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Decision-Oriented Risk Assessment in Micromobility Using AHP

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ABSTRACT

In the modern world, a lot of people and organizations are impacted both directly and indirectly by the micromobility sector, which is one of the most significant subheadings of the sharing economy model. The existing condition should be made public, and any hazards should be identified in order to reduce the negative consequences and take the appropriate actions. This study identified the hazards associated with the micromobility sector after looking at the sharing economy and risk allocation concepts. The optimal option is then identified using the AHP approach. It is a chance to direct and distribute accountability for the applications that will be submitted after that.

1. Introduction

Governments and businesses are continuously working to develop infrastructure and offer services to everyone by expanding options because the transportation sector, which gives people and businesses access to the economic market, is a significant area that directly affects issues like economic development, environmental development, urbanization, and the determination of living spaces [1], [2].

Micromobility has emerged as a transportation alternative driven by shifting mobility demands, evolving commuting habits, advances in transportation-related technologies, and the expanding economic scope of the mobility market. Defined by the use of lightweight and environmentally friendly vehicles for public benefit, micromobility has gained increasing attention due to its potential to reduce reliance on fossil fuel-powered cars, which have become a growing concern in recent years. Reducing the use of automobiles is thought to enhance air quality, reduce noise pollution, reduce greenhouse gas emissions, and ease traffic congestion [3]. From the drivers' perspective, it is anticipated that driving will become more enjoyable, particularly as lightweight and folding scooters proliferate [4]. By combining micromobility's accessibility and flexibility with the services offered by public transportation, which provides quick travel over both short and large distances, it seeks to decrease the usage of private vehicles and establish a sustainable mode of transportation.

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In a technical aspect, e-bikes and e-scooters are personal motor vehicles (e-PMVs) powered by rechargeable lithium-ion batteries, offering faster and more flexible mobility than conventional bicycles. Emerging as a micromobility alternative in urban areas, they are valued for avoiding traffic congestion, low carbon emissions, low maintenance costs, and economic accessibility. Also, these two-wheeled vehicles are used not only for personal travel but also for utility and cargo transport. Their electric assistance enables longer trips and higher speeds than bicycles, contributing to their growing popularity in European cities. However, the usage of sidewalks by these vehicles that allow speedy mobility may result in accidents and injuries.

Among micromobility options, electric scooters are the most common and prominent vehicles. Their widespread adoption is primarily driven by ease of parking and the ability to travel independently of public transportation systems and existing infrastructure quality. [5]. Difficulty in finding parking spaces, the inadequacy of public transportation and taxi facilities, changes in demographics and urbanization, and the emergence of new business areas are among the reasons for the increased interest in micromobility. In that sense, the transportation sector is currently experiencing a shift in its service perspective, where the primary motivation is to develop infrastructure systems that serve people from all social classes, rather than prioritizing fast and long-distance travel of people and goods, which has traditionally characterized motorized transportation [6]. It also shows that economic and social needs intersect with each other.

However, there are concerns about the widespread use of e-scooters. It is revealed in a study that the primary driver behind the popularity of e-scooters is the desire to lessen traffic, with air pollution and the battle against climate change appearing to be the secondary drivers [7] Due to the need for legal rules in some cities, e-scooters, which gained popularity due to their perceived ease and speed of transit, may be implemented with delays and pauses in practice. Before e-scooters are put into service, health and safety issues, the usage of public areas, speed limits, and irresponsible driving are highlighted as major issues in media outlets.

Applications for bike sharing, which have become a green solution to the last-mile problem, which can be defined as the issue of short-distance transportation between one's home and public transportation or between one's place of employment and public transportation, could help bridge the gap and establish an integrated transportation system. Other potential benefits of this system can be shown as increased mobility opportunities, economic savings, reduced traffic congestion, low-priced service and operation opportunities, reduced fuel consumption, increased use of public transportation, and health and environmental awareness. From an economic point of view, another important investor in these services, which are generally financed by local governments, is advertising companies. Examining environmental impacts, Reductions in CO2 emissions are seen through the decline in personal car use. Improvements must be made to lessen the environmental harm caused by fossil fuel vehicles used in the redistribution of bicycles. In addition to that, bicycle access and vehicle tracking using electronic cards must be developed in order to prevent bicycle theft. Limited infrastructure systems, theft, expensive technology investment costs, financing, and security concerns stand out as crucial issues to be taken into consideration when the barriers to these systems' adaptation are explored. [3].

Considering the rapid expansion of micromobility services within the sharing economy, selecting an appropriate operation and management model has become increasingly important for urban transportation systems. Different governance structures may lead to varying outcomes in terms of efficiency, risk distribution, and public benefit. This study aims to evaluate and compare alternative operation and management approaches for micromobility projects using a multi-criteria decision-making framework. In this context, the identified alternatives are assessed based on a set of predefined evaluation criteria, and sensitivity analysis is conducted to examine the robustness of the results. The findings are intended to support decision-makers in selecting suitable strategies and to contribute to more informed and resilient micromobility policies.

2. Literature Review

2.1 Sharing Economy

Rising economic costs and environmental concerns have made traditional product ownership increasingly challenging, leading to the growth of the sharing economy, where access to products and services is prioritized over ownership. This shift is driven by changing consumer habits and the widespread use of digital platforms, mobile applications, and secure online services that enable fast and convenient access. In the sharing economy, which appears to be a hybrid mixture of the traditional and the new business model when analyzed as an economic model, service suppliers generate economic income by attracting users to use their services [8].

The sharing economy, which is driven more by economic considerations than by social or cultural ones, refers to the capacity to access and utilize both actual goods like automobiles and intangible ones like money and time through online platforms. With the widespread use of mobile phones, people have the opportunity to access services in line with real-time information, and service providers have the opportunity to provide services using real-time information. These intermediary platforms help to create economic movements by providing integration between the product and the user. These intermediary platforms help to create economic movements by providing integration between the product and the user.

There are 2 elements of the sharing economy, which are the temporary possession of products and services by consumers without owning them, and the provision of these services via the internet. While short-term product rentals create revenue in the business models developed in this field, free product use combined with advertising revenue stands out as an alternative and appears to be a cutting-edge industry for the future [9].

Today, the largest component of the sharing economy is the shared transportation sector, which includes the sector of micromobility [10]. To support, when the shared transportation sector is examined, the micromobility industry is the one that receives the most investment and has achieved significant market success after the shared driving sector [11]. Despite advancements in public transportation, last-mile connectivity remains a challenge due to limited short-distance travel options, and IoT-enabled micromobility vehicles provide a practical solution by facilitating access to transit nodes while reducing reliance on conventional transport modes [12]. To expand the context, the development of information and communication technology could make it possible to obtain real-time information through shared transportation applications, and altogether they help to increase the recognition and efficiency of shared micromobility.

2.2 Micromobility

Shared micromobility is a sub-title of shared transportation, and it defines the use of vehicles such as bicycles, e-bikes, scooters, and e-scooters according to the preferred service model within the scope of service regions where services are provided by using online payment methods temporarily in line with short-term needs, as in shared transportation. Traditional bicycles, pedal-assist electric bicycles (e-bikes), and electric scooters (e-scooters) are the most common shared micromobility items [13]

Shared micromobility consists of 2 main areas: bike sharing and scooter sharing. According to [14], bike-sharing systems are classified into three service models: station-based (docked), station-free (dockless), and hybrid. In station-based systems, bicycles are picked up and returned at designated stations, whereas dockless systems allow bicycles to be left anywhere within the service area; hybrid models combine both approaches by permitting bicycles to be picked up and returned either at stations or at flexible locations. These three are the primary models used to operate shared devices in the USA.

Scooter-sharing services, on the other hand, are the name given to the service that allows users to travel with access to electric or motorized, or human-powered scooters as a result of joining service provider organizations. Scooter-sharing services are categorized into two main types: electric scooters, which are used while standing, and moped-style scooters, which are used while seated and operate with either electric or gasoline-powered motors [15], [16]

The bicycle is one of the most accessible and cost-effective transportation modes, and since the early 2000s, it has been increasingly promoted by governments as an alternative to private car use, particularly in urban areas where terrain and road networks are suitable [17], [18]. Although bicycles have been used as a means of transportation in cities for many years, traditional bicycles have begun to have difficulties in meeting this need due to the effects of urbanization. Even while bicycles have long been a popular mode of transportation in urban areas, the effects of urbanization have made it harder for traditional bicycles to match this demand. Today, the 4th generation process of bike sharing has begun, due to bicycles that can move with an electric motor without the need for human power, and the ability to provide services such as tracking and payment of vehicles regarding the development of information and communication technologies.

Through increasing Technologies, it is anticipated that bicycle sharing, a subheading of shared transportation, will address the first-last mile issue. Bike-sharing service providers are responsible for operations such as charging, maintenance, distribution, and tracking of vehicles and earn money from their users by charging per minute or distance [16] With the introduction of bike-sharing services, opportunities have emerged for cities to demonstrate their commitment to tackling problems such as climate change, public health problems, traffic congestion, and fossil fuel dependence.

In contrast, e-scooter sharing services have gained popularity recently, particularly in America, Europe, and China. Their capacity to travel farther and faster, especially with the help of electric motors, has made them the preferred mode of transportation. Service providers are in charge of operations like maintenance and charge redistribution. They also disperse the vehicles throughout the cities they serve and make them readily accessible to the public [16].

There are different limits in different countries regarding the hardware features of micromobility vehicles. Since the legal regulations in the world are generally made up of bicycles, the regulations regarding scooters that have just entered the market are insufficient. The speed limit in Europe is 25 km/h for electrically powered micromobility vehicles, 20-32 km/h in the United States, and 25 km/h in Asia [19]. As the years pass, The International Transport Forum (ITF) categorizes micromobility vehicles into four types based on vehicle weight and design speed: Type A includes powered or unpowered vehicles weighing less than 35 kg with a maximum design speed of 25 km/h; Type B covers powered or unpowered vehicles weighing between 35 kg and 350 kg with a maximum design speed of 25 km/h; Type C consists of powered vehicles weighing less than 35 kg with design speeds between 25 km/h and 45 km/h; and Type D includes powered vehicles weighing between 35 kg and 350 kg with design speeds between 25 km/h and 45 km/h [20].

3. Methodology

3.1. Analytic Hierarchy Process (AHP)

Developed by Saaty in 1971, the Analytical Hierarchy Process (AHP) method is an approach that could be applied in both social and physical domains, particularly when making decisions based on multiple criteria and comparing them to one another [21]. In the evaluation method designed according to the hierarchical structure created, the criteria are brought together according to the homogeneity axiom. Three key guidelines should be considered when applying the AHP method: separation, comparison, and concretization of the priority rankings that are obtained. The criteria are divided based on their levels during the separation process, and an assessment is conducted starting at the highest level and working down to the lowest. Comparatively speaking, criteria at the same level are assessed, and their relative importance levels are determined. To determine local and global priority values during concretization, the priority levels derived from each level are multiplied by the lower levels.

3.1.1 Axioms of AHP

In the following, the fundamental axioms of the Analytic Hierarchy Process (AHP) are briefly presented to outline the basic assumptions underlying the method [21].

- Reciprocal Axiom: This proposition, which forms the foundation of AHP logic, states that when assessing the relative importance of the second criterion to the first criterion, the numerical equivalent of the first criterion's importance to the other criterion among the two criteria compared should be used as the opposite. That is, it should be in the form of $a_{ij} = 1 / a_{ji}$ in the evaluation matrix. In this way, inconsistencies are avoided.
- Homogeneity Axiom: It is a claim that the sub-criteria and the upper criteria should logically depend on one another, and that the status and level of the criteria being compared should be related to one another. Results from binary evaluations between this axiom and the criterion are more reliable. Furthermore, it is impossible to conclude that one criterion is inherently superior to another.
- Dependence Axiom: This concept asserts that criteria and alternatives at lower levels of the hierarchical structure should not affect the priority levels of criteria at the same level. To put it another way, the criteria ought to be assessed separately from the options.
- Expectations Axiom: It claims that every criterion and option is covered by the hierarchical structure. If not all criteria are present in the hierarchical structure used, the decision makers' assessments will result in flaws, and the evaluation will be inconsistent.

Decision-makers are frequently employed to make judgments in the process of analyzing viewpoints from environmental, social, and political perspectives in order to make rational and useful conclusions in the decision-making process on complicated multi-criteria situations. The AHP method is a helpful strategy in this regard. In this way, several aspects should be analyzed to construct a hierarchical structure in circumstances where uncertainty and hazards are high. When individual methods are inadequate in terms of expertise and experience, the best outcomes can be obtained in conjunction with a benefit-cost analysis of several options, allowing decisions to be made with the interests of the majority in mind.

Effective decision-making processes should allow for the easy construction of a decision structure, apply to both individual and group use, and enable stakeholders to reach consensus without requiring specialized knowledge. Accordingly, the AHP framework begins with a clear problem definition and the selection of key factors, which are then evaluated based on stakeholders' judgments and expressed in numerical form. One of the biggest advantages of AHP is to help people reach judgment by reflecting on the emotions, experiences, and approaches of people to the decision-making process together [22].

In another study, [23] found that seven elements are the optimal number based on the flow of information that people can accurately assess simultaneously because the information is dimensionless and immeasurable. He defined this as the appropriate decision-making width.

People are known to have varying memory and appraisal capacities, which are influenced by the flow of information.

In a study on the ideal number of elements, [24] analyzed the relationship between the size of pairwise comparison matrices and consistency measures, concluding that increases in the number of elements reduce improvements in consistency. Based on these findings, it was suggested that the ideal number of criteria should be seven or fewer, with an upper limit of nine criteria. In the case of group decision-making, the geometric mean should be used to reveal the general approach of the group by bringing together individual evaluations. In this way, the importance levels of individuals are reflected in the evaluation [25].

3.1.2 Making a Pair-wise Comparison

Using the 1–9 comparison scales developed, the evaluation's numerical equivalents are derived when doing a pairwise comparison. Because of the reciprocal proposition, $n \times (n - 1)/2$ comparisons are conducted in an evaluation with n criteria, and a square matrix is created by describing which criterion is more important and how much more essential. The AHP evaluation rating scale is displayed in Table 1 below [22].

Table 1
Rating Scale of AHP

Intensity of Importance	**Definition**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective.
3	Moderate Importance	Judgment slightly favors one activity over another.
5	Strong Importance	Judgment strongly favors one activity over another.
7	Very Strong Importance	An activity is favored very strongly over another.
9	Extreme Importance	Favoring one activity over another is of the highest possible order of affirmation.

3.1.3 How does AHP Work?
3.1.3.1 Problem and Goal Definition

First of all, the problem and purpose are clearly defined. A hierarchical structure is created so that the criteria and sub-criteria required to achieve the determined goal are related to each other. Afterwards, the alternatives to be used to achieve this goal are determined and evaluated.

3.1.3.2 Creating the Comparison Matrix

The most crucial step in the AHP approach is the creation of the pairwise comparison matrix and the evaluation of the criteria against one another. To begin, a square matrix of size n x n is produced if there are n examined criteria. Then, using the verbal scale given in Table 1 among the matrix elements, the upper triangular part of the matrix is filled in such a way that each element a_{ij} is bigger than 0. Then, the lower triangular part is filled in line with the reciprocal proposition so that $a_{ij} = a_{ji}$, and the comparison process is completed. In cases where extra criteria are compared, if the condition $a_{ij} = a_{ik} / a_{jk}$ is satisfied, this matrix is consistent, and its maximum eigenvalue is equal to n ($\lambda_{max} = n$). Then, the element weights of this matrix are found by solving the eigenvector problem Eq.(1).

$$A \times w = \lambda max \times w. \tag{1}$$

Mathematical representation of the matrix is shown as Eq.(2):

$$\begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \end{bmatrix} = \lambda_{max}\, x \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \end{bmatrix} \tag{2}$$

where *w* represents the priority eigenvector and λ_{max} represents the principal eigenvalue, and here *A* is a comparison matrix that is filled by experts. Then, the value of each matrix element a_{ij} is normalized by dividing it by the sum of the values of the elements in the column, and is expressed as Eq.(2):

$$x_{ij} = \frac{a_{ij}}{\sum_i a_{ij}} \tag{3}$$

where x_{ij} represents the normalized value of a_{ij}.

Then, the weights of the criteria are found with the arithmetic mean of the elements in the row in the normalized matrix, and the eigenvector is obtained and expressed as Eq. (4):

$$w_i = \textstyle\sum_1^n x_{ij}/n \tag{4}$$

where w_i is the weight of the criteria and *n* is the number of elements in the row where x_{ij} *is* defined before.

3.2 Consistency of AHP

Verifying the consistency of the evaluations is one of the most important AHP concerns. Because individuals are subjective, they are unable to make completely consistent judgments because they are impacted by their knowledge, feelings, and assessments of intangibles. According to [25], inconsistency, no matter how minor, is essential for new ideas to arise and be accepted, since without it, inconsistency would not be feasible. For this reason, it is accepted that the rate of inconsistency should not exceed 10% for the evaluation made in the AHP analysis to be taken into account. If the participant comments that X is 3 times more important than Y, 5 times more important than Z, and then evaluates that Z is 7 times more important than Y, inconsistent results will emerge, and the stage of re-evaluation should be returned. Not all reciprocal matrices must produce consistent findings, even if every consistent comparison necessitates the creation of one. This is because human nature makes it impossible to fully define the relationship between many criteria in the dual comparison process.

After the weights are found, the principal eigenvalue is calculated to measure whether the evaluation made is consistent. The principal eigenvalue is found as Eq.(5):

$$\lambda_{max} = \frac{1}{n} x \sum_{1}^{n} \frac{a_{ij} \, x \, w_j}{w_i} \tag{5}$$

where λ_{max} is the principal eigenvalue. Here, a_{ij} represents the elements of the comparison matrix, and w_i is the weight of the criteria.

The consistency index value is found by using the principal eigenvalue. In the case of having an inconsistent matrix, since $\lambda_{max} \neq n$ will occur, the principal eigenvalue is used as an index of deviation from consistency since it is known to have principle eigenvalue is bigger than n in measuring this inconsistency level because all elements of matrix A are bigger than zero. By averaging other eigenvalues starting from $i = 2$. We calculate how far our $n - 1$ matrix eigenvalues are from the consistent case. The consistency index value is obtained as Eq.(6):

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{6}$$

where CI is the consistency index value, n is the number of criteria, and λ_{max} is the principal eigenvalue.

Finally, using the consistency index value, the consistency ratio value is calculated. In this calculation, the random consistency index value created by Saaty that changes according to the number of criteria is used, which represents the average CI values calculated from randomly generated reciprocal matrices. In obtaining the RI value, [21] randomly generated 500 diagonally symmetric matrices filled with 1-9 verbal scales and calculated whether they came lower than 0.10. The RI values used are shown below. It was stated by Saaty that the CR value should not exceed 0.1. For this reason, he showed that the number of evaluated criteria should not be large, and he stated that if the number of criteria is more than 10, the effects on the inconsistency calculation will be less. The random consistency index table is shown in Table 2.

Table 2
Random Consistency Index.

Order	1	2	3	4	5	6	7	8	9	10	11	12
R.I	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.52	1.54

The consistency ratio can be found by using a consistency index and a random index. By dividing the consistency index by a random index, a consistency ratio can be obtained. This is expressed as Eq.(7):

$$CR = \frac{CI}{RI_{(n)}} \tag{7}$$

where CR is the consistency ratio, CI is the consistency index, and RI represents the random consistency index.

4. Problem Definition

Micromobility systems have rapidly become part of urban transportation networks, creating new challenges in terms of operation, regulation, and responsibility allocation. The diversity of governance and management approaches increases the complexity of decision-making for micromobility projects. Therefore, identifying an appropriate operation and management model has emerged as a critical problem that requires systematic evaluation. Firstly, focusing on government-led control, operation, and management of the micromobility industry as a centralized approach to regulate services and mitigate potential risks. Second, focusing on the operation and management of the micromobility sector by private companies, emphasizing market-driven efficiency and flexibility in service provision. Third, focusing on the operation and management of micromobility projects through cooperation between the public and private sectors, aiming to combine regulatory oversight with operational efficiency. This study proposes that the order of preference of these alternatives was evaluated using 11 different criteria.

5. Definition of Alternatives and Criteria

5.1 Definition of Alternatives

A1. Governments' control, operation, and management of the micromobility industry

State control is the potential for the state to have an impact on important business choices, such as choosing the managing bodies of the company, allocating earnings, or creating the company's strategy [26]. In that sense, the primary driving force behind the government-run system for micromobility sector implementation is the state's ability to use a more thorough and appropriate approach when establishing and implementing national and international standards. For the good of society, it is believed that the state will be more sensitive to matters like the need for laws, security, public space utilization, and data security.

A2. Operation and management of the micromobility sector by private companies

Empirical research has demonstrated that innovative businesses typically perform better, and nations that allocate public funds to innovation also enhance the environment for economic growth [27], [28]. The significance of the private sector can be seen by the fact that new technical investments often increase based on venture capital, and that, as a result of company competition, the quality of goods and services will rise while prices fall.

A3. Operation and management of micromobility projects in cooperation with the public and private sectors

Public–private partnerships involve private firms participating in the design, financing, construction, ownership, and/or operation of public facilities, offering an alternative to traditional public service delivery by combining the complementary strengths of public and private sectors [29]. In this context, public-private sector cooperation could increase the possibility of successful implementation, especially depending on the state's providing a financially and politically suitable environment. While the government determines service and usage standards through legal regulations, it explains that the private sector is taking on more duties and responsibilities in business and operational processes.

5.2 Definition of Criteria

Economic Aspect
C1. Vehicles are open to problems such as theft and hacking

Micromobility systems are particularly vulnerable to theft and hacking, as shared vehicles can be physically stolen or digitally compromised through attacks targeting onboard controllers, communication channels, or firmware [30]. In addition to the fact that vehicles used and parked in dockless services are not insured against theft, it also relates to the possibility of vehicle damage if micromobility vehicles are carelessly utilized on inappropriate roads.

C2. High vehicle maintenance and redistribution transaction costs

In shared micromobility systems, economic viability is strongly influenced by the total cost of ownership, which is largely driven by vehicle durability, maintenance requirements, and operational costs throughout the product lifecycle [31]. To add, it alludes to the high expense of distribution activities in various service places when micromobility vehicles are gathered for charging and upkeep.

C3. Significant decrease in micromobility vehicle use in bad weather conditions

Weather conditions significantly influence micromobility use, with lower temperatures, wind, and rainfall leading to reductions in usage levels, travel distance, and trip duration [32]. This effect highlights the sensitivity of micromobility demand to adverse weather conditions.

C4. State's interference in private sector competition and loss of private sector investors

The government may restrict or prohibit private projects that increase risk levels, thereby directly shaping the scope of private sector activities [33]. Such constraints are typically implemented through legal regulations that define the boundaries of market competition and permissible private action.

Environmental Aspect
C5. More emissions during the collection and redistribution of scooters compared to public transport

Micromobility vehicles generally exhibit lower per passenger-kilometer emission values during the use phase compared to public transport modes. However, when life cycle assessment is considered, the total emissions of micromobility vehicles increase due to battery production and manufacturing impacts, bringing their emission levels closer to those of electric and hybrid public transport systems [34]. This indicates that operational and production-related factors play a critical role in determining the overall environmental performance of micromobility systems.

C6. Visual pollution as a result of careless parking and stacking of vehicles

Micromobility sharing systems have significantly transformed urban streetscapes, with these changes often described as a “mess” resulting from dockless vehicles left in public spaces and subject to vandalism or misuse [35]. This also reflects the improper use of shared micromobility vehicles within pedestrian spaces.

Safety Aspect

C7. High rates of serious injury and accidents

The growing use of micromobility in urban areas has increased collision risks, highlighting the need for user training and information, especially given the lack of permit or traffic education requirements [36]. It refers to situations such as injury and death as a result of accidents, especially in vehicles used without personal protective equipment.

C8. Low use of personal protective equipment

Several safety precautions and protective equipment including as lights, high-visibility clothes, and helmets, can be employed to increase the security of micromobility users [37]. However, personal protective equipment is not used due to insufficient legal regulations and people’s preferences. These risks could be further intensified by the absence of mandatory safety requirements and standardized user training.

Public Policy Aspect

C9. Due to insufficient data, managers are insufficient in measuring micromobility vehicle performances and improve the process

The growing popularity of micromobility has introduced challenges related to user safety, social and environmental impacts, and system efficiency, making data collection and analysis essential for effective planning and decision-making [38], [39]. In this context, usage data are predominantly collected by private operators, resulting in limited data availability for public-sector decision-making, particularly due to the novelty of usage patterns and the current insufficiency of long-term datasets for analysis.

C10. Protection and sharing of personal data

Cyberattacks are attacks that are carried out through networks and include direct attacks on control devices within micromobility vehicles’ systems, as well as acts like creating delays, inflicting losses, or altering communication data [40]. In that sense, it indicates a situation in which personal data generated through shared micromobility systems may be exposed to cyberattacks, allowing malicious actors to gain unauthorized access to sensitive user information.

C11. Lack of legal regulations on the use of micromobility vehicles

Shared micromobility services initially operated in a regulatory blind spot, revealing the inadequacy of existing legal frameworks to address their impacts on public space and safety [41]. This situation leads to uncertainty and systemic challenges in the transportation system due to the absence of clear legal arrangements governing both service providers and users.

6. Results

6.1 General Overview

The experts first compared the 4 main criteria among themselves using the 1-9 Saaty scale. Then, the global and local priority degrees were determined by comparing the sub-criteria of each primary criterion. Ultimately, three distinct options were assessed for each criterion, and the alternatives' priority levels were determined. The AHP approach mentioned above was applied during this assessment, and the outcomes were a result.

The individual priority weights of the main and sub-criteria of micromobility were evaluated by nine experts, and the risk-sharing results among the alternatives were derived by averaging their joint assessments. According to the results, among the four main criteria, the security aspect was identified as the most significant, with a weight of 0.376, followed by the economic aspect with a weight of 0.333. These findings indicate that experts consider security and economy-related issues to be the most critical sources of risk.

Within the economic sub-criteria, the state's intervention in the private sector was ranked as the most important factor, with a weight of 0.386, followed by economic losses resulting from theft and hacking of micromobility vehicles, which received a weight of 0.290. To mitigate these two risks, the alternative with the highest priority was identified as state-operated micromobility practices.

Regarding the environmental and safety aspects, the increase in GHG emissions due to micromobility operations emerged as the most significant environmental risk, with a weight of 0.698, while high accident and injury risks were determined to be the most critical safety-related criterion, with a weight of 0.809.

Finally, within the public-policy aspect, the lack of legal regulations was identified as the most important risk criterion, with a weight of 0.409, followed by the insufficiency of data required for performance measurement and issues related to data protection and sharing. The resulting overall weights and priority rankings are presented in Table 3.

Table 3
General Overview of the Evaluation of Experts.

EXPERT A					
Main Criteria	Local Weight	Risk Criteria	A1	A2	A3
			Global Weight of Alternative		
Economic Aspect		C1	0,03	0,03	0,03
		C2	0,01	0,03	0,02

	0,33	C3	0,02	0,02	0,02
		C4	0,06	0,04	0,03
Environmental Aspect	0,16	C5	0,06	0,03	0,03
		C6	0,03	0,01	0,01
Safety Aspect	0,37	C7	0,16	0,07	0,08
		C8	0,02	0,02	0,02
Public-Policy Aspect	0,14	C9	0,01	0,02	0,01
		C10	0,02	0,01	0,01
		C11	0,03	0,01	0,02
		Priority of Alternative	0,47	0,28	0,25

6.2 Sensitivity Analysis

After determining the priorities of all risk criteria with the AHP method, the sensitivity analysis method was applied to reveal which risk criteria are more important in terms of cost. Considering the uncertainties of the risks during the sensitivity analysis, the priority weights determined by the AHP were accepted as the realization probabilities. The probability of realization of the risk criteria is shown in Table 4 below. The most important risk criteria are selected and used in the sensitivity analysis. Their impact on economic evaluation is considered with the parameters that are changed during the implications of performance evaluations.

Table 4
Probability of Risk Criteria.

Risk Criteria	Probability
Theft and Hacking	%10
High Maintenance and Redistribution Cost	%5
Bad Weather Conditions	%6
State Interference	%13
High GHG Emissions	%12
Visual Pollution	%5
High injury and accident Rates	%30
Absence of PPE	%7
Data inadequacy	%4
Data Protection and Sharing	%4
Lack of Regulations	%5

A pilot program scenario was created for the sensitivity analysis. In the scenario created, it is assumed that 1000 micromobility vehicles provide service in operations for 1 month. In the sensitivity analysis, the following variables were used as variable parameters, respectively.

- Life-span of Vehicles: If there are no hazards, the vehicles' service life is accepted to be 30 days. If hazardous materialized, the cost was calculated by varying the cars' usage duration.
- Vehicles in Service (Month): The vehicles' duration of use and the total number of vehicles in service during a given month have been established.
- Vehicle Cost: It is used to determine the cost of automobiles that result from accidents that happen over their lifetime.
- Trip Duration: The vehicles' trip duration and the number of minutes they spend in a single use were calculated. A comparison between the time periods found in academic research and corporate data was undertaken.
- Price of Trips: The duration of the trip obtained is used to determine the revenue generated by charging per minute.
- Cost of Service: The overall average of maintenance, redistribution, and charging expenses per vehicle usage is utilized to calculate expenditures.
- Number of Trips (Day): Cost calculations take into account how frequently a vehicle is used for trips during the day.

Following parameter determination, the income-expense relationship was calculated using iterations for the six risk criteria that are anticipated to have the greatest impact on the cost to construct the profit-loss graph.

6.2.1 Theft and Hacking Risk Criteria

Both the reduction of the service area and the cost adjustments that will arise from having to buy the vehicle again have been considered as a result of the vehicles being removed from service following issues like theft or hacking. After the parameters are obtained, a three Iterations example of Cost Calculations is shown in Table 5 below. The total number of Iterations for the sensitivity analysis was obtained as 100. By using these parameters, changes in expanse, income, and profit are calculated for each risk criterion.

Table 5
Theft and Hacking Risk Criteria.

Iteration	Probability	Lifespan of Vehicles	Number of Vehicles	Trip Duration(min) /Price of 1 Trip		Cost of Service ($)	Number of trips (per vehicle/day)
1	0,13	162	4860000	9	1,80	1,93	4
2	0,03	300	9000000	9	1,80	1,72	7
3	0,15	151	4530000	7	1,40	1,91	2

For sensitivity analysis, 5 different risk is selected in addition to theft and hacking risk criteria. 5 different risk is used, and the same iterations table is created as follows:

- High Redistribution and Maintenance Cost

- Decrease in Usage due to Bad Weather Conditions
- State’s Interference in Private Sector Competition
- Lack of Regulations
- High Injury and Accidents Rates

Given the impact of the risk criteria on the parameters and their financial provisions, the sensitivity analysis's findings indicate that the vehicles' maintenance, distribution, and charging operation costs rank highest among the risk criteria. Furthermore, it has been established that removing accident and injury hazards and fixing regulatory shortcomings are necessary to optimize income levels. As shown in the literature review, the relationship between these two risk criteria was also demonstrated by sensitivity analysis. The resulting profit-loss graph is shown in Figure 1 below.

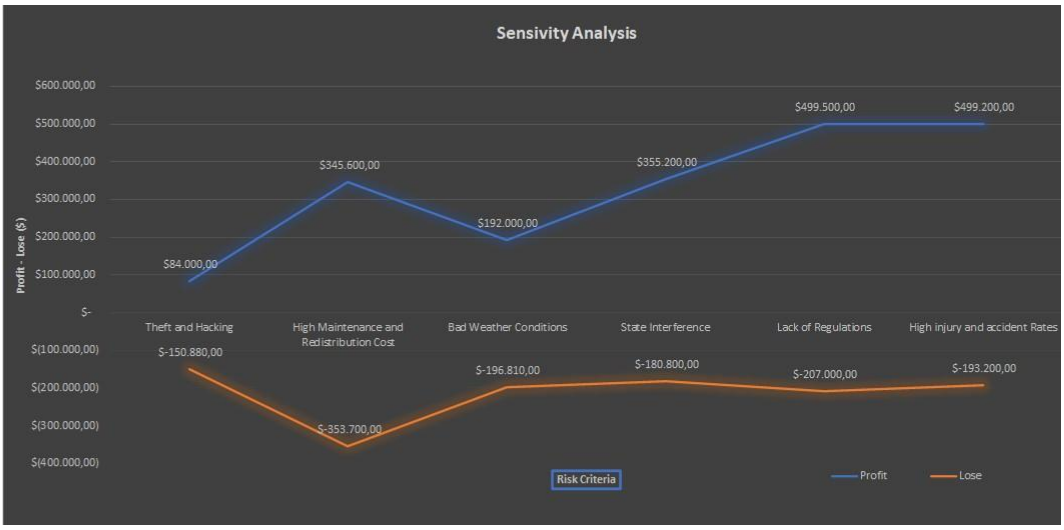

Fig. 1. Sensitivity Analysis for Risk Criteria

7. Discussion

This study evaluates the micromobility sector through identified risk criteria using the AHP method, a reliable multi-criteria decision-making approach based on expert assessments. Examining the results, it was found that each expert placed a distinct emphasis on risk criteria and options. This happens as a result of micromobility apps being a relatively new technology with a user experience that is still in its infancy. It also matches the scenario of being assessed from a single viewpoint, which is seen in scholarly research in this area. It should be taken into account that the economic, environmental, security, and public-policy aspects, which are the 4 main criteria determined in this study, are interconnected and that the improvement made in one area will reduce the possibility of risks in other areas. For this reason, the relations of the evaluated criteria, both separately and with each other, were taken into consideration when evaluating the results.

The fact that the analysis's most significant finding was security indicates that customers have misgivings and that this is one of the primary reasons they do not prefer micromobility vehicles in their daily lives. One could argue that this is largely due to the insufficiency of local and national laws as well as the application of disparate legal systems in various geographical areas. This outcome is consistent with the study of [7], which found that public perception is the biggest barrier to the usage of micromobility equipment.

According to the findings of the experts' assessment, the state's intervention in the private sector should be justified by two primary factors. Of the sub-criteria of the economic aspect, which is ranked second in importance, this one stands out as the most significant risk scale. [42] identifies the first of these as the endeavor to avert competition with the state-installed docked sharing systems in the current transportation network, and the limitations to be implemented to safeguard the public from potential security issues with the municipalities' implementation of the micromobility sector. Private companies must implement licensing processes, vehicle maintenance controls, and infrastructure arrangements to address these shortcomings. More crucially, plans must be made in accordance with performance metrics and reciprocal data sharing to meet public demands. Additionally, since the micromobility market is unstable and prices are low because of intense competition, steps must be taken to improve service quality. Additionally, rules and regulations must be established before private companies can begin offering services without first obtaining the required permits to enter the market and then waiting for services to develop over time [43]. Because of this, attempts should be made to help reduce market errors as the most functional regulation model [42].

According to the regulations created, the environmental component is the one that is most impacted when it comes to the necessity of the restrictions. It should be taken into consideration because of its mutual linkages with the public-policy element, even if it was shown to be the third most important risk criterion in the evaluations. It is claimed that fewer people will drive their own cars, which will reduce GHG emissions and air pollution [44], [45]. In this regard, integration between micromobility vehicles and public transportation infrastructure should be ensured to reduce the use of individual vehicles. In addition, one of the most critical issues is to increase the level of accessibility to micromobility vehicles and public transportation stations and to provide equal access to all segments of the public. For this reason, it becomes inevitable for the state to cooperate with the private sector and create an equitable transportation system [4], [46]

8. Policy Implications

Although the sharing economy is sometimes viewed as a disruptive innovation for existing market actors, the lack of clear legal regulations creates uncertainty and discourages companies from entering the micromobility sector, leading them to demand privileges from governments. Therefore, cooperation between sharing economy companies and local and national authorities is essential. While data analysis and sharing are critical for the development of micromobility services, private operators often prioritize profit-oriented decisions over equitable public service, frequently avoiding low-density areas [47].

What's more, policy measures should focus on creating a suitable service environment through planning and regulation. Providing accessible and affordable micromobility parking at public transportation stations can prevent visual pollution and the occupation of public space. Inequalities in access persist due to long distances to transit stations, inadequate infrastructure, high usage costs, and limited access to digital payment systems [45]

Furthermore, data governance represents a major policy challenge. Existing datasets are often insufficient for performance evaluation and problem detection due to the reluctance of private companies to share data and limited data infrastructure [48]. Secure data-sharing frameworks should be established under governmental responsibility, while the commercial use of personal and travel data should be restricted [41], [49]. Including the public in data-driven planning processes is expected to reduce societal resistance and enhance public benefit [16].

9. Conclusion

Beyond users, the micromobility sector affects government, the private sector, and society as a whole. A comprehensive literature review was conducted to identify sector-related risks, and alternatives reflecting current conditions were defined by focusing on the roles of different stakeholders. A hierarchical structure was established using the AHP method to evaluate these risks through a reliable multi-criteria decision-making framework, in which economic, environmental, safety, and public-policy dimensions were defined as the main categories to ensure the inclusion of all affected stakeholders.

Based on the AHP results, the study highlights that risks cannot be effectively addressed through a one-sided approach and emphasizes the necessity of cooperation between the state and the private sector to minimize these risks. This finding contributes to the academic literature by underlining the importance of cooperation, particularly in the context of the state's limited capacity to rapidly establish adequate infrastructural and legal frameworks for private sector investments. Without such cooperation, the micromobility sector may fail to reach its potential and become dysfunctional before completing its development.

Author Contributions

Conceptualization, Gokasar; methodology, Gokasar and Yemlihalioglu; software, Yemlihalioglu; validation, Yemlihalioglu; formal analysis, Yemlihalioglu; investigation, Gokasar and Yemlihalioglu; resources, Gokasar and Yemlihalioglu; data curation, Gokasar and Yemlihalioglu; writing—original draft preparation, Gokasar and Yemlihalioglu; writing—review and editing, Gokasar and Yemlihalioglu; supervision, Gokasar. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] R. Eberts, “Understanding the Impact of Transportation on Economic Development,” 2000. Accessed: Feb. 06, 2026. [Online]. Available: https://onlinepubs.trb.org/onlinepubs/millennium/00138.pdf

[2] G. Weisbrod, “Models to predict the economic development impact of transportation projects: historical experience and new applications,” *The Annals of Regional Science 2007 42:3*, vol. 42, no. 3, pp. 519–543, Jan. 2008, doi: 10.1007/s00168-007-0184-9.

[3] S. Shaheen, S. Guzman, and H. Zhang, “Bikesharing in Europe, the Americas, and Asia,” *Transp. Res. Rec.*, no. 2143, pp. 159–167, Jan. 2010, doi: 10.3141/2143-20.

[4] G. Oeschger, P. Carroll, and B. Caulfield, “Micromobility and public transport integration: The current state of knowledge,” *Transp. Res. D Transp. Environ.*, vol. 89, p. 102628, Dec. 2020, doi: 10.1016/j.trd.2020.102628.

[5] C. S. Kopplin, B. M. Brand, and Y. Reichenberger, “Consumer acceptance of shared e-scooters for urban and short-distance mobility,” *Transp. Res. D Transp. Environ.*, vol. 91, p. 102680, Feb. 2021, doi: 10.1016/j.trd.2020.102680.

[6] K. Johnston, D. A. Oakley, A. Durham, C. Bass, and S. Kershner, “Regulating Micromobility: Examining Transportation Equity and Access,” *Journal of Comparative Urban Law andPolicy*, vol. 4, pp. 685–723, 2020, Accessed: Feb. 06, 2026. [Online]. Available: https://readingroom.law.gsu.edu/cgi/viewcontent.cgi?article=1074&context=jculp

[7] S. Gössling, “Integrating e-scooters in urban transportation: Problems, policies, and the prospect of system change,” *Transp. Res. D Transp. Environ.*, vol. 79, p. 102230, Feb. 2020, doi: 10.1016/j.trd.2020.102230.

[8] T. Puschmann and R. Alt, “Sharing economy,” *Business and Information Systems Engineering*, vol. 58, no. 1, pp. 93–99, Jan. 2016, doi: 10.1007/s12599-015-0420-2.

[9] B. Cohen and J. Kietzmann, “Ride On! Mobility Business Models for the Sharing Economy,” *Organ. Environ.*, vol. 27, no. 3, pp. 279–296, Sep. 2014, doi: 10.1177/1086026614546199.

[10] S. Ganapati and C. G. Reddick, “Prospects and challenges of sharing economy for the public sector,” *Gov. Inf. Q.*, vol. 35, no. 1, pp. 77–87, Jan. 2018, doi: 10.1016/j.giq.2018.01.001.

[11] K. Heineke, B. Kloss, T. Möller, and C. Wiemuth, “McKinsey Center for Future Mobility,” 2021. Accessed: Feb. 06, 2026. [Online]. Available: https://www.mckinsey.com/~/media/mckinsey/industries/automotive%20and%20assembly/our%20insights/shared%20mobility%20where%20it%20stands%20where%20its%20headed/shared-mobility-where-it-stands-where-its-headed.pdf

[12] A. A. Dubey, S. Singh, and R. Astya, “IoT Enabled Micro Mobility Vehicle With Fault Determination,” *Proceedings - 2nd International Conference on Advancement in Computation and Computer Technologies, InCACCT 2024*, pp. 793–799, 2024, doi: 10.1109/InCACCT61598.2024.10551195.

[13] S. T. Jin and D. Z. Sui, “Shared micromobility and equity: A comparison between station-based, hybrid, and dockless models,” *Transp. Res. D Transp. Environ.*, vol. 129, p. 104113, Apr. 2024, doi: 10.1016/j.trd.2024.104113.

[14] S. Shaheen and A. Cohen, “Mobility on demand (MOD) and mobility as a service (MaaS): early understanding of shared mobility impacts and public transit partnerships,” *Demand for Emerging Transportation Systems: Modeling Adoption, Satisfaction, and Mobility Patterns*, pp. 37–59, Jan. 2020, doi: 10.1016/B978-0-12-815018-4.00003-6.

[15] S. Shaheen, A. Cohen, and E. Martin, “Public bikesharing in North America,” *Transp. Res. Rec.*, no. 2387, pp. 83–92, Dec. 2013, doi: 10.3141/2387-10.

[16] U.S. Department of Transportation | Federal Highway Administration, “Shared Micromobility: Current Practices and Guiding Principles,” 2016. Accessed: Feb. 06, 2026. [Online]. Available: https://ops.fhwa.dot.gov/publications/fhwahop16022/fhwahop16022.pdf

[17] K. Martens, “The bicycle as a feedering mode: experiences from three European countries,” *Transp. Res. D Transp. Environ.*, vol. 9, no. 4, pp. 281–294, Jul. 2004, doi: 10.1016/j.trd.2004.02.005.

[18] G. Apostolou, A. Reinders, and K. Geurs, “An Overview of Existing Experiences with Solar-Powered E-Bikes,” *Energies 2018, Vol. 11,* vol. 11, no. 8, Aug. 2018, doi: 10.3390/en11082129.

[19] International Transport Forum, “Safe Micromobility,” 2020. Accessed: Feb. 06, 2026. [Online]. Available: https://www.itf-oecd.org/sites/default/files/docs/safe-micromobility_1.pdf

[20] International Transport Forum, “Safer Micromobility.” Accessed: Feb. 06, 2026. [Online]. Available: https://www.itf-oecd.org/sites/default/files/docs/safer-micromobility.pdf

[21] R. W. Saaty, “The Analytical Hierarchy Process - What it is and How it is Used,” 1987. Accessed: Feb. 06, 2026. [Online]. Available: https://www.sciencedirect.com/science/article/pii/0270025587904738/pdf?md5=4050e284cabc0a9f733b31ca9c8ff63f&pid=1-s2.0-0270025587904738-main.pdf

[22] T. L. Saaty, “How to make a decision: The analytic hierarchy process,” *Eur. J. Oper. Res.*, vol. 48, no. 1, pp. 9–26, Sep. 1990, doi: 10.1016/0377-2217(90)90057-I.

[23] G. A. Miller, “The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information[1],” 1956, Accessed: Feb. 06, 2026. [Online]. Available: https://labs.la.utexas.edu/gilden/files/2016/04/MagicNumberSeven-Miller1956.pdf

[24] T. L. Saaty and M. S. Ozdemir, “Why the magic number seven plus or minus two,” *Math. Comput. Model*, vol. 38, no. 3–4, pp. 233–244, Aug. 2003, doi: 10.1016/S0895-7177(03)90083-5.

[25] T. L. Saaty, “Decision making with the analytic hierarchy process,” 2008. Accessed: Feb. 06, 2026. [Online]. Available: https://www.rafikulislam.com/uploads/resourses/197245512559a37aadea6d.pdf

[26] M. Bałtowski and P. Kozarzewski, “Formal and real ownership structure of the Polish economy: state-owned versus state-controlled enterprises,” *Postcommunist Econ.*, vol. 28, no. 3, pp. 405–419, Jul. 2016, doi: 10.1080/14631377.2016.1196885.

[27] J. Taalbi, “What drives innovation? Evidence from economic history,” *Res. Policy*, vol. 46, no. 8, pp. 1437–1453, Oct. 2017, doi: 10.1016/j.respol.2017.06.007.

[28] W. W. Powell and K. Snellman, “The knowledge economy,” *Annu. Rev. Sociol.*, vol. 30, no. Volume 30, 2004, pp. 199–220, Aug. 2004, doi: 10.1146/annurev.soc.29.010202.100037.

[29] A. Akintoye, M. Beck, and C. Hardcastle, “Public-Private Partnerships: Managing Risks and Opportunities,” *Public-Private Partnerships: Managing Risks and Opportunities*, pp. 1–422, Jan. 2008, doi: 10.1002/9780470690703.

[30] N. Vinayaga-Sureshkanth, R. Wijewickrama, A. Maiti, and M. Jadliwala, “Security and privacy challenges in upcoming intelligent urban micromobility transportation systems,” *AutoSec 2020 - Proceedings of the 2nd ACM Workshop on Automotive and Aerial Vehicle Security*, vol. 20, pp. 31–35, Mar. 2020, doi: 10.1145/3375706.3380559.

[31] H. H. Heimes, A. Kampker, M. Kehrer, J. Gerz, R. Marzolla, and E. Zancul, “Design for Reliability and Total Cost of Ownership: the case of electric micromobility,” *Procedia CIRP*, vol. 119, no. 22, pp. 302–308, Jan. 2023, doi: 10.1016/j.procir.2023.02.137.

[32] R. B. Noland, "Scootin' in the rain: Does weather affect micromobility?" *Transp. Res. Part A Policy Pract.*, vol. 149, pp. 114–123, Jul. 2021, doi: 10.1016/j.tra.2021.05.003.

[33] C. Kousky *et al.*, "Private investment and government protection," *Journal of Risk and Uncertainty 2006 33:1*, vol. 33, no. 1, pp. 73–100, Sep. 2006, doi: 10.1007/s11166-006-0172-y.

[34] L. D'Acierno *et al.*, "Adoption of Micro-Mobility Solutions for Improving Environmental Sustainability: Comparison among Transportation Systems in Urban Contexts," *Sustainability 2022, Vol. 14,* vol. 14, no. 13, Jun. 2022, doi: 10.3390/su14137960.

[35] A. Leszczynski, J. Cinnamon, S. Asa, and L. Jahiu, "Docklessness, aesthetic governance, and the urban 'micromobility mess,'" *Urban Studies*, vol. 62, no. 12, pp. 2508–2525, Sep. 2025, doi: 10.1177/00420980251316773.

[36] A. Sanjurjo-de-No, A. M. Pérez-Zuriaga, and A. García, "Factors Influencing the Pedestrian Injury Severity of Micromobility Crashes," *Sustainability 2023, Vol. 15,* vol. 15, no. 19, Sep. 2023, doi: 10.3390/su151914348.

[37] A. K. Høye, O. Johansson, and I. S. Hesjevoll, "Safety equipment use and crash involvement among cyclists – Behavioral adaptation, precaution or learning?" *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 72, pp. 117–132, Jul. 2020, doi: 10.1016/j.trf.2020.05.002.

[38] H. H. Schumann, H. Haitao, and M. Quddus, "Passively generated big data for micro-mobility: State-of-the-art and future research directions," *Transp. Res. D Transp. Environ.*, vol. 121, p. 103795, Aug. 2023, doi: 10.1016/j.trd.2023.103795.

[39] V. E. Uz and F. E. Kesmez, "Micromobility Data Need and Data Use," in *Springer Tracts in Civil Engineering*, vol. Part F47, Springer Science and Business Media Deutschland GmbH, 2025, pp. 225–262. doi: 10.1007/978-3-031-77098-2_16.

[40] S. Sato *et al.*, "Data Acquisition Framework for Micromobility Vehicles Toward Driving Risk Prediction Against Cyberphysical Security Attack," *IEEE Secur. Priv.*, vol. 23, no. 2, pp. 61–70, 2025, doi: 10.1109/MSEC.2024.3441731.

[41] N. Fearnley, "Micromobility – Regulatory Challenges and Opportunities," *Shaping Smart Mobility Futures: Governance and Policy Instruments in times of Sustainability Transitions*, pp. 169–186, Jan. 2020, doi: 10.1108/978-1-83982-650-420201010.

[42] R. Deighton-Smith, "The Economics of Regulating Ride-Hailing and Dockless Bike Share Discussion Paper," 2018. Accessed: Feb. 06, 2026. [Online]. Available: https://www.itf-oecd.org/sites/default/files/docs/economics-regulating-ride-hailing-dockeless-bike-share.pdf

[43] K. Button, H. Frye, and D. Reaves, "Economic regulation and E-scooter networks in the USA," *Research in Transportation Economics*, vol. 84, p. 100973, Dec. 2020, doi: 10.1016/j.retrec.2020.100973.

[44] M. Weiss, P. Dekker, A. Moro, H. Scholz, and M. K. Patel, "On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers," *Transp. Res. D Transp. Environ.*, vol. 41, no. 5, pp. 348–366, Dec. 2015, doi: 10.1016/j.trd.2015.09.007.

[45] R. L. Abduljabbar, S. Liyanage, and H. Dia, "The role of micro-mobility in shaping sustainable cities: A systematic literature review," *Transp. Res. D Transp. Environ.*, vol. 92, p. 102734, Mar. 2021, doi: 10.1016/j.trd.2021.102734.

[46] B. Şengül and H. Mostofi, "Impacts of E-Micromobility on the Sustainability of Urban Transportation—A Systematic Review," *Applied Sciences 2021, Vol. 11,* vol. 11, no. 13, Jun. 2021, doi: 10.3390/app11135851.

[47] S. Sareen, D. Remme, and H. Haarstad, "E-scooter regulation: The micro-politics of market-making for micro-mobility in Bergen," *Environ. Innov. Soc. Transit*, vol. 40, no. 6, pp. 461–473, Sep. 2021, doi: 10.1016/j.eist.2021.10.009.

[48] M. McQueen, G. Abou-Zeid, J. MacArthur, and K. Clifton, "Transportation Transformation: Is Micromobility Making a Macro Impact on Sustainability?" *J. Plan. Lit.*, vol. 36, no. 1, pp. 46–61, Feb. 2021, doi: 10.1177/0885412220972696.

[49] S. Shaheen and A. Cohen, "Shared micromobility: policy and practices in the United States," *A Modern Guide to the Urban Sharing Economy*, Aug. 2021, doi: 10.4337/9781789909562.00020.