Research Article

Factors Affecting the Integration of Micromobility into Smart Cities and Effects on Urban Transport

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Abstract: In the transport of the future, the development of smart cities and the use of micromobility vehicles play an important role in terms of sustainability and efficiency. Micromobility vehicles such as electric scooters, bicycles and e-mopeds provide environmental, economic and social benefits by offering an important alternative in urban transport. However, many factors need to be considered for the successful integration of these vehicles. The aim of this paper is to analyse the main factors affecting the integration of micromobility vehicles into urban transport systems. In this paper, 9 sub-criteria under 6 main criteria affecting the integration of micromobility vehicles are considered and the relationships between these criteria are analysed by DEMATEL method. As a result of the analysis, the importance ranking of the criteria related to micromobility vehicles is determined as follows: roads reserved for micromobility vehicles, integration of micromobility vehicles with public transport, accidents, legislation deficiencies, lighting and signing, accessibility to micromobility vehicles, digital literacy level, effects of micromobility vehicles on environmental sustainability and fuel cost. The study makes an important contribution towards better understanding the impacts of micromobility vehicles on urban transport and identifying important factors to be considered in the integration process.

Keywords: Micromobility vehicles, smart cities, DEMATEL method

Mikromobilitenin Akıllı Şehirlere Entegrasyonunu Etkileyen Faktörler ve Şehir İçi Ulaşıma Etkileri

Özet: Geleceğin ulaşımında, akıllı şehirlerin gelişimi ve mikromobilite araçlarının kullanımı, sürdürülebilirlik ve verimlilik açısından önemli bir rol oynamaktadır. Elektrikli scooter, bisiklet ve e-moped gibi mikromobilite araçları, şehir içi ulaşımda önemli bir alternatif sunarak çevresel, ekonomik ve toplumsal faydalar sağlamaktadır. Ancak, bu araçların başarılı entegrasyonu için birçok faktörün dikkate alınması gerekmektedir. Bu makalenin amacı, mikromobilite araçlarının şehir içi ulaşım sistemlerine entegrasyonunu etkileyen temel faktörleri analiz etmektir. Makalede, mikromobilite araçlarının entegrasyonunu şekillendiren 6 ana kriter altında 9 alt kriter ele alınmış ve bu kriterler arasındaki ilişkiler DEMATEL yöntemi ile incelenmiştir. Analiz sonucunda, mikromobilite araçlarıyla ilgili kriterlerin önem sıralaması şu şekilde belirlenmiştir: mikromobilite araçları için ayrılmış yollar, mikromobilite araçlarının toplu taşıma ile entegrasyonu, kazalar, mevzuat eksiklikleri, ışıklandırma ve işaretlendirmeler, mikromobilite araçlara erişilebilirlik, dijital okuryazarlık seviyesi mikromobilite araçlarının çevresel sürdürülebilirliğe etkileri ve yakıt maliyetidir. Çalışma, mikromobilite araçlarının şehir içi ulaşım üzerindeki etkilerini daha iyi anlamaya ve entegrasyon sürecinde dikkate alınması gereken önemli faktörleri belirlemeye yönelik önemli bir katkı sunmaktadır.

Anahtar Kelimeler: Mikromobilite araçlar, akıllı şehirler, DEMATEL yöntemi

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1. Introduction

The dynamics of modern urbanization, characterized by rapid city growth and increasing population density, have introduced new transportation challenges. Issues such as traffic congestion, rising carbon emissions, and inadequate infrastructure underscore the limitations of traditional transportation systems in meeting sustainability goals. In this context, innovative approaches are gaining prominence to make urban transportation more efficient, eco-friendly, and accessible.

Smart cities, leveraging technological advancements such as the Internet of Things (IoT), artificial intelligence, and big data analytics, aim to enhance quality of life and foster a sustainable urban future. Within this framework, micromobility—encompassing eco-friendly and user-friendly modes of transportation such as electric scooters, shared bicycles, and e-mopeds—has emerged as a crucial component. These vehicles are particularly effective in addressing the “last-mile” problem in urban mobility, bridging gaps in traditional public transportation systems.

The integration of micromobility vehicles into intelligent cities represents a significant advancement in urban transportation systems, promoting sustainability and enhancing urban mobility. Research highlights their potential to reduce greenhouse gas emissions, especially in cities with high private vehicle usage, such as Barcelona (Felipe-Falgas et al, 2022; Sun and Ertz, 2022). Transitioning from traditional motorized transport to micromobility options contributes to environmental sustainability while aligning with smart city goals that emphasize intelligent transportation systems and sustainable urban planning (Munhoz et al, 2020; Moch and Wereda, 2020).

However, the successful implementation of micromobility solutions is contingent on their integration with existing public transportation networks. This integration facilitates the concept of Mobility as a Service (MaaS), enhancing accessibility and convenience for urban residents (Sun and Ertz, 2022). Yet, the political economy of micromobility services is complex, as their sustainability often hinges on public funding or private investment, raising concerns about equity and accessibility (Stehlin and Payne, 2022). Effective governance and strategic planning are therefore essential to ensure that these services are both economically viable and inclusive.

Safety and infrastructure are also critical considerations. The increasing adoption of micromobility has been accompanied by a rise in accidents and injuries, highlighting the need for dedicated infrastructure and regulations to mitigate risks (Sanjurjo-de-No, 2023; Karpinski et al, 2022). Cities must develop comprehensive strategies to establish circulation spaces for micromobility vehicles, ensuring their safe coexistence with pedestrians and motor vehicles. Additionally, smart technologies such as data acquisition systems and intelligent traffic management can enhance the safety and efficiency of micromobility systems (Pérez-Zuriaga et al, 2022).

This study aims to evaluate the integration of micromobility vehicles into smart cities through a multi-criteria approach, analyzing safety,environmental, economic, ınfastructure, policy and accessibility dimensions. By exploring how micromobility aligns with sustainable urban transportation goals, this article seeks to contribute both to academic discourse and practical solutions, offering insights into the future of micromobility in intelligent cities.

2. Literature Review

The integration of micromobility solutions into smart cities represents multifaceted challenges and opportunities that directly influence urban transportation systems. Micromobility encompasses a variety of lightweight vehicles, including electric scooters, bicycles, and e-mopeds, aimed at addressing last-mile connectivity while promoting sustainable urban mobility. The factors affecting this integration can be categorized into technological, infrastructural, environmental, and social aspects, each playing a critical role in determining the success of micromobility initiatives within urban environments.

Technological advancements are paramount in shaping the micromobility landscape. The emergence of shared micromobility platforms facilitates user access to transportation options that were previously less available or nonexistent. For instance, the integration of app-based services allows for real-time data collection, supporting better urban planning and policy-making aimed at enhancing transportation systems (Tamagusko et al, 2023). Infrastructure plays a crucial role in the successful integration of micromobility. The availability of dedicated lanes and safe parking for micromobility vehicles significantly influences their adoption rates. Studies indicate that cities that have invested in dedicated cycling and e-scooter lanes, as well as secure parking facilities, experience higher usage rates of micromobility solutions (Rześny-Cieplińska et al, 2023; Hassam et al, 2024).

From an environmental standpoint, micromobility presents an opportunity to mitigate urban traffic congestion and reduce emissions associated with traditional fossil fuel-powered vehicles. Evidence suggests that if cities successfully encourage a modal shift from cars to micromobility modes, there will be substantial reductions in overall transportation-related emissions (Felipe-Falgas et al, 2022; Sun and Ertz, 2022; Rześny-Cieplińska et al, 2023). Furthermore, micromobility aligns with urban sustainability goals, particularly in cities seeking to comply with climate action plans aimed at reducing carbon footprints (McQueen et al, 2020).

Social factors, including public perceptions and user behaviors, also critically affect micromobility integration. The prevailing attitudes toward shared micromobility services often dictate their success or failure within urban landscapes. Research indicates that consumer innovativeness and perceptions of environmental consciousness influence the acceptability and adoption of these services (Flores and Jansson, 2021). In many instances, positive experiences with micromobility during the COVID-19 pandemic catalyzed a shift away from public transit to these alternative modes, suggesting that the pandemic altered users' travel patterns in a way that favors micromobility (Fonseca-Cabrera et al, 2021). Additionally, equity concerns arise when evaluating micromobility solutions, as access may be disproportionately available to certain demographics, potentially exacerbating inequality in urban mobility (Bylieva et al, 2022).

Moreover, the integration of micromobility into existing transportation networks necessitates coordinated efforts among various stakeholders, including local governments, private operators, and community organizations. Effective policies should encompass considerations of equity, sustainability, and user safety while fostering an inclusive approach to urban mobility (Rześny-Cieplińska et al, 2023).

Identifying the factors affecting the integration of micromobility into smart cities involves a variety of research methods that span qualitative and quantitative approaches. The systematic analysis of these factors is essential for understanding how micromobility can play a transformative role in urban transport modalities. Several methodologies are frequently employed in the literature on this topic.

Quantitative methods such as statistical analysis are widely used to explore the impacts of micromobility on urban transportation systems. For instance, Štefancová et al. evaluated the impact of the COVID-19 pandemic on micromobility, analyzing changes in usage patterns and identifying variables that promote the effective integration of shared bicycles and scooters with public transport Štefancová et al. (2022). This method allows for identifying correlations and dependencies that inform policy decisions and design of integrated transport systems.

Qualitative case studies serve as an effective method for understanding the multifaceted factors involved in micromobility integration. For example, Aguilera-García et al. investigated moped scooter-sharing systems in Spanish urban contexts, drawing insights on user engagement, city policy adaptation, and technological interface (Aguilera-García et al, 2020). Such case analyses facilitate a deeper contextual understanding of how micromobility functions within distinct urban frameworks, revealing local challenges and opportunities. Surveys and interviews of micromobility users and non-users provide valuable insights into user preferences, behaviors, and needs. Research by Jafarzadehfadaki and Sisiopiku explores user attitudes towards e-scooter adoption across differing U.S. cities, outlining factors influencing acceptance such as convenience, cost, and safety perceptions (Jafarzadehfadaki and Sisiopiku, 2024). These user-centered approaches enable cities to design services better aligned with the expectations of potential users, thereby fostering effective integration.

Investigating existing policy documents and regulatory frameworks surrounding micromobility can uncover barriers to integration. Marques and Coelho conducted a literature review that highlighted the need for comprehensive policies enabling micromobility integration through life cycle thinking approaches (Marques and Coelho, 2022). The outcome of such analysis is critical for identifying gaps in legislation or community engagement that may inhibit the successful embedding of micromobility options. GIS techniques allow for spatial analysis of micromobility patterns and infrastructure needs. Tamagusko et al. utilized safety data mapping to identify high-risk areas for micromobility users

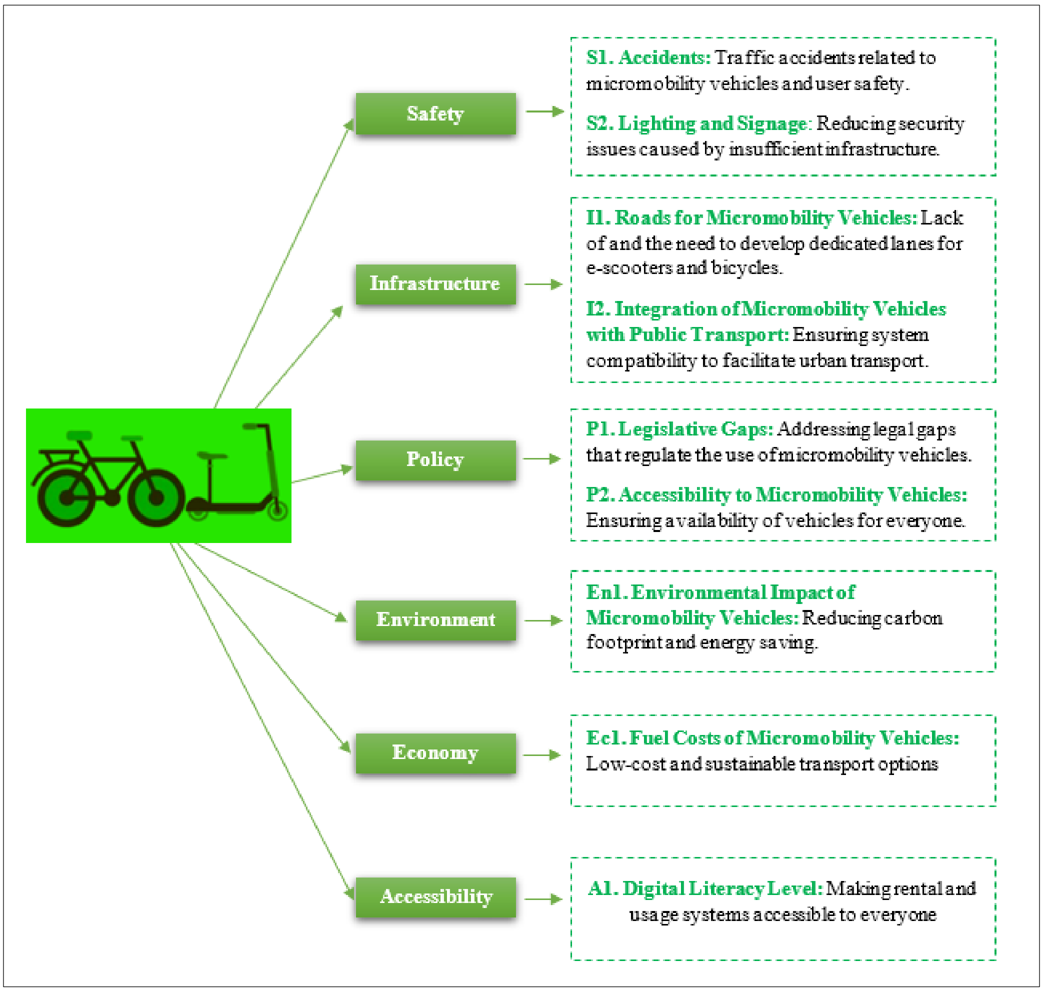
(Tamagusko et al, 2023). By visualizing data geographically, cities can make informed decisions on where to allocate resources for infrastructure improvements that enhance safety and accessibility. Approaches such as the Analytic Hierarchy Process (AHP) are employed in decision-making related to the selection of micromobility systems. Bajec et al. utilized AHP-DEA to optimize the selection of electric bike-sharing system providers (Bajec et al, 2021). This approach allows for the simultaneous evaluation of multiple criteria, ensuring that selected systems meet a range of urban mobility objectives.

In conclusion, the successful integration of micromobility into smart cities relies on a comprehensive understanding of the interplay between technological advancements, infrastructure development, environmental impacts, and social dynamics. A holistic approach is essential for policymakers and urban planners to address key factors such as user safety, equitable access, and sustainability, ensuring that micromobility solutions align with contemporary urban mobility goals. This process necessitates a combination of quantitative and qualitative methods to identify and analyze influencing factors, providing valuable insights for more effective transportation planning. Moreover, continuous feedback loops should be emphasized, enabling adaptive strategies that respond to emerging trends and user needs, ultimately enhancing the functionality and sustainability of smart cities.

3. Materials and methods

3.1. Materials

In the study, the main criteria affecting micromobility vehicles were identified as safety, infrastructure, policy, environment, economy and accessibility. Based on these main criteria, nine sub-criteria were defined within the scope of the study. These sub-criteria that constitute the data set are; accidents, lighting and signalling, roads for micromobility vehicles, integration of these vehicles with public transport, legislative gaps, accessibility to micromobility vehicles, effects on environmental sustainability, fuel cost advantages and digital literacy level. These criteria play a critical role in the integration of micromobility vehicles into smart city systems. Figure 1 shows the criteria used in the study.



S1. Accidents: Traffic accidents related to micromobility vehicles and user safety.

S2. Lighting and Signage: Reducing security issues caused by insufficient infrastructure.

I1. Roads for Micromobility Vehicles: Lack of and the need to develop dedicated lanes for e-scooters and bicycles.

I2. Integration of Micromobility Vehicles with Public Transport: Ensuring system compatibility to facilitate urban transport.

P1. Legislative Gaps: Addressing legal gaps that regulate the use of micromobility vehicles.

P2. Accessibility to Micromobility Vehicles: Ensuring availability of vehicles for everyone.

En1. Environmental Impact of Micromobility Vehicles: Reducing carbon footprint and energy saving.

Ec1. Fuel Costs of Micromobility Vehicles: Low-cost and sustainable transport options

A1. Digital Literacy Level: Making rental and usage systems accessible to everyone

Figure 1. Criteria Used in the Study

3.2. Method

The Decision Making Trial and Evaluation Laboratory Method (DEMATEL), one of the multi-criteria decision making methods, is used in the study. For the decision matrix to be created in the DEMATEL method, literature reviews and expert opinions (decision maker group consisting of 3 academicians and 2 civil engineers) are utilised. DEMATEL method is considered superior to other methods due to the existence of a relationship between the criteria, classification of the criteria, strong complex system analysis and visual outputs. In this context, DEMATEL method is preferred for the analysis results of the criteria to be used in the study.

3.2.1. DEMATEL Method

The DEMATEL method analyses the causal relationship between criteria in solving complex problems in research (Wu and Lee, 2007; Fontela, 1974; Fontela, 1976). The DEMATEL method offers the opportunity to create an outline for the planning and solution of problems by categorising the relevant factors into cause and effect groups in order to better understand causal relationships (Li, 2009). In this method, the opinions and assessments of decision makers are utilised. Thanks to DEMATEL, the weights of the evaluation criteria can be calculated and the criteria can be ranked according to their importance levels. This approach enables the criteria that affect and are affected by each other in the decision process to be analysed within the framework of a common consensus (Güler et al, 2022).

As a result, the main distinction of DEMATEL from other methods is that it can analyse the relationships between the criteria and visualise the cause-effect links in the system and offer solutions to complex systems. This feature provides a great advantage especially in strategic decision making processes. The process steps of this method are given below.

Step 1. In this step, the criteria are evaluated pairwise in line with the expert opinion. This evaluation is made according to the DEMATEL method evaluation scale given in Table 1.

Table 1. DEMATEL Method Evaluation Scale (Nilashi et al. 2015)

Numerical Value	Description
0	Ineffective
1	Low Impact
2	Medium Impact
3	High Impact
4	Very High Impact

Step 2. In this step, a normalisation process is performed in order to preserve the integrated decision structure as much as possible. In this process, using the direct relationship matrix (A), the normalised direct relationship matrix (X) is obtained with the following formulas. In this process, each value in the direct relationship matrix is normalised by dividing the largest parts of the row sum of this matrix.

$$X=k.A \qquad (1)$$

$$k=\frac{\frac{1}{max}}{1\leq i\leq n\sum_{j=1}^{n} aij}, \quad i,j=1,2,3,\ldots,n \qquad (2)$$

Step 3. In this step, after the normalised relationship matrix (X) is created, the total relationship matrix (T) is calculated by the following formula.

$$T= X.(1-X)^{-1} \qquad (3)$$

Step 4. In this step, D and R values are determined. The sum of the row values of the T matrix gives the D value and the sum of the column values gives the R value.

$$T=[tij]_{nxn}, \quad i,j=1,2,3,\ldots.,n \qquad (4)$$

$$D=\left[\sum_{j=1}^{n} tij\right]_{nx1} \qquad (5)$$

$$R=\left[\sum_{j=1}^{n} tij\right]_{1xn} \qquad (6)$$

Step 5. In this step, D+R values indicating the level of relationship for each factor and D-R values determining the influence levels of the factors are calculated. The D+R value on the horizontal axis in the influence graph expresses the level of interaction of a factor with other factors. In other words, as the D+R value of a factor increases, the interaction of this factor with other factors also increases. On the vertical axis of the influence graph, there are D-R values indicating the influence power of a factor. If the D-R value of a factor is positive, this factor is in the influencing group; if D-R is negative, it is in the influenced group. The importance weights of the factors are calculated as follows (Koçak and Diyadin, 2018).

$$W_i=\sqrt{}(D_i+R_i)^2+(D_i-R_i)^2 \qquad (7)$$

$$W_i=\frac{wi}{\sum_{i=1}^{n} wi} \qquad (8)$$

4. Results

In the application phase of the study, the sub-criteria were evaluated in line with the opinions obtained from the decision makers and the importance rankings were determined by using the average values. Table 2 shows the direct and average relationship matrix obtained by averaging the opinions of the experts.

Table 2. Direct and average relation matrix

	S1	S2	I1	I2	P1	P2	En1	Ec1	A1
S1	0	2	3	4	3	3	1	4	2
S2	3	0	2	3	2	3	2	3	4
I1	4	3	0	2	3	3	3	4	3
I2	2	4	3	0	3	2	3	3	3
P1	3	2	1	2	0	4	2	1	2
P2	2	1	2	2	4	0	2	2	4
En1	3	2	3	2	4	1	0	3	3
Ec1	1	1	2	2	2	1	2	0	1
A1	1	1	2	3	2	3	2	0	0

The row and column sum of each value of the direct and average relationship matrix is found. The highest value of the row and column sum was found to be 25. The normalised matrix is obtained by dividing each value in the direct relationship matrix by the highest value of the row and column sum values (Table 3).

Table 3. Normalised matrix

	S1	S2	I1	I2	P1	P2	En1	Ec1	A1
S1	0,000	0,080	0,120	0,160	0,120	0,120	0,040	0,160	0,080
S2	0,120	0,000	0,080	0,120	0,080	0,120	0,080	0,120	0,160
I1	0,160	0,120	0,000	0,080	0,120	0,120	0,120	0,160	0,120
I2	0,080	0,160	0,120	0,000	0,120	0,080	0,120	0,120	0,120
P1	0,120	0,080	0,040	0,080	0,000	0,160	0,080	0,040	0,080
P2	0,080	0,040	0,080	0,080	0,160	0,000	0,080	0,080	0,160
En1	0,120	0,080	0,120	0,080	0,160	0,040	0,000	0,120	0,120
Ec1	0,040	0,040	0,080	0,080	0,080	0,040	0,080	0,000	0,040
A1	0,040	0,040	0,080	0,120	0,080	0,120	0,080	0,000	0,000

In Table 4, the unit matrix used to obtain the total relationship matrix, the matrix obtained by subtracting the normalised matrix from the unit matrix and the inverse of this matrix are calculated.

Table 4. Unit matrix, (I-M) matrix ve (I-M)$^{-1}$ matrix

Unit matrix

	S1	S2	I1	I2	P1	P2	En1	Ec1	A1
S1	1	0	0	0	0	0	0	0	0
S2	0	1	0	0	0	0	0	0	0
I1	0	0	1	0	0	0	0	0	0
I2	0	0	0	1	0	0	0	0	0
P1	0	0	0	0	1	0	0	0	0
P2	0	0	0	0	0	1	0	0	0
En1	0	0	0	0	0	0	1	0	0
Ec1	0	0	0	0	0	0	0	1	0
A1	0	0	0	0	0	0	0	0	1

(I-M) matrix

	S1	S2	I1	I2	P1	P2	En1	Ec1	A1
S1	1,000	-0,080	-0,120	-0,160	-0,120	-0,120	-0,040	-0,160	-0,080
S2	-0,120	1,000	-0,080	-0,120	-0,080	-0,120	-0,080	-0,120	-0,160
I1	-0,160	-0,120	1,000	-0,080	-0,120	-0,120	-0,120	-0,160	-0,120
I2	-0,080	-0,160	-0,120	1,000	-0,120	-0,080	-0,120	-0,120	-0,120

P1	-0,120	-0,080	-0,040	-0,080	1,000	-0,160	-0,080	-0,040	-0,080
P2	-0,080	-0,040	-0,080	-0,080	-0,160	1,000	-0,080	-0,080	-0,160
En1	-0,120	-0,080	-0,120	-0,080	-0,160	-0,040	1,000	-0,120	-0,120
Ec1	-0,040	-0,040	-0,080	-0,080	-0,080	-0,040	-0,080	1,000	-0,040
A1	-0,040	-0,040	-0,080	-0,120	-0,080	-0,120	-0,080	0,000	1,000

$(I-M)^{-1}$ matrix

	S1	**S2**	**I1**	**I2**	**P1**	**P2**	**En1**	**Ec1**	**A1**
S1	1,320	0,353	0,414	0,480	0,493	0,453	0,337	0,474	0,441
S2	0,422	1,272	0,379	0,448	0,457	0,451	0,366	0,433	0,506
I1	0,498	0,413	1,343	0,457	0,540	0,493	0,434	0,512	0,517
I2	0,413	0,431	0,429	1,357	0,511	0,438	0,417	0,455	0,496
P1	0,364	0,293	0,286	0,349	1,314	0,421	0,307	0,304	0,374
P2	0,347	0,274	0,334	0,365	0,472	1,301	0,326	0,348	0,454
En1	0,416	0,338	0,399	0,401	0,508	0,375	1,281	0,423	0,455
Ec1	0,229	0,203	0,253	0,270	0,301	0,240	0,247	1,195	0,254
A1	0,263	0,233	0,286	0,340	0,345	0,348	0,279	0,232	1,259

Table 5 shows the total relationship matrix obtained by using Equation 3. For the total relationship matrix, the total relationship matrix is obtained by subtracting the normalised matrix from the unit matrix, taking the inverse and multiplying it by the normalised matrix again.

Table 5. Total relation matrix

	S1	**S2**	**I1**	**I2**	**P1**	**P2**	**En1**	**Ec1**	**A1**
S1	0,000	0,028	0,050	0,077	0,059	0,054	0,013	0,076	0,035
S2	0,051	0,000	0,030	0,054	0,037	0,054	0,029	0,052	0,081
I1	0,080	0,050	0,000	0,037	0,065	0,059	0,052	0,082	0,062
I2	0,033	0,069	0,051	0,000	0,061	0,035	0,050	0,055	0,059
P1	0,044	0,023	0,011	0,028	0,000	0,067	0,025	0,012	0,030
P2	0,028	0,011	0,027	0,029	0,076	0,000	0,026	0,028	0,073
En1	0,050	0,027	0,048	0,032	0,081	0,015	0,000	0,051	0,055
Ec1	0,009	0,008	0,020	0,022	0,024	0,010	0,020	0,000	0,010
A1	0,011	0,009	0,023	0,041	0,028	0,042	0,022	0,000	0,000

D values are obtained from the sum of the rows of the total relationship matrix and R values are obtained from the sum of the total relationship matrix. D-R, D+R and W_{ia} values are calculated by using Equation 7 and Equation 8. According to the importance weights, the criteria were ranked (Table 6).

Table 6. Importance weights

Criteria	**D**	**R**	**D-R**	**D+R**	**W_{ia}**	**W_i**	**Ranking**
S1	0,3929	0,3046	0,0883	0,6974	0,7030	0,1181	3
S2	0,3876	0,2258	0,1618	0,6134	0,6344	0,1066	5
I1	0,4858	0,2606	0,2252	0,7464	0,7796	0,1310	1
I2	0,4140	0,3188	0,0953	0,7328	0,7390	0,1242	2
P1	0,2405	0,4303	-0,1899	0,6708	0,6972	0,1171	4
P2	0,2968	0,3363	-0,0395	0,6331	0,6343	0,1066	6
En1	0,3586	0,2376	0,1209	0,5962	0,6083	0,1022	8
Ec1	0,1228	0,3550	-0,2323	0,4778	0,5313	0,0893	9
A1	0,1752	0,4051	-0,2299	0,5803	0,6242	0,1049	7

The threshold value is important for the influence directional distribution diagram. The threshold value plays an important role in determining the direction of the criteria. It can be used in a scatter plot or in cases where the number of criteria is high to show which criteria affect each other unidirectionally or reciprocally. In addition, indicating the threshold value on the figure contributes to a clearer visualisation of the interactions between the criteria. This value is usually calculated by averaging the total relationship matrix. The threshold value in this study is 0.036.

Table 7. Criterion direction

Criteria	D+R	D-R	Criterion direction
S1	0,6974	0,0883	Affecting
S2	0,6134	0,1618	Affecting
I1	0,7464	0,2252	Affecting
I2	0,7328	0,0953	Affecting
P1	0,6708	-0,1899	Affected
P2	0,6331	-0,0395	Affected
En1	0,5962	0,1209	Affecting
Ec1	0,4778	-0,2323	Affected
A1	0,5803	-0,2299	Affected

Close D+R values indicate that the criteria are related to each other. Positive D-R values are labelled as ‘affecting’ and negative ones as ‘affected’. In Table 7, S1, S2, I1, I2, En1 are the influencing criteria and P1, P2, Ec1, A1 are the influenced criteria.

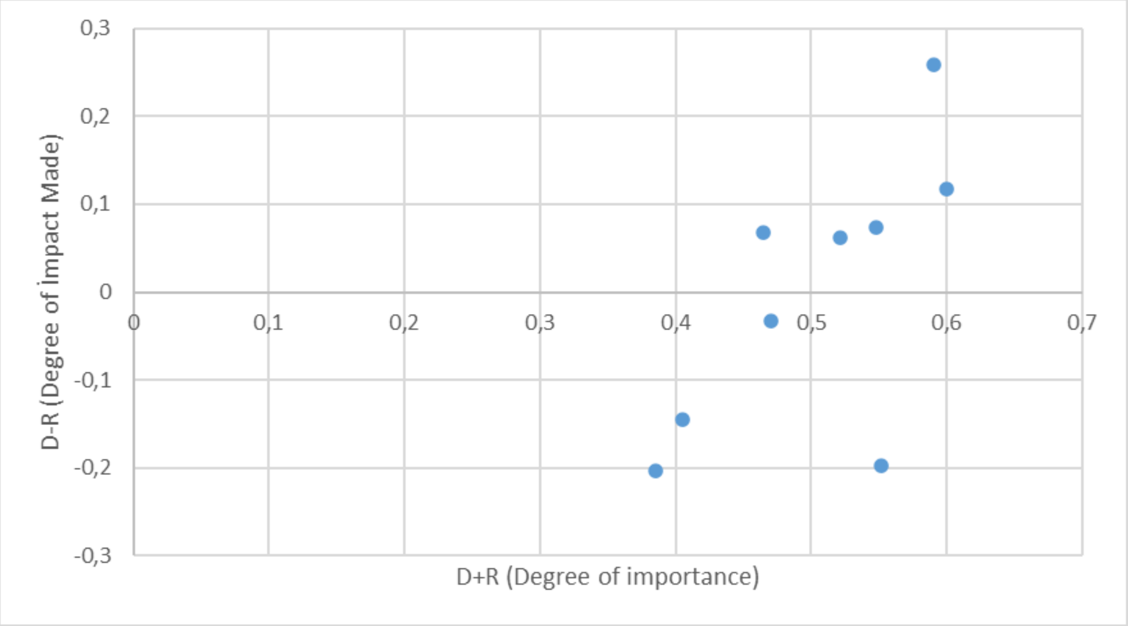


Figure 2. Effect directional scatter plot

In the effect direction scatter plot, D+R forms the horizontal axis and D-R forms the vertical axis. The direction of influence is indicated by the arrow in the diagram according to the affecting and affected status (Figure 2).

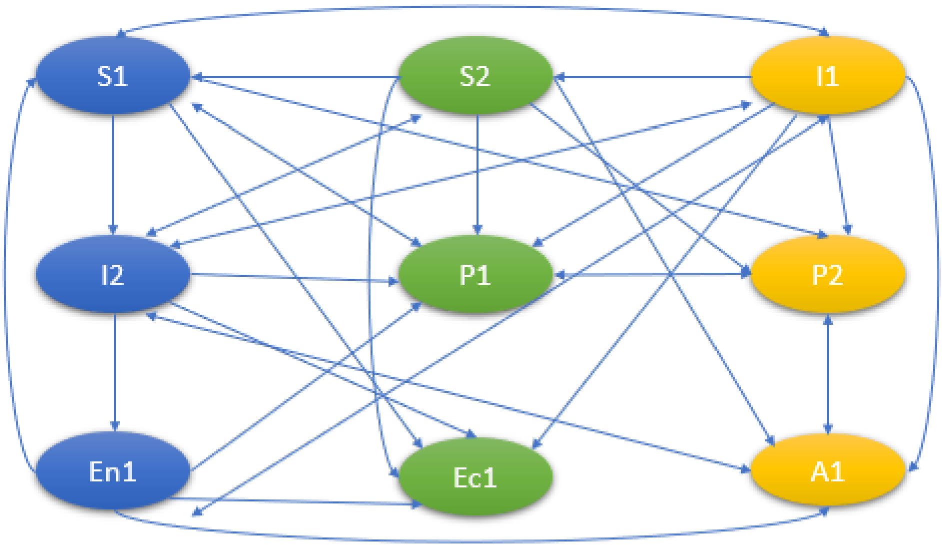


Figure 3. Impact directional distribution map

According to the total relationship matrix in Table 5, the values above the threshold value are coloured. Figure 3 is drawn according to this effect directional relationship. It is seen that S1 to I1, S1 to P1, S2 to I2, I1 to I2, I1 to En1, I2 to A1, P1 to P2, P2 to A1 are bidirectional, and the others are unidirectional (Figure 3).

5. Discussion

The integration of micromobility vehicles in smart cities brings both opportunities and challenges. Many factors such as technology infrastructure, legal regulations and urban planning play a critical role in the success of this integration. When the effects of micromobility systems on urban transport are analysed, it is seen that positive contributions such as reduced traffic density, lower carbon emissions and reduced individual transport costs cannot be ignored. However, issues such as infrastructure deficiencies and user safety are still important problems that need to be solved.

Another critical point is the social acceptance of micromobility and its effects on user behaviour. Society's adoption of these systems depends on the effectiveness of education and awareness campaigns. In this context, the digital literacy level of the public and insufficient inclination towards technology create a negative impact for micromobility vehicles. In order to ensure user safety, compliance with traffic rules and safe driving practices should be prioritised. In addition, integrating micromobility systems with public transport systems will enable these systems to reach a wider audience and be used more effectively.

The integration of micromobility with smart cities faces significant challenges such as infrastructure and security issues. In terms of infrastructure, cities need to harmoniously organize elements such as roads, parking areas and charging stations for the efficient use of micromobility vehicles. Safety is an important factor, especially as vehicles such as bicycles and electric scooters interact with pedestrians and increase accidents. Furthermore, factors such as the lifetime, maintenance and durability of these vehicles pose additional challenges for urban transportation systems.

The production and diffusion of micromobility products generally has a positive aspect on environmental impacts, but can also have some negative consequences. The batteries used in these vehicles can increase energy intensity and pressure on natural resources. However, the proliferation of micromobility vehicles, especially in urban transportation, is significantly reducing carbon emissions and air pollution by replacing conventional fossil fuel vehicles. Increasing the number of vehicles such as electric scooters and bicycles, easing traffic congestion and achieving energy efficiency helps cities develop a cleaner and more sustainable transportation system.

Legal regulations play a critical role in incorporating micromobility into smart cities in terms of safety, accessibility and sustainability. Changing legal frameworks can regulate the use of micromobility vehicles, improving traffic efficiency and ensuring orderly urban transportation. These regulations help to prevent potential accidents by determining elements such as speed limits, parking spaces, user insurance and responsibilities. In addition, standards and sustainability goals for the production, leasing and use of micromobility vehicles can be promoted through legal regulations. However, these legal frameworks need to be dynamically updated and adapted to the rapid provision of cities.

In the economic dimension, the micromobility sector offers a significant potential. Partnerships to be established between local governments and the private sector can produce solution-oriented approaches to ensure the sustainability of the systems. However, managing these partnerships in a way that respects social interests will prevent micromobility from being reduced to an economic gain. Environmentally, although micromobility systems have a great potential to reduce carbon emissions, the production and maintenance processes of these systems must also comply with sustainability principles. Especially the development of recycling programmes for electric micromobility vehicles and the use of renewable energy sources will be decisive in achieving environmental targets.

Harmonising micromobility with the smart city concept is an important step towards creating livable and sustainable cities in the future. However, in order to achieve this goal, technological innovations and policy development processes need to be handled together. New research and pilot projects to better understand the long-term effects of micromobility will deepen the knowledge in this field and allow for more effective strategies.

6. Conclusion and Suggestions

The integration of micromobility vehicles into smart cities has a critical importance in reshaping urban life. The factors affecting this process include technology infrastructure, legal regulations, user habits, environmental sustainability goals and urban planning strategies. Research findings reveal that micromobility vehicles have multifaceted effects on urban transport. While the positive impacts include reduced traffic density, lower greenhouse gas emissions and lower individual transport costs, new problems such as infrastructure deficiencies, user safety and vehicle density also come to the fore. In this context, for the successful implementation of micromobility vehicles in smart cities, a broad approach with a wide scope and impact area is required. Based on the literature reviews and expert opinions, it has been determined that the main criteria affecting micromobility vehicles are safety, infrastructure, policy, environment, economy and accessibility. In the context of this study, a data set consisting of nine different sub-criteria based on the main criteria was determined. This data set consists of accidents, lighting and signalling, roads for mobility vehicles, integration of mobility vehicles with public transport, legislative deficiencies, accessibility to mobility vehicles, impact of mobility vehicles on environmental sustainability, fuel cost of mobility vehicles and digital literacy level. These criteria play an important role in the integration of micromobility vehicles into smart cities.

DEMATEL method, one of the multi-criteria decision making methods, was used in the study. With this method, which is preferred among the pairwise comparison methods, the importance weights of these nine sub-criteria were determined and ranked. The importance ranking of the criteria is determined as follows: roads reserved for micromobility vehicles, integration of micromobility vehicles with public transport, accidents, legislative deficiencies, lighting and signalling, accessibility to micromobility vehicles, digital literacy level, effects of micromobility vehicles on environmental sustainability and fuel cost. According to D-R values, S1, S2, I1, I2, En1 are affecting criteria and P1, P2, Ec1, A1 are affected criteria.

Strategies and recommendations that can increase the effectiveness of micromobility vehicles:

- The co-operation of the public sector, private sector and academia is vital for the sustainable development of micromobility systems. Comprehensive policies and strategies to be prepared jointly will be especially useful in terms of ensuring the continuity of the systems, eliminating legislative deficiencies and developing solution-oriented approaches. Such co-operation can provide an effective basis for improving legal regulations, setting standards and providing innovative solutions.

- User-oriented education campaigns should be organised to increase social acceptance and usage rates of micromobility vehicles. These campaigns can include topics such as safe driving, environmental awareness, benefits of sustainable transport and rules of use of micromobility systems. In addition, awareness-raising activities for the target audience can be disseminated through social media, local administrations and educational institutions.
- Infrastructure investments should be prioritised for the safe and effective use of micromobility vehicles. Physical infrastructures such as segregated roads, parking areas, charging stations and lighting systems increase the safety of car users and facilitate their integration into the traffic flow. In addition, designing these infrastructures in harmony with existing public transport systems will shorten travel times and improve the user experience..
- Smart technologies such as IoT (Internet of Things), GPS-based tracking systems and data analytics can be used to make micromobility systems more efficient. These technologies can be effective in route optimisation, safety monitoring, vehicle maintenance and analysing user behaviour. In addition, micromobility solutions that will work integrated with smart city systems can increase transport efficiency throughout the city.
- Integration of micromobility vehicles with public transport systems can make journeys faster and more accessible by encouraging multi-modal transport. In this context, locating micromobility vehicles close to public transport stops can enable users to easily combine different modes of transport.
- To increase the environmental sustainability of micromobility vehicles, systems powered by renewable energy sources can be encouraged. In addition, minimising the environmental impacts in the production and use of vehicles will support the adoption of these vehicles as an environmentally friendly alternative.
- Financial incentives can be offered to increase the use of micromobility vehicles. For example, policies such as tax breaks, affordable leasing options or subsidised public transport integration can make these vehicles more accessible to all segments of society.

In conclusion, the integration of micromobility applications with smart cities will not only revolutionise transportation, but also support the creation of livable, sustainable and more efficient cities. New research and innovative solutions to be implemented in this field will enable micromobility systems to reach a much wider potential.

Conflict of Interest Statement, if any

The authors have no conflict of interest to declare.

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The authors' contribution rates in the study are equal.

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