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Challenges of the Integration of Micromobility Vehicles into Modern Traffic and Transportation Systems

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ABSTRACT

This paper presents the main challenges of integrating micromobility vehicles into modern traffic and transportation systems. Although micromobility seems to be an effective concept for the first and last mile, the reality points to the potential problems that the integration of micromobility vehicles can create and that must be resolved appropriately. Micromobility vehicles are characterised by extensive development, which is not accompanied by appropriate legal regulations. The street design has its spatial limitations and usually separates non-motorised and motorised users, which is a notion that could be disrupted by new micromobility options. When it comes to Serbia, the existing legislation does not recognise the majority of micromobility vehicles, which results in the lack of safety of these participants and their place in the street profile. The aim of this paper is to provide guidelines for improving the existing regulations and integrating these vehicles into the traffic system of Serbia, with special reference to general recommendations through which micromobility vehicles can be treated in other countries. The results of this paper can be useful to decision-makers but also to all other participants in the process of developing effective policies and strategies for the integration of micromobility vehicles into traffic and transportation systems.

KEYWORDS

micromobility vehicles; regulations; vehicle characteristics; infrastructure; policies.

1. INTRODUCTION

Urban traffic and transportation systems represent, through their performance, technology, quality, costs and influence on the environment, one of the essential factors of the functioning of modern cities, their economy, social relationships, quality of life, etc. In a wider context, urban traffic and transportation systems represent one of the key elements of convenience of life for all users in urban areas. Through this system, different problems are being tackled, ranging from the unlimited freedom of individuals to choose the optimal way of resolving mobility issues, coming up with optimal variants to resolve transportation problems, treating the urban traffic and transportation system as a free market, the distinct influence of all levels of authorities and politics, or demands in the realisation of mobility of different social groups, etc.

An inadequate understanding of these complex problems in urban traffic and transportation systems results in the high pressure of different interest groups which are often a serious obstacle to the process of finding quality solutions which are in the general interest of the local community. The obligation of the owner of the transportation market to realise a higher level of quality of transportation services along with acceptable requirements while using the available mobility technology represents a key requirement that is asked of the system. These requirements directly imply a constant adjustment of the system to the market and permanent pressure on its development and efficiency. The flexibility of each of these service elements varies, and the key elements are determined in the time near the service being performed (or immediately before the service being performed). The main focus of the micromobility market is the realisation of transportation needs on short distances, that is, this is efficiently the solution for the realisation of the first and the last kilometre of a passenger's trip.

The structure of the technology for the use of micromobility vehicles (e-bikes, e-scooters, segways, etc.) offers the potential for fast, clean and sustainable transportation, which could reduce the load on street networks and conventional systems of urban public transportation. Observed in a wider context, this technology can reduce the pressure on the entirety of the city transportation system. Hence, new micromobility services can represent one of the effective measures in the process of developing sustainable and innovative means of transportation. Micromobility vehicles are simple to use, ecologically acceptable, and, in certain situations, even faster than the traditional system of passenger transportation (like the public transportation system or passenger cars) and they provide passengers with fast and cheap transportation, as well as the autonomy of movement [1].

Bearing in mind the various challenges that cities have faced so far, regarding the integration of micromobility vehicles, the aim of this paper is to examine the possibilities of modern traffic and transportation systems accepting these new transportation options. Accordingly, this paper presents the results of a case study for the Republic of Serbia, and at the end of the paper, there are general guidelines for the regulation and integration of micromobility vehicles in other countries, i.e. cities.

Based on the above, the initial research question was defined: Is it possible to adequately and efficiently integrate micromobility vehicles into modern traffic and transportation systems, despite the existence of significant differences in the design characteristics of these vehicles and the requirements for the use of infrastructure?

The results of a survey of experts, users and potential users, experiences of good practices from other countries, European Union legislation and recommendations or standards were used as a starting point for the integration of micromobility vehicles into traffic and transportation systems. The survey of experts consisted of five units related to the advantages and disadvantages of using micromobility vehicles, the way of using the infrastructure and regulating the exploitation of vehicles, requirements related to the characteristics and use of vehicles as well as requirements for their public use. The sample obtained by the research consists of 36 experts, and the method of conducting the survey is an indirect interview. The survey of users and potential users determined the basic characteristics of users (gender, age, work status, municipality/city, etc.), trip characteristics (purpose, frequency of use, length of trip, etc.), vehicle type and characteristics, conditions and restrictions (possession of a license, use of a protective helmet, insurance, speed limit, etc.), characteristics of the infrastructure used, the impact of the Covid-19 virus pandemic, security aspects, as well as preferences and basic reasons for using certain micromobility options. The sample in total, using the direct interview method, consists of 1,002 respondents (users and potential users).

This paper consists of seven chapters, as follows: the introductory chapter in which the basic assumptions, hypotheses and the aim of the paper are given. The methodology of the research with a detailed explanation of the research process follows. The third chapter presents a brief overview of the literature, while the fourth chapter presents the basic characteristics and classification of micromobility vehicles according to examples of the world's best practices. The fifth chapter includes proposals for measures for the integration of micromobility vehicles on the territory of the Republic of Serbia, while the sixth chapter gives a brief discussion of the proposed measures. The last chapter includes the conclusion and general guidelines for the integration of these vehicles in other countries and cities.

2. METHODOLOGY OF THE RESEARCH

For the purposes of this paper, several researches were carried out, grouped into five phases.

The first phase includes an analysis of global (world) experiences and good practices in the mentioned field based on the available literature. This analysis is sublimated through the "Literature review" chapter, in which the important features of this new system are presented, such as vehicle characteristics, regulations, required infrastructure, safety and the attitudes of users and potential users regarding the use of vehicles for micromobility.

The second phase includes a detailed examination of the technical characteristics and existing classifications of vehicles for micromobility, the manner and purpose of their use, the safety aspects of their use, etc. The results of this research are presented in the chapter “Characteristics and classification of micromobility vehicles”.

The third phase includes the research of the characteristics of vehicles for micromobility that are used in local areas, their exploitation potential as well as the infrastructure potential for the use of these vehicles in the Republic of Serbia. The main part of these results is presented in the chapter “Micromobility vehicle integration – a case study of the Republic of Serbia”.

The fourth phase covers the research of users, potential users and experts’ requirements on the usage of micromobility vehicles. For the purposes of this research, a survey of the mentioned interest groups was carried out. In 2020, an online survey of the aforementioned users was conducted, which provided the necessary guidelines for future plans. The survey form (made in Google Forms) was sent by e-mail to cities and municipalities in Serbia, but it was also shared via social networks. The total sample is 1,002 respondents (users and potential users). The survey contained 29 questions (which, due to the limitations of the paper, will not be presented in detail). The questions related to the following important characteristics:

- User characteristics (gender, age, employment status, municipality/city, etc.);
- Travel characteristics (purpose, frequency of use, length of trip, etc.);
- Vehicle type and characteristics;
- Conditions and limitations (having a license, using a safety helmet, insurance, speed limit, etc.);
- Characteristics of the infrastructure;
- The impact of the Covid-19 pandemic;
- Safety aspects;
- Preferences and the main reasons for using certain micromobility options.

The survey of experts resulted in a sample of 36 respondents, from different professions and different work positions. The survey of experts contained 23 basic questions, with sub-questions, which are grouped into 5 important categories:

- Advantages and disadvantages of using vehicles for micromobility;
- Ways of using the infrastructure and regulating the exploitation of vehicles;
- Requirements related to the characteristics of the vehicles (e-bike, e-scooter, other vehicles);
- Requirements related to the use of vehicles;
- Requirements related to the public use of vehicles for micromobility and operators.

The last, fifth phase within the methodological procedure is the proposal of measures, i.e. the proposal of the legal framework and the definition of requirements for micromobility vehicles and the conditions for their use (categorisation, vehicle technical characteristics, infrastructure, etc.) in local areas in the Republic of Serbia. The results of this phase are presented in the chapter “Micromobility vehicle integration – a case study of the Republic of Serbia”. A special part of this phase refers to the provision of general guidelines for the integration of micromobility vehicles in cities, which is presented in the concluding remarks of this paper.

3. LITERATURE REVIEW

Micromobility vehicles, which most often include e-bikes, e-scooters, hoverboards, segways, e-skateboards, etc., have quickly become a globally popular means of transportation. Various advantages and benefits of using these vehicles, such as efficiency on shorter distances, environmental suitability, attractiveness, low cost of use (exploitation), etc., [2] have significantly accelerated their development and use. However, this expansion of micromobility vehicles has caused mixed reactions and concerns from users. Despite the initial enthusiasm, problems and numerous issues related to regulations, infrastructure, the safety of road users, the creation of visual clutter, etc. appeared [3–5], which to a certain extent slowed down the further process of integration of these vehicles into transportation systems and made it questionable. In this chapter, a brief overview of the literature will be given, through which the previous world experiences will be presented, as well as the biggest obstacles that cities have encountered during the “struggle” with these new transportation options.

One of the most significant issues that arises as a major challenge is the availability and adequacy of the existing infrastructure for micromobility vehicles. This issue reflects the modernity of the regulation, that is, its flexibility for changes. The infrastructure is one of the factors that has a significant impact on the safety of passengers, but also on their willingness to start or stop using these vehicles [1]. Accordingly, in the parts of the paper to follow, a summary of the infrastructural capacities intended for micromobility vehicles, in the selected countries, is given (*Table 1*).

Table 1 – Infrastructure for micromobility vehicles

Country	E-bike	E-scooter	Segway	E-skateboard	Hoverboard
Australia	r, bi, s	r, bi, s	ss	pp	pp
Austria	r, bi	r, bi	nd	s	s
Belgium	r, bi	r, bi, pz	r, bi	r, bi	bi
Denmark	r, bi	bi	bi, ss	bi	bi
Italy	r, bi	r, bi, pz	r, bi, ss	s	s
California	r, bi, t	r, bi	r, bi, s	r, bi, s	r, bi
Germany	r, bi	r, bi, s	r, bi	r	nd
Singapore	r, bi, yl	bi, ss	bi, ss	bi, ss	bi, ss
Serbia	in the process of regulation at the national level				
Texas	r, bi	r, bi	r, bi	r, bi	nd
Finland	r, bi	r, bi	r, bi, s	r, bi, s	s
Florida	r, bi, s	r, bi	r, bi, s	pp	r, bi, s
France	r, bi	r, bi, pz	nd	r, bi, s	nd
Netherlands	r, bi	r, bi	pp	pp	pp
Spain	r, bi	r, bi	r, bi	r, bi	r, bi

r – roadway, bi – bicycle infrastructure, s – sidewalk, pz – pedestrian zone, yl – "yellow lanes" for public transportation, ss – shared space, pp – private properties, nd – no data

Several interesting points can be observed from *Table 1*. First of all, most countries identify e-scooters with e-bikes, i.e. traditional bicycles, which is why the use of the same infrastructure is allowed. The problem arises in situations with vehicles that can move much faster than the standard recommended speed of 25 km/h. For example, a "pedelec" (pedal electric cycle or *EPAC*) that can move at a speed of up to 45 km/h (as well as certain models of e-scooters) is categorised in a number of countries as a motorcycle, which is why this means of transportation must move on the road and must not use the bicycle infrastructure. Such is the situation with France, Switzerland and the Netherlands [3, 4]. For example, in Switzerland, high-speed pedelecs are allowed to travel on roads that are marked as "no motorised bicycles", if they are used without the engine running [5]. The country where pedelec drivers can use the cycling infrastructure is Denmark [6].

On the other hand, it is important to note that the use of sidewalks by e-bikes is expressly prohibited in most European countries. When it comes to e-scooters, the situation is somewhat different, precisely because of the constructive characteristics of these vehicles, so they can be used on sidewalks in Australia, Germany, Abu Dhabi and New Zealand [7, 8]. In addition to sidewalks for e-scooters, the use of pedestrian zones, i.e. shared spaces, is usually allowed, subject to compliance with certain conditions. For example, in Italy, the use of pedestrian zones is allowed with a speed limit of up to 6 km/h [9].

What is important to note at this point is that the use of pedestrian areas for the movement of e-scooters is not recommended that often, primarily due to the high resistance of passengers, and above all pedestrians. For example, in a study conducted in Arlington [10] pedestrians were asked to answer the question to what extent they feel safe when moving around e-scooter users. The obtained results showed that as many as 38% of respondents stated that they felt very unsafe in the presence of these vehicles. A similar study was conducted in Portland [11], in which the comments of both e-scooter users and all other road users were analysed. Out of the total number of respondents, as many as 30% of them stated that the biggest problem is the unsafe movement of e-scooters on sidewalks, which is why a certain number of traffic accidents occur precisely between micromobility vehicles and pedestrians [10–12].

The infrastructure provided for other micromobility vehicles (segways, e-skateboards, hoverboards, etc.) varies from country to country, that is, depends on the national and local regulations that cover them (which can be seen in *Table 1*). For example, it is interesting to note that most of these vehicles are treated as "toys" in the Netherlands, which is why they can only be used on private properties [13]. The situation is similar in some American cities.

As mentioned at the beginning of this chapter, various problems arose during the integration and exploitation of these vehicles, which, it may be said, have escalated in recent months in certain cities. The most recent example is Paris, where citizens expressed great dissatisfaction with the business of private e-scooter rental companies. Visual clutter, parking, reduced safety and lack of vehicle maintenance are cited as the most common reasons for displeasure [14]. Therefore, the rental of e-scooters will be banned in Paris after the residents of the French capital voted against the "machines" on the streets in a public referendum [15]. It is important to note that this decision will not apply to privately owned e-scooters. In addition to Paris, officials in Montreal, Canada also banned both private and public use of e-scooters in 2020 [16], while Denmark's capital Copenhagen banned rentals in 2020 before allowing their use a year later under significantly stricter conditions [17]. Dubai followed a similar development, while for example, the use of e-scooters in Great Britain is currently illegal [13].

According to the points above, it is clear that there is still a large number of doubts, as well as problems faced by cities when implementing and using micromobility vehicles, such as different technical and operational characteristics of the vehicle, the issue of space, the way of movement and use of the vehicle, the behaviour of the user while driving, compliance with regulations, user requests, traffic signals, etc. [18]. All the listed characteristics can be generally classified into four groups: regulation, vehicle characteristics, infrastructure and safety. In accordance with the above, in the rest of the paper, a methodological procedure will be proposed for the integration of micromobility vehicles into the modern traffic and transportation system, following existing trends and requirements in the Republic of Serbia, as well as experiences and examples of the best world practices.

4. CHARACTERISTICS AND CLASSIFICATION OF MICROMOBILITY VEHICLES

The classification of micromobility vehicles on the territory of Europe is done on the basis of Regulation No. 168/2013 of the European Parliament and Council on the approval and market surveillance of two- or three-wheel vehicles and quadricycles [19] and European standards EN 15194:2017 [20] and EN 17128:2020 [21]. In the classification, micromobility vehicles belong to L-category vehicles, that is, to a subcategory of L1e – "light two-wheel powered vehicles" (L1e-A ("powered cycle") and L1e-B ("two-wheel moped")). For the purposes of this Regulation, "two-wheel powered vehicles" are defined as vehicles with two wheels powered by an engine, including powered cycles, two-wheel mopeds and two-wheel motorcycles.

Pedelec, which belongs to the category of "slower" e-bicycles, is not covered by the Regulation, and the requirements for producing these kinds of micromobility vehicles are defined by the standard of the European Committee for Standardization EN 15194:2017, whereby production requirements for e-bikes on the territory of Europe are complete. As for the purposes of classification of all categories of micromobility vehicles which are not covered by the Regulation (EU) No. 168/2013 of the European Parliament and Council on the approval and market surveillance of two- or three-wheel vehicles and quadricycles and the standards of the European Committee for Standardization EN 15194:2017, another European standard EN 17128:2020 was provisioned. European standard EN 17128:2020 is related to the light electric vehicles for personal use which are powered, completely or partially, from an independent source power supply with or without the self-balancing system, except for rental vehicles. *Table 2* shows a classification of light electric vehicles for personal use.

Class 1 comprises vehicles without the self-balancing system and seats, reaching up to 6 km/h in design speed. Vehicles in class 2, just like in class 1, do not have a self-balancing system and seats, but their maximum design speed is 25 km/h. Representatives of these two classes of vehicles are electric scooters (e-scooter) without seats, electric tricycles, electric skateboards, etc. Vehicles in classes 3 and 4 possess the self-balancing system and can be with or without seats, with the maximum design speed being 6 km/h for vehicles in class 3

Table 2 – Classification of light electric vehicles for personal use [21]

Class number	Has a self-balancing system	Maximum design speed [km/h]	Has a seat
Class 1	No	6	No
Class 2	No	25	No
Class 3	Yes	6	Yes, and it can be without a seat
Class 4	Yes	25 km/h	Yes, and it can be without a seat

and 25 km/h for vehicles in class 4. Representative vehicles of these classes are segways, hoverboards, self-balancing unicycles, electric roller skates (e-roller skates), etc.

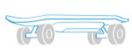
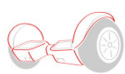
Micromobility vehicles can be classified based on the maximum speed and mass of the empty vehicle, and according to this classification, four types of vehicles are distinguished (type A, B, C and type D), which is presented in *Table 3*.

Table 3 – Classification of micromobility vehicles [22]

Type A	Type B	Type C	Type D
Vehicles without or with additional drive with a maximum design speed of up to 25 km/h		Vehicles with an additional drive with a maximum design speed of 25 km/h to 45 km/h	
Empty vehicle weight up to 35 kg	Empty vehicle weight from 35 kg to 350 kg	Empty vehicle weight up to 35 kg	Empty vehicle weight from 35 kg to 350 kg
Bicycle, Pedelec, E-scooter, E-skateboard, Hoverboard, E-roller skates, Segway, Unicycle	Electric scooter	Fast e-bike	Moped

According to the classification shown in *Table 3*, micromobility vehicles of type A include vehicles without or with additional drive with a maximum speed of up to 25 km/h and with an empty vehicle mass of up to 35 kg. This micromobility vehicle type is the most represented and it includes conventional bicycles, "slow" e-bikes (pedelec), electric scooters, self-balancing vehicles (hoverboards, segways, etc.), electric skateboards and roller skates, and other vehicles. Also, according to the SAE J3194 standard, six (6) types and categories of micromobility vehicles are defined (*Table 4*).

Table 4 – Types and characteristics of micromobility vehicles according to the SAE J3194 standard [23]

Vehicle characteristics	Electric bicycle	Non-self-balancing vehicle with additional drive	Self-balancing vehicle with additional drive	Roller skates with additional drive	Moped	Electric scooter
						
Centre column	Yes	No	Optional	No	Yes	Yes
Seats	Yes	No	No	No	Yes	No
Floorboard	Optional	Yes	Yes	Yes	Yes	Yes
Self-balancing	No	No	Yes	Optional	No	No

On the basis of the previously mentioned classification, taking into consideration the existing legal regulations in the Republic of Serbia and the potential for the use of micromobility vehicles, the authors of this work suggest the following classification of micromobility vehicles which is displayed in *Table 5*.

Based on the data from *Tables 4 and 5*, it can be concluded that the majority of micromobility vehicles are not recognised by the legislating bodies and legal regulations of the Republic of Serbia, even though these vehicles are used for the realisation of transportation needs.

Table 5 – Proposal for the classification of micromobility vehicles on the territory of the Republic of Serbia

Type of vehicle	E-bike "pedelec"	E-bike (L1e-A)	E-bike (L1e-B)	E-scooter	Other vehicles (hoverboard, segway, e-skateboard, e-roller skates)
Legally regulated	Yes	No	Partially	No	No
Regulation	*Rulebook on Motor Vehicles and Connecting Vehicles Classification and Technical Requirements for Vehicles in Traffic on the Roads* (Other vehicles - category K3)	*Regulation (EU) No. 168/2013*	*Rulebook on Motor Vehicles and Connecting Vehicles Classification and Technical Requirements for Vehicles in Traffic on the Roads* defines the vehicle L1 - moped *Regulation (EU) No. 168/2013*	-	-
Standard	EN 15194:2017	-	-	EN 17128:2020	EN 17128:2020

5. A CASE STUDY OF THE REPUBLIC OF SERBIA

In this chapter, the basic recommendations for the integration of micromobility vehicles on the territory of the Republic of Serbia are presented. Recommendations are defined based on previous results, i.e. opinions and demands of experts, users and potential users, experience and examples of good practice from other countries, and legal regulations of the European Union while respecting the national regulations and existing restrictions. This chapter is made of three important parts: defining the general design and operational characteristics of each type of micromobility vehicle, requirements for using micromobility vehicles and infrastructure needed for micromobility vehicles.

5.1 Design and operational characteristics of micromobility vehicles

Design and operational characteristics that are of greatest importance for micromobility vehicles are maximum design speed [km/h], maximum continuous rated power [W], maximum vehicle width [m] and pedestrian mode. The values shown in *Table 6* are aligned with the views of experts, European Union regulations and norms (standards).

Table 6 – Basic harmonised design and operational characteristics of micromobility vehicles

Type of vehicle	E-bike (pedelec)	E-bike (L1e-A)	E-bike (L1e-B)	E-scooter	Other vehicles
Maximum design speed	25 km/h	25 km/h	45 km/h	25 km/h	25 km/h
Maximum continuous rated power	250 W	1,000 W	4,000 W	600 W	500 W
Maximum vehicle width	1.00 m	1.00 m	1.00 m	0.70 m	1.00 m
Pedestrian mode	Not applicable	Not applicable	Not applicable	Yes (conditional)	Yes (conditional)*

** if such installation is possible*

Within the EN 15194:2017 standard, it is recommended that an e-bike ("pedelec") has a maximum design speed of 25 km/h. For e-bikes (L1e-A), the EU Regulation No. 168/2013 defines the maximum design speed as 25 km/h, while for e-bikes (L1e-B) it is 45 km/h. For e-scooters and other micromobility vehicles, the maximum design speed should be 25 km/h, which is in accordance with the recommendations of the EN 17128:2020 standard.

The EN 15194:2017 standard recommends that an e-bike ("pedelec") does not exceed the maximum permanent nominal power of 250W. For the e-bicycle (L1e-A), Regulation EU No. 168/2013 defines the maximum permanent nominal power of 1,000W, while for e-bicycles (L1e-B) it is 4,000W. For e-scooters, the maximum permanent nominal power is defined on the basis of the maximum permanent nominal power of these kinds of vehicles in the market of the Republic of Serbia, which opens up the potential for the usage of this kind of vehicle, and it is 600 W. The value of the maximum permanent nominal power for e-scooters is the same as in e.g., Austria, where the regulation on this matter is similar to the regulations of the Republic of Serbia. Just like for e-scooters, for the rest of micromobility vehicles, the maximum permanent nominal power is defined on the basis of the maximum permanent nominal power for this kind of vehicle in the market of the Republic of Serbia, which amounts to 500W, except the hoverboard, where this value is given as per one drive wheel, which amounts to a total of 1,000W. The value of the maximum permanent nominal power for the rest of micromobility vehicles is similar to those in, for example, Italy and the United Kingdom.

According to the requirements of the EN 17128:2020 standard for micromobility vehicles (e-scooters and other vehicles), the vehicles must be equipped with devices which limit the maximum speed at 6 km/h, that is, to have the ability to activate the "pedestrian mode".

5.2 Requirements for using micromobility vehicles

To define the requirements related to the use of micromobility vehicles, the results of a survey of experts, experiences of good practice from other countries, European Union legislation and recommendations (that is, standards) were used as a starting point. The most important requirements related to the use of micromobility vehicles are shown in *Table 7*.

Table 7 – Requirements related to the use of micromobility vehicles in the Republic of Serbia

Type of vehicle	E-bike (pedelec)	E-bike (L1e-A)	E-bike (L1e-B)	E-scooter	Other vehicles
Type approval before use	x	✓	✓	x	x
Vehicle registration	x	x	✓	x	x
User training	x	x	✓	x	x
Possession of a driver's license	x	x	✓	x	x
Using a safety helmet	✓	✓	✓	✓	✓
Use of reflective clothing	✓	✓	✓	✓	✓

Regarding the condition of type approval before use, as shown in *Table 7*, this condition should be met by e-bikes regardless of the design features. This coincides with the legal regulations and recommendations (standards), except in the case of the e-bike (pedelec) for which, according to the recommendations of the EN 15194:2017 standard, type approval is not required. According to the above, type approval is subject to e-bikes that have the maximum continuous nominal power over 250W (categories L1e-A and L1e-B), which is in accordance with the EU Regulation 168/2013.

When it comes to vehicle registration for micromobility, it is necessary only for the (fast) e-bike - L1e-B, which is in accordance with the provisions of the EU Regulation 168/2013. An e-bike (L1e-A) does not require registration even though it goes through the type approval procedure for use. The reason is an example of a good practice that was achieved in Belgium, where these vehicles are the most widely represented and no registration is required, while in other countries where registration of these vehicles is required, they are almost not even in use due to the high costs and time necessary for their registration. This is another reason why users opt for an e-bike (pedelec).

Taking into account that the proposal on registration and mandatory training for the L1e-B e-bike type has been given, it is also proposed that the users of the vehicles belonging to the AM category (mopeds, light tricycles and light quadricycles) have a registration. This is in accordance with the regulations of most countries in Europe.

For all types of micromobility vehicles, the use of a protective helmet is recommended, except for the "fast" e-bike, for which the use of a helmet is obligatory. Another interesting fact is that 63% of users and potential users declared that the obligation to use a protective helmet would not deter them from using a micromobility vehicle, which indicates that this requirement would not be a limiting factor for using a micromobility vehicle.

As with the issue of using a protective helmet, the use of light-reflecting clothing in conditions of reduced visibility is given as a recommendation. Also, 55.4% of users and potential users support the use of light-reflective clothing in conditions of reduced visibility, which further emphasises the importance of introducing this requirement as a recommendation for the use of micromobility vehicles.

5.3 Infrastructure for micromobility vehicles

To define and propose infrastructure capacities for micromobility vehicles, the following research was carried out: analysis of existing infrastructure potential/capacity in the Republic of Serbia, comparative analysis of the views of experts, users and potential users, and analysis of the experiences of selected European countries.

In the continuation of this chapter, a proposal for the use of infrastructure capacities for micromobility vehicles on the territory of the Republic of Serbia is given.

Table 8 gives a summary of the infrastructure that could be used by micromobility vehicles.

It is important to note that the highest rank of the network - the city motorway - has been omitted, given that this category of roads cannot accept the movement of micromobility vehicles due to its characteristics. Bearing in mind the characteristics of the other ranks of the primary city street network, primarily city highways, it was proposed that these streets be conditionally prohibited from the movement of "pedal bikes" and "fast" e-bikes. In the case of acceptance of this proposal, it is necessary to harmonise the regulations governing the movement of traditional bicycles with the regulations for the movement of these micromobility vehicles. On the other hand, for the category of other micromobility vehicles, a proposal was made to prohibit the use of driving lanes, regardless of the street category. The situation is somewhat different with regard to e-scooters, compared to other micromobility vehicles. Namely, e-scooters would be prohibited from using lanes on the streets of

Table 8 – Proposal of infrastructure capacities for individual categories of micromobility vehicles

Infrastructure		Category of micromobility vehicles			
		E-bike "pedelec"	"Fast" E-bike	E-scooter	Other micromobility vehicles
Driving Lanes (Streetway)	City highway				
	City streets				
	Collector streets				
	Access streets				
Cycling infrastructure	Bicycle paths				
	Bicycle lanes				
Pedestrian and bicycle infrastructure	Pedestrian and bicycle paths				
Pedestrian infrastructure	Footpaths (Pedestrian paths)				
	Sidewalks				
	Pedestrian zones/ streets				
Infrastructure for public transportation vehicles	Yellow lanes				
	Tramway tracks				
Infrastructure for non-motorised and motorised vehicle users	Integrated streets				
	Shared spaces				

Use of the infrastructure is allowed, Use of the infrastructure is forbidden, Conditionally allowed use (along existing legal limitations), Conditionally forbidden use (existing regulation need adjustment).

the primary city network, while the use of the streets of the secondary city network would be conditionally allowed, and only in situations where there is no connected bicycle infrastructure network.

The cycling infrastructure is proposed to allow the movement of all analysed categories of micromobility vehicles.

Bearing in mind the design, geometric and traffic characteristics of pedestrian-cycling paths, it is proposed to enable the movement of all micromobility vehicles in this category (with the condition that the speed be limited to 10 km/h), except for "fast" e-bikes.

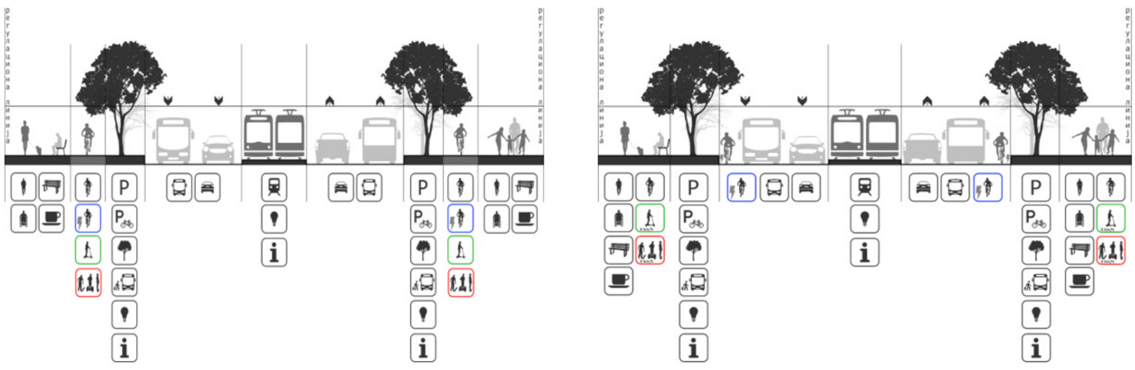
When it comes to pedestrian infrastructure, it is proposed that all micromobility vehicles, with the exception of "fast" e-bikes, be allowed to move on footpaths, sidewalks and pedestrian zones/streets, with the condition that the speed be limited to 6 km/h.

It is proposed to ban the movement of micromobility vehicles on yellow lanes and tramway tracks. The exception goes for "fast" e-bikes, whose use of yellow lanes can be considered if this infrastructure allows the movement of mopeds and other vehicles with similar technical-operational and design characteristics. In that case, it is necessary to additionally harmonise the existing regulations for the movement of two-wheel vehicles with the regulations for the movement of micromobility vehicles.

When it comes to infrastructure that is equally intended for motorised and non-motorised users (integrated streets and shared spaces), it is proposed that all micromobility vehicles be allowed to use this infrastructure, with the condition that the speed be limited to 10 km/h.

What is important to note at this point, as a general conclusion regarding the definition of infrastructure capacities, is the need to reconcile the often-conflicting demands of users on the one hand and the possibilities, i.e. the system's offers, on the other. In this specific case, the authors (respecting the user's requirements, considering examples of good practice and respecting the existing limitations) observed the system two-dimensionally through space and speed dependence. Namely, if there was a suitable infrastructure, with the satisfaction of the previously mentioned requirements, the authors proposed a simple integration and use of that infrastructure by micromobility vehicles. Such is the example of bicycle infrastructure. If the aforementioned infrastructure is missing or not available, certain "faster" micromobility vehicles are redirected to the streetway, i.e. the right edge of the streetway in the direction of movement, which is an example of good European practice in managing bicycle traffic. A special case can be observed for other areas where there is no built or clearly defined cycling infrastructure, such as pedestrian infrastructure, shared spaces and integrated streets. In this case, the emphasis is on the speed of the user, instead of the space, so micromobility vehicles are allowed to move on the specified surfaces while respecting the specially defined speed limits. Of course, specific infrastructures such as the infrastructure for public transportation vehicles, as well as a specific category of micromobility vehicles – "fast" e-bikes, are exceptions to the previously presented proposals, as they are subject to somewhat different rules.

In order to make it easier to see the spatial frameworks and ways of using the networks of different levels, the following are examples of characteristic cross-sections, where micromobility vehicles are marked with pictograms with a corresponding graphic symbol and a separate colour code: the blue frame of the pictogram indicates e-bikes, the green frame indicates e-scooters and the red frame of the pictogram indicates other micromobility vehicles.

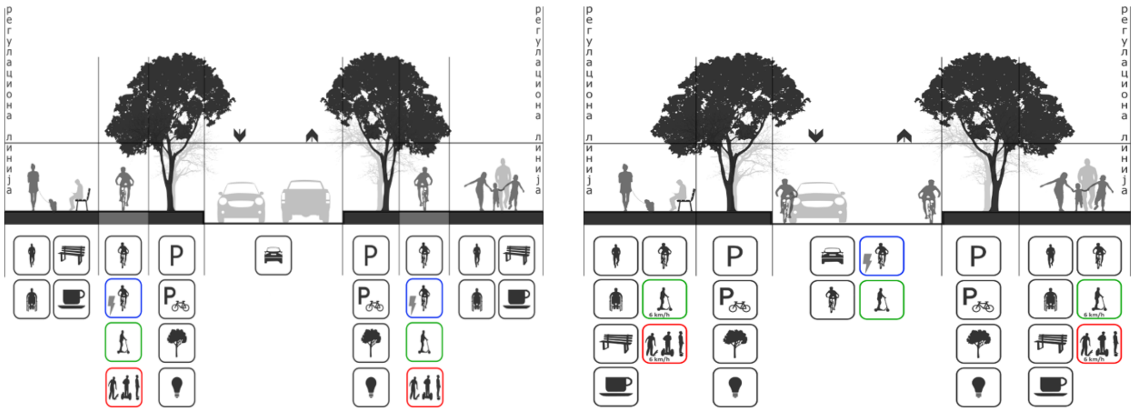


a) with a separate bicycle infrastructure *b) without a separate bicycle infrastructure*

Figure 1 – Cross-section of the primary city street

Figure 1 shows the profiles of a primary city street with and without separate bicycle infrastructure. From the figure below, it can be seen that only e-bikes are allowed to use parts of the streetway (under the same conditions as classic bikes), on streets where there is no separate cycling infrastructure (*Figure 1b*). In that case, other micromobility vehicles would share the infrastructure with pedestrians. If there is a separate cycling infrastructure, all micromobility vehicles should use it (*Figure 1a*).

Figure 2 shows the profile of the secondary city street with and without separate bicycle infrastructure.

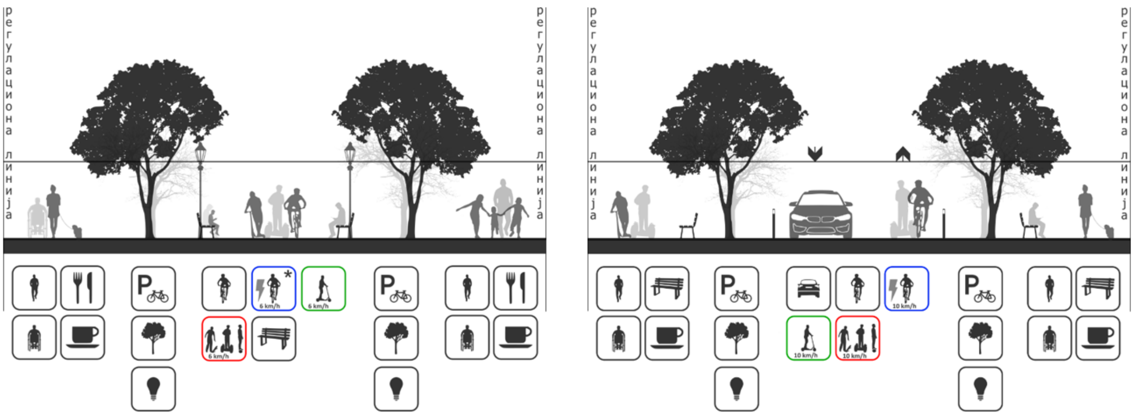


a) with a separate bicycle infrastructure *b) without a separate bicycle infrastructure*

Figure 2 – Cross-section of the secondary city street

What is important to note at this point is the obligation that, in the case of sharing the infrastructure with pedestrians, micromobility vehicles must adhere to the speed limit of up to 6 km/h.

Figure 3 shows examples of cross-sectional profiles of a pedestrian zone and an integrated street, as not only specific but also frequent design solutions of central urban areas of cities in Europe.



a) *b)*

Figure 3 – Cross-section of the pedestrian zone (a) and integrated street (b)

In the case of pedestrian zones, it is recommended that the speed of micromobility vehicles be limited to 6 km/h (that is, the speed of pedestrians), so as not to hinder and endanger the movement of non-motorised users. Also, it is important to note that the recommendation is to limit the movement speed to 10 km/h for all users of integrated streets and shared spaces, in order to maintain the required level of traffic safety.

6. DISCUSSION OF THE RESULTS

This paper presents the results of the possibilities and potentials for the comprehensive integration of micromobility in the traffic and transport system of the Republic of Serbia. Important aspects were discussed, such as the issue of regulation, which binds all other characteristics: the categorisation of these vehicles, the way of their use, infrastructure, safety, etc.

As already mentioned, the guidelines and recommendations given in this paper are defined in relation to the best world practice (existing experiences), attitudes and demands of different interest groups, as well as existing local restrictions. What is evident are the very rapid changes in this area and the specific development of this industry. Despite the fact that at the beginning there was great enthusiasm for these new modes of transport, which in some countries were integrated quite quickly into the traffic systems, now the situation is in a certain sense slowing down and being re-examined. Looking at all the characteristics of this system during the period of exploitation, certain radical measures took place in some cities such as Paris, where "an overwhelming majority of Parisians who took part in a referendum on rental electric scooters have voted to ban (89% of voters) the devices from the streets of the French capital" [16]. This is one of the aspects that in a certain sense reverses the existing situation and the development itself, that is, the integration of these vehicles into the city's traffic systems.

One of the main issues that usually arises in such situations is the redistribution of space and the place of these vehicles on the road network, i.e. in the profile of the roads/streets. This paper states the experiences of the countries in this matter, with most of the analysed countries focusing on bicycle infrastructure as one of the most common solutions. Of course, in the absence of such an infrastructure, additional options have been defined. The difference between the recommendations given in this paper and the mentioned world experiences is that the use of certain infrastructure is not expressly prohibited here (except for the one intended for public transport, due to the still non-harmonised classification of other categories of vehicles at the local level in Serbia), but was left with the possibility of adapting to specific conditions. Unlike e.g. in certain states of the USA where the use of sidewalks is prohibited, the possibility of using this infrastructure under precisely defined conditions is left open for Serbia. Of course, the question can be raised here as to how to control the fulfilment of the conditions defined for the user to use the sidewalks and respect the norms defined by law. This is one of the main issues that should be considered very soon.

Also, the issue that currently arises is the non-compliance of regulations at the international level, i.e. the lack of an adequate international initiative in this area. The lack of a regulatory framework and EU support, (especially regarding providers and public use of micromobility vehicles) leads to regulatory interventions at national and local levels that increase fragmentation across Europe and set unfavourable regulatory conditions for shared micromobility operations [24]. This is very important considering that a certain number of problems from the user's point of view are related to the service itself (rental, payment, parking, visual clutter) and the use of these vehicles [25]. What should exist are general EU-level guidelines directed towards states (globally) and cities (locally). One part of the survey in this paper, which is intended for experts, dealt with issues of public use of vehicles for micromobility, however, these results are not discussed in detail in the paper, but this topic will be covered more in future research.

The classification of these vehicles can be considered, which is the starting point. What has been the practice so far is that most countries have assigned these vehicles to certain "similar" categories that already exist on the traffic network. Either because of similar technical and operating characteristics or because of the simplicity and speed with which these vehicles are implemented into the traffic system in an aforementioned manner. What represents one of the potential solutions is a completely separate categorisation of these vehicles, as a completely new type of transportation for which a separate infrastructure would be defined. Of course, this way of solving the problem is quite complex and demanding, which is why the first option is used more often. In Serbia, it was also proposed that these vehicles should only be added to the already existing categories of vehicles, with certain corrections and requirements for micromobility vehicles.

Finally, it is important to mention the potential integration of these vehicles with other modes, primarily public transport. In addition to the mentioned service of public use of these vehicles, they can also be integrated into the public transport system (for trips on shorter distances), which is why separate policies for the development of the traffic system or only the public transport system in cities should be defined. What is certainly a fact is that vehicles for micromobility represent a challenge in every aspect, which is why solving this problem should be approached systematically and hierarchically. At this point, the importance of global guidelines for the integration of these vehicles is underlined once again, and only then their adaptation to local conditions and requirements.

7. CONCLUSION

New options for the realisation of trips, such as micromobility vehicles, represent current challenges for modern traffic and transportation systems in terms of their integration with other subsystems. In order to successfully integrate micromobility vehicles into traffic and transportation systems, it is necessary to apply a systemic approach to problem-solving. This approach implies the involvement of all interested parties, the application of the latest knowledge and postulates from transportation engineering (examples of good practice) and standards. In order to include all interested parties, it is necessary to conduct various types of research, i.e. research of the opinions of experts, users and potential users, for creating a "tailor-made" micromobility system.

Within the scope of the paper, special attention is paid to vehicle characteristics, infrastructure and conditions for using micromobility vehicles, which the authors believe are key elements for the successful integration of micromobility vehicles into modern traffic and transportation systems and which represent a good basis for the development of quality regulations, both locally as well as at the national level.

In order to define the requirements for micromobility vehicles, the paper presents the three most important classifications of micromobility vehicles, as well as a proposal for the classification of micromobility vehicles for the Republic of Serbia, which, in addition to the basic characteristics of the vehicle, also took into consideration local requirements, as well as the requirements of users of the micromobility system. In addition to vehicle classification, some other important aspects are the selection and definition of the maximum values of the vehicle's design and operational characteristics, without which it is not possible to organise a micromobility system. In order to clearly define the value of each of the characteristics, the experiences of authors from other countries, recommended standards, as well as opinions of experts, were used in the paper.

A special part of this paper is dedicated to the proposal of infrastructure capacities that can be used by micromobility vehicles in the Republic of Serbia. As in the previous chapters, experiences of best European practices, respected opinions of experts, users and potential users were discussed in this part. Based on that, clear proposals were defined – proposals that create a balance and optimise the requirements of different users on the one hand and spatial, management and other limitations on the other.

Regarding the requirements for the use of micromobility vehicles, in addition to the analysis of the existing legislation, it is necessary to investigate the views of users and potential users to define what a successful implementation is, and what would possibly discourage its use. The requirements for using micromobility vehicles must be defined by the type of vehicle due to the different design properties of each of them individually, which is adequately presented in the paper.

At the very end, it is possible to give general guidelines on the basis of which an adequate starting point can be made for the integration of micromobility vehicles into modern traffic and transportation systems. These guidelines cover the following:

- Classification of vehicles in accordance with existing standards and regulations;
- Definition of the basic design requirements for types of vehicles based on standards, existing regulations, and analysis of the characteristics of vehicles used in exploitation;
- Conducting extensive research of opinions of users, potential users and experts in order to create a tailor-made system;
- When defining the conditions for the use of micromobility vehicles, in addition to the experiences of good practice and regulations, it is necessary to investigate the attitudes of users and potential users in order to remove barriers to the use of these types of vehicles;
- Create a balance between the system user's requirements on the one hand and the system's offers (possibilities) on the other. This aspect is particularly important in the case of considering infrastructure for the use of these vehicles;
- The issue of infrastructure should be viewed-treated locally in relation to the specifics of the environment, with adequate generalisation at a national level, respecting existing regulations: urban mobility strategies and plans, laws, regulations, standards and other by-laws;
- The local definition of the infrastructure that can be used by micromobility vehicles should be viewed and defined through the dependence of space and speed, as illustrated in this paper on the example of the Republic of Serbia.

The authors believe that the results and recommendations presented in this paper can help all interested parties, and primarily decision-makers, in the process of strategic shaping of the modern traffic system while meeting the demands of various traffic participants.

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Izazovi integracije vozila za mikromobilnost u savremene saobraćajno-transportne sisteme

Rezime

U ovom radu predstavljeni su glavni izazovi i potencijali za integraciju vozila za mikromobilnost u savremene saobraćajno-transportne sisteme. Iako se čini da je koncept mikromobilnosti efikasan za realizaciju prvog i poslednjeg kilometra, postojeće stanje ukazuje na potencijalne probleme koje ove promene donose i koji se moraju rešiti na odgovarajući način. Vozila za mikromobilnost karakteriše ekstenzivni razvoj, koji nije praćen odgovarajućom zakonskom regulativom. Tradicionalno projektovanje i postojeći dizajn ulica imaju svoje nedostatke koji se najbolje ogledaju u segregaciji nemotorizovanih i motorizovanih korisnika, što bi u određenoj meri, moglo biti izmenjeno sa integracijom novih opcija mikromobilnosti. Kada je u pitanju Srbija, postojeća zakonska regulativa ne prepoznaje većinu vozila za mikromobilnost, što rezultira nebezbednošću ovih učesnika i neadekvatnom preraspodelom prostora u profilu ulice. Cilj ovog rada je da se pruže smernice za unapređenje postojeće regulative i integraciju ovih vozila u saobraćajni sistem Srbije, sa posebnim osvrtom na opšte preporuke kroz koje se ova vozila mogu tretirati i u drugim zemljama. Rezultati ovog rada mogu biti korisni donosiocima odluka, ali i svim ostalim učesnicima u procesu razvoja efikasnih politika i strategija za integraciju vozila za mikromobilnost u savremene saobraćajno-transportne sisteme gradova.

Ključne reči

vozila za mikromobilnost; regulativa; karakteristike vozila; infrastruktura; politike.