which has since been applied to various sectors such as management, manufacturing, industry, government, and engineering to model and prioritize factors [41]. AHP enables the systematic and structured evaluation and prioritization of alternatives based on multiple criteria [41]. One key advantage of AHP lies in its ability to handle complex decision problems involving subjective and objective factors, accommodating both qualitative and quantitative data. By quantifying and assigning relative weights to different criteria, AHP facilitates a comprehensive understanding of the decision-making process and aids in identifying the most favorable alternative. Moreover, AHP promotes transparency and consistency in decision making by providing a logical framework for evaluating and comparing options. Its hierarchical structure enables the decomposition of complex problems into manageable subproblems, facilitating a more focused and structured analysis. Additionally, AHP allows for sensitivity analysis, enabling the examination of the impact of changes in criteria weights on the final decision.

The evaluations of criteria were gathered through a survey process. The assessors were asked to conduct pairwise comparisons while considering the hierarchy levels established in the survey. The initial level of comparison involved the overarching criteria, denoted as C1 to C6. These criteria encompassed various aspects of the evaluation. Subsequently, the assessors compared the sub-criteria within each criterion, denoted as C1.1 to C6.3, ensuring that comparisons were made among the sub-criteria belonging to the same group. In the AHP process, the consistency of responses is evaluated using Saaty's consistency index (CI) and consistency ratio (CR) (Equations (1) and (2)). This is necessary because experiential matrices often lack resistance and can introduce inconsistencies.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

where CI is the consistency index, λ_{max} is the maximum eigenvalue and n is the number of rows in the matrix. CR can be determined by the following:

$$CR = \frac{CI}{RI} \quad (2)$$

where RI is the average CI value of a randomly generated pairwise comparison matrix of the same size. In our research, there are two values of RI : zero for $n = 2$, and 0.58 for $n = 3$, based on Saaty [42] measurements. The answers are consistent if CR is less than 0.1.

The participants' weights are aggregated by using the geometric mean, as stated by Aczél and Saaty [43], as shown in Equation (3).

$$f(x_1, x_2, \dots, x_n) = \prod_{k=1}^n X_k^{\frac{1}{n}} \quad (3)$$

where x_1, x_2, \dots, x_n stand for the entries (e.g., the AHP scale values), and n is the number of the participants ($k = 1, 2, 3, \dots, n$).

Once a consistent matrix is obtained, the final weight vectors are calculated by using Equation (4), after getting the geometric mean of the respondents' answers.

$$w_{A_i} = \frac{w_j}{w} + \frac{w_{ij}}{\sum_{k=1}^n w_{ik}} = \left(\frac{w_j}{w} \frac{1}{\sum_{k=1}^n w_{ik}} \right) w_{ik} \quad (4)$$

where w_{A_i} is the final score of the current level elements. The weight from the previous level $w = \sum_{i=1}^m w_j, j = 1, 2, \dots, m$, and $w_j > 0 \forall j$. The eigenvector of the current level is given by $w_{ij} > 0 \forall I (I = 1, 2, \dots, n)$.

4. Results

Participation in the survey was voluntary. The experts were 35 including professors/academics in transportation engineering (11), in addition to technical staff specialized in micro-mobility planning (8), and (16) PhD candidates in transportation the Ministry of Transport, and the Ministry of Local Government, as well as specialized academic staff. They ranked the criteria levels C1 through C6 as presented in Table 2.

Table 2. Level 1 results of the criteria.

Index	Criterion	Score	Rank
C1	Proximity to Public Transportation	0.859	1
C2	Accessibility to Key Destinations	0.848	2
C3	Demographics	0.615	4
C4	Safety	0.587	5
C5	Land use	0.554	6
C6	Pedestrian and Cyclist Infrastructure	0.843	3

The criterion values reveal that C1 (proximity to public transportation), with a score of 0.859, holds the highest position in the ranking, while C5 (land use) has the lowest criterion value of 0.554.

In the context of the location optimization of shared electric micro-mobility stations in cities, the primary criterion identified is proximity to public transportation (C1). This criterion holds significant importance because it recognizes the value of integrating the micro-mobility system into the public transportation network. This finding is in line with previous studies [44,45], whose work emphasizes the benefits of integrating shared electric micro-mobility systems with public transportation for enhanced connectivity and accessibility. The second-ranking criterion, which was accessibility to key destinations (C2), highlights the importance of ensuring that the micro-mobility stations are conveniently located near important and frequently visited destinations within the city. This can include commercial centers, educational institutions, tourist attractions, and areas with high pedestrian traffic. By strategically placing the stations in such locations, users can easily access the services, fostering greater utilization and convenience. This criterion supports the notion put forth by researchers [46,47] that emphasizing accessibility to key destinations enhances the attractiveness and viability of shared electric micro-mobility systems. Pedestrian and

cyclist infrastructure (C6) was another prominent criterion in the ranking. This criterion emphasizes the importance of well-developed infrastructure to support pedestrians and cyclists in the vicinity of the micro-mobility stations. Having dedicated bike lanes, sidewalks, and shared paths that promote safe and convenient access to the stations enhances the overall user experience and encourages active transportation. The finding on C6 aligns with the broader goal of promoting sustainable and healthy mobility options in cities.

On the contrary, in the context of locating shared electric micro-mobility stations, the demographics criterion (C3) is identified as one of the least important factors. This suggests that factors such as age, income level, or lifestyle preferences of the surrounding population have less influence on decision making. It implies that the success of the micro-mobility stations may rely less on catering to specific demographic segments and more on broader accessibility and usability factors. Similarly, safety (C5) is considered not as important in the location optimization of shared electric micro-mobility stations. While safety is undoubtedly a crucial consideration in any transportation system, this finding suggests that other criteria, such as proximity to public transportation and accessibility to key destinations, hold greater weight in the decision-making process for the micro-mobility stations. This does not imply that safety should be overlooked, but rather that it may be addressed through broader urban planning and infrastructure development efforts. The criterion of land use (C6) ranks last and is assigned the least importance in the analysis. This indicates that the specific land use characteristics of the surrounding area, such as zoning regulations or compatibility with green areas, have a relatively lower influence in determining the optimal locations for the micro-mobility stations.

The scale of the 16 proposed sub-criteria varies, making it challenging to interpret their relative importance. Consequently, the analysis was divided into two sections to facilitate understanding. The local classification, which focuses on specific aspects in the urban environments, is first discussed. The global classification, which considers the broader perspective, is then addressed. Table 3 shows the results of the analysis of the sub-criteria weights and rankings.

Table 3. Level 2 analysis of the weights and rankings of the sub-criteria.

Index	Sub Criterion	Local Weight	Local Rank	Global Weight	Global Rank
C1.1	Distance to the nearest bus or train stop	0.363	1	0.312	5
C1.2	Frequency and reliability of public transportation services	0.290	3	0.249	12
C1.3	Availability of transfer options to other modes of transportation	0.345	2	0.297	8
C2.1	Distance to major employment centers, such as business districts or universities	0.373	2	0.317	3
C2.2	Distance to popular destinations, such as shopping centers, and tourist attractions	0.392	1	0.332	2
C2.3	Distance to residential areas and other potential user populations	0.235	3	0.199	13
C3.1	Population density of the surrounding area	0.510	1	0.314	4
C3.2	The average income of the surrounding population in the area	0.205	3	0.126	16
C3.3	Young age percentage of the surrounding population in the area	0.284	2	0.175	14
C4.1	Crime rate and security concerns in the surrounding area	0.505	1	0.297	7
C4.2	Improvements for micro-mobility environment needed to reduce accidents	0.495	2	0.290	9
C5.1	Green space and vegetation in the surrounding area	0.510	1	0.283	10
C5.2	Cost of land acquisition or lease for the station site	0.490	2	0.271	11
C6.1	Availability and quality of sidewalks and bike lanes in the surrounding area	0.454	1	0.382	1
C6.2	Accessibility of pedestrian/cycling crossings and intersections	0.179	2	0.150	15
C6.3	Proximity to the near micro-mobility station	0.368	3	0.310	6

5. Discussion

5.1. Local Classification

For criterion C1 (proximity to public transportation), the sub-criterion C1.1 (distance to the nearest bus or train stop) holds the highest ranking and has a local weight of 0.363. This suggests that the proximity of the shared electric micro-mobility stations to the nearest bus or train stops is considered of utmost importance. Placing the stations near these transit hubs can enhance accessibility and convenience for users, allowing them to easily access the micro-mobility services when shifting from or to public transportation. The sub-criterion C1.3 (availability of transfer options to other modes of transportation), holds the second ranking with a local weight of 0.345. This criterion highlights the significance of having transfer options available for users to seamlessly switch between different modes of transportation. By providing convenient transfer points, such as intermodal stations or shared transportation hubs, users can efficiently transition from public transportation to shared electric micro-mobility services. The sub-criterion C1.2 (frequency and reliability of public transportation services), holds the third ranking with a local weight of 0.290. While still important, this criterion carries slightly less weight compared to the other sub-criteria. It emphasizes the need to consider the frequency and reliability of public transportation services when determining the optimal locations for the micro-mobility stations.

In regard to criterion C2 (accessibility to key destinations), the sub-criterion C2.2 (distance to popular destinations), has the highest rank with a local weight of 0.392. This indicates that the proximity of the shared electric micro-mobility stations to popular destinations such as shopping centers and tourist attractions is considered of utmost importance. The sub-criterion C2.1 (distance to major employment centers, such as business districts or universities), holds the second ranking with a local weight of 0.373. This criterion highlights the significance of locating the micro-mobility stations near major employment centers. By providing easy access to these areas, the stations can cater to the commuting needs of individuals working in business districts or universities, facilitating a convenient and sustainable mode of transportation. The sub-criterion C2.3 (Distance to residential areas and other potential user populations), holds the third-ranking with a local weight of 0.235. This criterion carries slightly less weight compared to the other sub-criteria. It emphasizes the need to consider the distance between the micro-mobility stations and residential areas, as well as other potential user populations.

Concerning C3 (demographics), the sub-criterion C3.1 (population density of the surrounding area) is the most important and carries a local weight of 0.510. This suggests that the density of the population in the vicinity of the shared electric micro-mobility stations is of utmost significance. A higher population density indicates a larger potential user base and stronger demand for micro-mobility services. Placing the stations in densely populated areas can ensure higher utilization rates and contribute to the overall success and sustainability of the system. The sub-criterion C3.3 (young age percentage of the surrounding population in the area), is ranked second and holds a local weight of 0.284. This criterion underscores the importance of considering the proportion of young individuals in the surrounding population. Younger age groups are more likely to embrace innovative mobility solutions and actively engage in micro-mobility options. Therefore, locating the stations in areas with a higher percentage of young individuals can potentially drive higher adoption rates and usage of micro-mobility services. The sub-criterion C3.2 (average income of the surrounding population in the area) is ranked third with a local weight of 0.205. This criterion carries slightly less weight compared to the other sub-criteria. It highlights the consideration of income levels within the surrounding population. However, it suggests that income may not be the primary factor influencing the decision-making process for the optimal location of the micro-mobility stations.

For criterion C4 (safety), the sub-criterion C4.1 (crime rate and security concerns in the surrounding area), holds a slightly higher local weight of 0.505. Ensuring safety and security can contribute to enhancing the overall user experience and promoting the adoption of micro-mobility services. The sub-criterion C4.2 (improvements for micro-

mobility environment needed to reduce accidents) follows closely with a local weight of 0.495. This criterion highlights the importance of creating a safe environment for micro-mobility users by implementing necessary improvements to minimize accidents.

In regard to criterion C5 (land use), the sub-criterion C5.1 (green space and vegetation in the surrounding area) holds a higher local weight of 0.510. This suggests that considering the presence of green spaces and vegetation in the vicinity of the shared electric micro-mobility stations is deemed significant. Incorporating these elements into the station's surroundings can enhance the overall user experience and contribute to a more sustainable and attractive environment. The sub-criterion C5.2 (cost of land acquisition or lease for the station site) follows closely with a local weight of 0.490. Evaluating the cost implications is crucial for ensuring the feasibility and economic viability of establishing the micro-mobility stations. Balancing the financial aspects with other criteria can help optimize the location selection process.

Finally, concerning criterion 6 (pedestrian and cyclist infrastructure), the sub-criterion C6.1 (availability and quality of sidewalks and bike lanes in the surrounding area) stands out with a local weight of 0.454. This indicates the significance placed on the presence and condition of sidewalks and bike lanes in the vicinity of the shared electric micro-mobility stations. Access to well-maintained infrastructure can enhance the safety and convenience of pedestrians and cyclists, thereby fostering their willingness to utilize micro-mobility services. The sub-criterion C6.3 (proximity to the nearest micro-mobility station) follows closely with a local weight of 0.368. This criterion highlights the importance of considering the proximity of the station to potential users. Placing the micro-mobility stations near their target audience can reduce travel time and encourage greater utilization. It also contributes to the overall accessibility and convenience of the shared electric micro-mobility system. On the other hand, the sub-criterion C6.2 (accessibility of pedestrian/cycling crossings and intersections), carries a lower weight of 0.179. It suggests that while the ease of navigating pedestrian/cycling crossings and intersections is a factor to consider, it may not be as influential in the decision-making process compared to the availability of sidewalks, bike lanes, and proximity to micro-mobility stations.

The findings align with previous research in urban planning and transportation studies, emphasizing the multifaceted considerations necessary for optimal micro-mobility station placement. For instance, the prioritization of proximity to public transportation hubs resonates with the findings of studies such as those by Sun et al. [48] and Qian et al. [49], which underscore the importance of integration with existing transit networks to enhance accessibility and ridership. Additionally, the emphasis on proximity to popular destinations is consistent with research by Mix et al. [50], who highlight the role of destination accessibility in influencing bike stations. Moreover, the significance attributed to population density echoes the findings of Tuli et al. [51], who emphasize the correlation between population density and micro-mobility usage rates. In terms of safety considerations, the prioritization of crime rates and security concerns aligns with a study by Marquez and Soto [52], which stresses the importance of safety perceptions in locating bike infrastructure. Similarly, the focus on green space and vegetation corresponds with the research by Bai et al. [53], highlighting the role of urban greenery in promoting the well-being and attractiveness of active travel. Finally, the emphasis on pedestrian and cyclist infrastructure is supported by studies such as those by Pajares et al. [54], Wilson and Mitra [55], and Shaer and Haghshenas [30], which emphasize the importance of infrastructure quality in facilitating active transportation modes. Overall, these findings underscore the complexity of micro-mobility station siting decisions and the need for a holistic approach that considers various contextual factors and user preferences.

5.2. Global Classification

The availability and quality of sidewalks and bike lanes in the surrounding area (C6.1) emerge as the most significant criterion, emphasizing the importance of well-maintained infrastructure for pedestrian and cyclist mobility. Following closely is the proximity to

popular destinations such as shopping centers and tourist attractions (C2.2), highlighting the need for convenient access to high-traffic areas. Distance to major employment centers (C2.1) is also a crucial factor, recognizing the importance of connecting stations with areas of economic activity. Population density (C3.1) is another relevant criterion, considering the potential user base in the vicinity. The distance to the nearest bus or train stop (C1.1) is also significant for seamless multimodal travel experiences, as well as the proximity to the nearest micro-mobility station (C6.3). Other criteria include crime rate and security concerns (C4.1), transfer options for transportation modes (C1.3), micro-mobility environment improvements (C4.2), green space and vegetation (C5.1), land acquisition or lease cost (C5.2), and frequency and reliability of public transportation services (C1.2) have medium importance. On the other hand, distance to residential areas and potential user populations (C2.3), young age percentage in the area (C3.3), accessibility of pedestrian/cycling crossings and intersections (C6.2), and the average income of the surrounding population (C3.2) have the lowest ranking among all criteria. These rankings offer valuable guidance for making informed decisions regarding the optimal placement of shared electric micro-mobility stations.

6. Conclusions

This study used the AHP model to rank the criteria for the location optimization of shared electric micro-mobility stations in urban environments. The analysis revealed that proximity to public transportation emerged as the most significant criterion, followed by accessibility to key destinations and pedestrian and cyclist infrastructure. Safety, land use, and demographics were also considered important, albeit to a lesser extent. These findings highlight the importance of considering factors such as convenient access to public transportation, proximity to popular destinations, and the characteristics of the surrounding population when determining the optimal locations for shared electric micro-mobility stations. The study provides valuable insights for city planners and policymakers, enabling them to make informed decisions and effectively optimize the placement of micro-mobility stations, ultimately contributing to the development of sustainable and accessible urban transportation systems.

Our model for identifying the location of charging stations in shared electric micro-mobility systems possesses considerable scientific generalizability and holds substantial benefits for future research endeavors. The model's foundation lies in comprehensive analysis and optimization criteria, ensuring its adaptability to varying geographical contexts and evolving transportation landscapes. By considering the important factors, the model can be applied to different urban settings, aiding in the efficient deployment of charging infrastructure for electric micro-mobility systems worldwide. Its flexible design allows for the incorporation of novel data sources, including user behavior data and energy demand forecasting, fostering a deeper understanding of the interplay between charging station locations and system performance. Consequently, our model serves as a valuable foundation for future research investigations, facilitating advancements in optimizing charging infrastructure, sustainability assessment, energy management, and user experience in shared electric micro-mobility systems.

By identifying the most critical criteria for the optimal placement of shared electric micro-mobility stations, this research provides guidance for decision-makers in designing sustainable and accessible urban transportation systems. Understanding the significance of factors such as proximity to public transportation and key destinations can help cities prioritize infrastructure investments and effectively allocate resources to maximize the benefits of micro-mobility services. Additionally, transportation companies can strategically deploy shared electric micro-mobility stations to enhance connectivity, promote multimodal transportation, and improve overall urban mobility. Professionals can use our findings to advocate for policies that support the expansion of micro-mobility infrastructure and address key challenges related to safety, accessibility, and land use planning.

On the managerial aspects, the results could help urban transportation stakeholders involved in the planning and implementation of micro-mobility systems. By understanding the significance of factors such as proximity to public transportation, key destinations, and demographic characteristics, managers can make informed decisions regarding the location of shared electric micro-mobility stations. For example, prioritizing the placement of stations near transit hubs and popular destinations can attract a higher volume of users and increase ridership. Additionally, considering the demographic profile of surrounding areas can help tailor marketing strategies and service offerings to meet the needs of specific user groups. Moreover, integrating safety measures and enhancing infrastructure around micro-mobility stations can improve user confidence and contribute to the overall success of the system. By leveraging the insights derived from our research, managers can strategically deploy micro-mobility infrastructure to address urban transportation challenges and create more livable and sustainable cities.

The need for such research stems from the growing importance of micro-mobility solutions in addressing urban transportation challenges. As cities increasingly embrace shared electric micro-mobility as a sustainable mode of transportation, there is a pressing need to optimize the placement of charging infrastructure to ensure its accessibility and effectiveness. By filling this gap in the literature, our study contributes to the development of evidence-based strategies for integrating micro-mobility services into urban mobility ecosystems.

This analysis focuses primarily on urban environments and may not fully capture the complexities of micro-mobility deployment in rural or suburban areas. Future studies in this field should aim to enhance our understanding of user behavior, improve integration with public transportation, leverage spatial analysis techniques, assess environmental and social impacts, look deeper into rural areas, and explore innovative technologies to optimize the location of shared electric micro-mobility stations and enhance the overall effectiveness of these systems in urban environments.

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