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ORIGINAL PAPER

A SYSTEMATIZATION OF MICRO-MOBILITY SAFETY IN SUSTAINABLE CITIES

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K e y w o r d s: urban transportation systems, sustainable cities, micromobility, infrastructure, road safety.

A b s t r a c t

The purpose of this analysis was to introduce the safety category to the general context of micromobility development in modern cities. The article is theoretical and is intended to introduce the safety category in micromobility. It focuses on the relatively young and attractive micromobility market in terms of greening socio-economic activities and development.

The micromobility market is receiving increasing attention from both citizens and city planners. The safety category was determined by: a) various internationally differentiated technical vehicle standards, b) micromobility users road accidents, c) cities transport infrastructure, and d) personal data of micromobility users. It was demonstrated that safety is an important issue in transport and city planning. The micromobility vehicles hold high significance in promoting sustainable development. Therefore, it is imperative to incorporate micromobility into sustainable urban mobility plans and incentivize individuals to change their mobility patterns. However, there is a need to observe the market because it is rather dynamic and more and more vehicles appear, also for elderly and people with physical disabilities. The emergence of novel technologies and vehicles has the potential to transform cities, thereby ensuring their safety and fostering a friendly environment for their citizens.

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KATEGORIA BEZPIECZEŃSTWA MIKROMOBILNOŚCI W ZRÓWNOWAŻONYCH MIASTACH

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Słowa kluczowe: miejskie systemy transportowe, zrównoważone miasta, mikromobilność, infrastruktura, bezpieczeństwo ruchu drogowego.

Abstrakt

Celem artykułu było wprowadzenie kategorii bezpieczeństwa w ogólny kontekst rozwoju mikromobilności we współczesnych miastach. Artykuł ma charakter teoretyczny. Uwagę skoncentrowano na relatywnie młodym i atrakcyjnym rynku w kontekście ekologizacji życia i rozwoju społeczno-gospodarczego.

Rynek mikromobilności cieszy się coraz większym zainteresowaniem, zarówno mieszkańców, jak i urbanistów. Kategorię bezpieczeństwa określono przez: a) techniczne standardy pojazdów, b) wypadki drogowe użytkowników mikromobilności, c) infrastrukturę transportową miast i d) dane osobowe użytkowników mikromobilności. Wykazano, że bezpieczeństwo jest interdyscyplinarną kategorią istotną w planowaniu transportu i rozwoju miast. Mikromobilność ma duże znaczenie w promowaniu zrównoważonego rozwoju, dlatego konieczne jest jej włączenie do planów zrównoważonej mobilności miejskiej i zachęcanie osób do zmiany wzorców mobilności. Rynek jest dość dynamiczny i pojawia się coraz więcej pojazdów, także dla osób starszych i z niepełnosprawnościami ruchowymi. Pojawienie się nowych technologii może sprzyjać rozwojowi miast bezpiecznych dla mieszkańców i środowiska.

Introduction

Cities face a variety of negative impacts from transportation: congestion (including traffic jams), greenhouse gas emissions, noise, and vibrations. These impacts have significant knock-on effects on the quality of life and health of city residents (Nadrian *et al.*, 2020, p. 4). Transportation fulfils a basic societal needs. The car is the most common mean of transportation, but also the one considered to be the least environmentally friendly. It should be noted that the transport modal split is a function of user demands and preferences (Dembińska, 2011, p. 16) – in this case, the high competitiveness of cars over other modes of transport (such as trains, ships or boats). Pursuing greener transport – including minimizing the modal share of cars in passenger transport – is one of the most important considerations in transport policy.

Recent years have seen the development of micro-mobile vehicles/means of transportation (MMVs), used for short trips in urban areas (Oeschger *et al.*, 2020, p. 2). The most popular of these are scooters and bicycles, often powered

by electric motors (e-scooters and e-bikes). O'Hern and Estgfaeller (2020, p. 18) point to the many socioeconomic benefits that micro-mobility offers as a mode of transportation. They also note the importance of technological advancement and the potential for new technologies that facilitate urban mobility (by virtue of their features and built-in motors). Similarly, Gössling (2020, p. 3) posits that electric MMVs are a highly attractive form of transportation in cities – one which can compete with walking, cycling and motorized transport.

The EU's long-term transport strategy aims to make Europe climate-neutral by 2050 (*Going Climate-Neutral…*, 2019). The relationship between transportation and climate neutrality is an area of particular interest, forming a core aspect of urban development. More and more cities are implementing and incorporating sustainable urban mobility plans (SUMP) into their decarbonization and CO_2 reduction strategies. The overriding goal of this approach is to improve the quality of life for residents while ensuring environmental sustainability. In this context, micro-mobility vehicles offer an environmentally-friendly transportation alternative that can mesh well with SUMPs (Christoforou *et al.*, 2021, p. 4). After all, they provide a way to quickly and easily cover short distances while circumventing congested roads, especially during peak traffic hours. As such, MMVs offer a highly attractive form of commuting that also happens to produce less CO_2.

The growing demand for micro-mobiles is also shaped by sharing systems – pay-per-minute vehicle renting services. Given the attractiveness of micro--mobility, sharing systems may conceivably be integrated into urban public transit offerings going forward. If so, shared micro-mobility services would be subject to similar responsibility (area coverage requirements) and subsidized, as is the case for traditional urban public transport (*Urban Mobility Next…*, 2021, p. 6). Micro-mobility inscribes well into the desired model of urban transportation systems – zero-emission vehicles and a shift towards sustainable mobility patterns. As a further proof to the attractiveness of the European market, there has been growing investment into micro-mobility services. A McKinsey report (*How the Pandemic…*, 2023) shows the 2018-2022 value of public investments to be USD 8.4 bln, of which 29% were in Europe, 37% in Asia, 34% in North America. However, in the post-pandemic years of 2020-2022, almost 50% investments were made in Europe (approx. USD 1.9 bln).

The developments in vehicle technology and design, coupled with the growing demand for micro-mobility, speak to the need to build and modernize urban transport systems (including infrastructure) (Ma *et al.*, 2022, p. 18). Given the recent urban development trends, particular attention should be paid to providing residents with real and effective options to fulfill one of their basic needs – that of mobility (Couglin, 2009, p. 6). The present article examines the challenges facing the development of micro-mobility in today's urban landscape, with particular focus on safety as an interdisciplinary category. It also analyzes selected aspects of the safety of micro-mobility as a sustainable form of urban

transport: the formal and legal classification of micro-mobility vehicles, modes of use, road infrastructure, and user data safety. Data are presented relating to traffic accidents involving micro-mobility vehicles in Poland. The analysis aims to systematize aspects of safety in theoretical terms.

MMVs – Safety and Classification

There have been many definitions and classifications of micro-mobility vehicles posited internationally (globally). For example, the Society of Automobile Engineers (SAE) describes micro-mobility vehicles as human-powered or powered by an electric motor, with a weight smaller than 500 kg (Tab. 1). In most cases, only one person can steer and use the vehicle due to safety rules and vehicle design. MMVs are allowed to be used on designated paths (such as bikeways) or on paths shared with other users (such as bicycles and scooters on bikeways, or roller skates and skateboards on pedestrian paths).

Table 1

MMV classification according to SAE

Type of vehicle	Description of the vehicle
Powered bicycle	has a handlebar, pedals, two or three wheels and a handlebar, can be exclusively or partially powered by an electric motor
Powered non-self-balancing board (e-board, e-skateboard)	no handlebar, controlled by an operator through a handheld device or via floorboard sensors
Powered self-balancing board	has a handlebar, one or two parallel wheels, floorboard or footpegs for the user with a handlebar on a central column, exclusively powered by a motor/engine (electronic devices/means of mobility)
Powered skates	a motor-powered double-unit vehicle, with one unit for each foot
Seated electric scooter	a non-pedaled vehicle with two or three wheels, a handlebar, floorboard and/or footpegs, and a seat (for the user and passenger), exclusively or partially powered by a motor
Electric scooter (e-scooter)	has a handlebar, floorboard for the user (and passenger), two or three wheels, exclusively or partially powered by a motor

Source: based on *Taxonomy and Classification…* (2019).

The International Transport Forum (ITF/OECD) has put forward a classification of vehicles by maximum speed and weight (Tab. 2). It divides personal mobility vehicles into 4 groups, incorporating both muscle-powered and engine/motor-powered (including hybrid systems).

Table 2

Classification of micro-mobility vehicles according to ITF

Vehicle group	Propulsion	Maximum speed	Weight	Examples
A	unpowered or powered	less than 25 km/h	less than 35 kg	bicycle, pedal assisted bicycle, scooter, e-scooter, monowheels (powered and self-balancing)
B			35-350 kg	scooters designed for elderly or disabled people – mobility scooters
C	powered	25-45 km/h	less than 35 kg	e-bike, e-scooter, motor scooters
D			35-350 kg	motor scooters

Source: *Safe micro-mobility* (2019, p. 16).

The growth of the European market led to a separate category being delineated for MMVs – Category L. Pursuant to Regulation (EU) No 168/2013, the category includes 2-, 3- and 4-wheelers. Notably, however, the Regulation does not extend to vehicles most often used by citizens for short trips, including:

– those with a speed of 6 km/h or less,
– bikes with a pedal assisted speed of 25 km/h,
– self-balancing vehicles,
– vehicles equipped with a seating position (seated scooters).

The Regulation introduces technical safety standards for vehicle features (e.g., braking systems, lighting systems, audible warning devices, tires), design and approval (manipulation prevention safeguards, dimensions and weights, handlebars and footpegs), as well as environmental and motor specifications (Regulation (EU) No 168/2013, p. 94). These requirements are necessary to ensure the safety of travelers. Still, the EU classification differs from that proposed by the SAE or ITF. This speaks to the wide variety of micro-mobility vehicles in terms of design and function, which may mislead users crossing international borders (including tourists) and make the use of vehicles problematic or, in extreme cases, impossible.

The technical standardization of vehicles is crucial to establishing safety rules and, in the case of MMVs, developing tools to drive uptake and promotion of MMVs as a sustainable alternative for urban travel (*Safe Micro-Mobility*, 2020, p. 15). There is a wide range of MMVs available, which means that infrastructure and safety regulations need to be adapted to all possible vehicles and traffic participants.

Another key priority for vehicle safety is to develop a diverse offer adapted to the needs of various social and age groups. Contemporary social trends, including population ageing, merit particular attention in this regard. Indeed, it is highly likely that products designed for older people will soon become more common (Gitelman *et al.*, 2016, p. 3; Isaacson & Barkay, 2020, p. 4). Mobility scooters and wheelchairs, equipped with extra features to accommodate older

people and/or those with reduced mobility, are an increasingly common sight in urban spaces. Such vehicles can range from 2-, 3- to 4-wheelers, and require special adaptations to ensure greater stability, accessibility, and driver safety, as well as additional electrical systems and other features (Phannil & Jettanasen, 2021, p. 4). These types of products help counteract social exclusion and provide more opportunities for non-assisted living (Cirella *et al.*, 2019, p. 2), with their primary function being to enable and support quick and safe motility while fulfilling basic needs.

Safety and Urban Transport Infrastructure

Without infrastructure that meets the quantitative and qualitative growth in demand, real sustainability of urban mobility will remain out of reach. Infrastructure planning (including length and width of pedestrian routes, bikeways and designated lanes for specific vehicles) is a key part of urban development, especially in terms of enabling safe daily travel for residents.

Without investment in infrastructure, the proliferation of MMVs will lead to increased traffic on pedestrian routes and bikeways in the long run. This, in turn, could make micro-mobility a less appealing mode of travel. From an urban governance standpoint, diverting daily commute from cars to environmentally friendly MMVs is a problematic proposition. Thus, there is an urgent need to modify the urban transportation infrastructure to accommodate the burgeoning micro-mobility options, including by: creating accessible paths and roads dedicated to specific MMVs, establishing safe passageways, removing potentially hazardous obstacles, and finally – allocating secured parking spaces that do not interfere with pedestrian movement and other traffic (Isaacson & Barkay, 2020, p. 5).

There are certain difficulties in obtaining data on urban accidents and determining black spots (highly dangerous places with relatively elevated accident rates). In some cases, data can be obtained from mobile providers or shared micro-mobility operators (*Road Safety Annual*…, 2023, p. 18). Data on travel vectors and frequency coupled with accident locations are particularly valuable from a traffic safety standpoint, as they can be drawn upon to establish a safer urban mobility infrastructure. The ability to generate data from operators of sharing systems would make it possible to identify black spots in transport infrastructures. However, police statistics on accident locations are difficult to access, due to the lack of publicly available statistics (rates and severity of accidents on a street-by-street basis). Such data would be valuable and useful, making it possible to introduce technical and infrastructural solutions or shaping the behavior of MMV users.

A wide range of MMVs (see Tables 1 and 2) are available for use by individuals or shared micro-mobility operators. In other words, vehicles can be bought for private use or rented from a shared service. Of the latter, e-scooters and e-bikes

(including public bike rentals) are the most popular choices for city dwellers. Depending on the operator's particular arrangements with the city, shared MMV systems can be based around rent/return zones (mobile points that serve as special "parking" areas), or rentals without designated mobile points (the vehicle can be anywhere within the area designated by the operator) (Moran *et al.*, 2020, p. 663). Regardless of the rental scheme, safety should be made a priority, and creating parking spaces for micro-mobility vehicles would seem to be a central consideration in this regard. It is essential to designate safe parking zones, adapt mobile points, and provide vehicle docking facilities. A "quick repair" zone with free-to-use tooling is also a valuable part of mobile points. Another consideration is incorrectly parked or abandoned vehicles, which significantly increase the risk of accident for all traffic participants, including pedestrians. Finally, particular focus should be put on transportation infrastructure to offset the increased accident risk posed by the large number of micro-mobility users – which is very likely to grow going forward – and the ever-wider range of vehicles (Comi *et al.*, 2022, p. 25).

An important aspect of traffic safety is the behavior of the traffic participants themselves. In a study by Lanza *et al.* (2022), 45% of dog walkers and 33% e-scooter users were found to stray from their designated infrastructure. Furthermore, the majority of runners (56%) and walkers (51%) did not use the recommended infrastructure. This is a major issue, as crossing into traffic routes intended for other users can increase accident risk. E-scooters and e-bikes move at much higher speeds compared to other vehicles and pedestrians. Straying or using the "wrong" road may lead to a tragic accident. It thus follows that safety is also predicated on awareness among traffic participants and observing good road etiquette.

Safety in Numbers – Traffic Accidents

Basic data on traffic accidents are publicized via police statistics, whereas more detailed information (on the severity of accidents) is available in hospital statistics. In some countries, data are also reported on commune level (*Safe Micro-Mobility*, 2020, p. 69), though access is more difficult in this case.

Cloud *et al.* (2023, p. 7-12) found a significant relationship between shared e-scooter services and road safety. Variables analyzed in the study included bike-lane density and vehicle rates (cars per 1,000 inhabitants) from 93 UE cities. It was found that:

a) since the rollout of e-scooter services, the average number of accidents involving personal injuries increased by approx. 8%;

b) traffic rates were higher during summer;

c) high bike-lane density was correlated with accident rates – the higher the density of the bikeway network, the lower the number of accidents.

The International Transport Forum (ITF) showed that road fatalities decreased in 2022 compared to the average for 2017-2019 (*Road safety Annual…*, 2023, p. 16) – the pre-pandemic period. Cyclist fatalities decreased by 3.3% during this time. Notably, the report refers to the increasing popularity of e-bikes among urbanites and adverse changes in accident patterns. Of concern are the increased shares of fatal e-biker accidents, observed in countries such as Japan (60% of all accidents), Germany (44%) and the Netherlands (34%) (*Road Safety Annual…*, 2023, p. 18). ITF data also show that travelling by a powered two-wheeler is 5 times less safe than by a non-powered MMV (*Urban Mobility Next…*, 2021, p. 11).

In Poland, data on accidents involving micro-mobility vehicles is publicized in traffic accident reports by the Komenda Główna Policji (National Police Headquarters). Until 2022, the reporting only recorded micro-mobility accident data for bikes. Of course, the statistics also included groups of "other vehicles" and "undetermined vehicles" – designations which may refer to vehicles not defined by the Kodeks drogowy (Traffic Code), including micro-mobiles. Recent amendments to the Ustawa Prawo o ruchu drogowym (1997 Road Traffic Law) have made it possible to define, and thus statistically report on, other micro-mobility vehicles/modes of transport, including:

– non powered personal mobility devices (UWR – urządzenia wspomagające ruch), designed to be ridden standing up (p. 5); which include: scooters, roller skates, rollerblades, skateboards;

– electric-powered personal transporters (UTO – urządzenia transportu osobistego), non-seated and non-pedaled, designed for one person only (p. 10); which include: electric skateboards;

– electric scooters – electric-powered, two-axled vehicle, non-seated and non-pedaled, designed for one person only (without other passengers); under Polish legislation, an e-scooter is not a UTO (p. 10).

Police statistics show that the rates of accidents due to cyclists in Poland decreased from 2013 to 2023 (Fig. 1). Of note is that the biggest drop occurred during the COVID-19 pandemic. There has been a marked increase since 2022, but the rates are still below those recorded before the pandemic. Since other MMVs started to be included in the statistics, the overall number of accidents has been increasing (by approx. 17 percentage points).

It stands to reason that there may be a positive relationship between the number of available MMVs and accident rates. It seems that the development of infrastructure has not kept step with the growth of the MMV market. The patterns are somewhat similar to those of private motorized transport – after all, the more cars there are on the road, the greater the likelihood of traffic incidents. Conversely, a well-funded and safe infrastructure reduces accident rates. Poland has seen declining numbers of accidents – especially fatal accidents – since the focus in transportation investment has shifted to expressway and highway expansion.

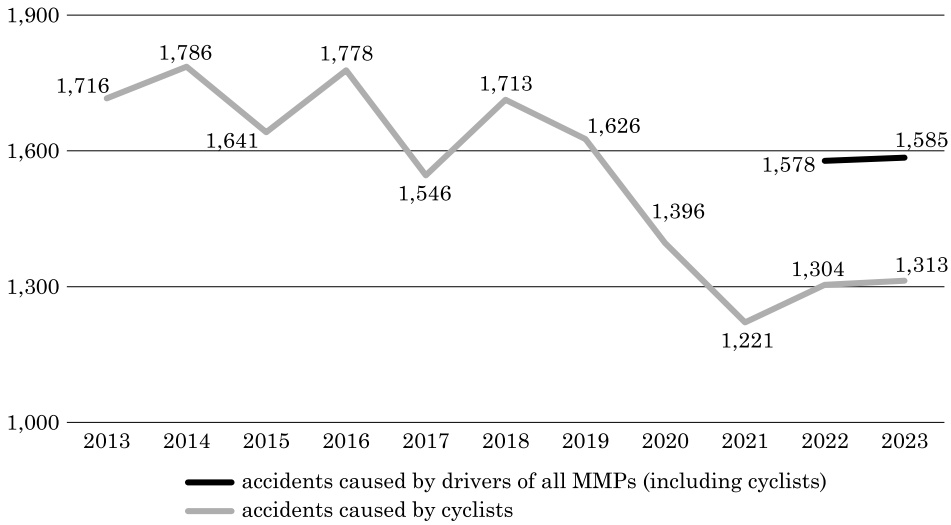

Fig. 1. Number of accidents by MMV of person responsible – data for 2013-2023
Source: based on *Wypadki drogowe w Polsce…* (2014-2024).

MMV user Data Security

Geopositioning data could be useful for profiling major movement trajectories, establishing convenient locations for mobile points, and creating infrastructure for docking systems. However, cities tend not to archive such data, and operators are rarely willing to part with them (Moran *et al*., 2020, p. 12). Micro-mobility data sharing schemes would certainly contribute to the growth and uptake of micro-mobility vehicles as a real alternative to passenger cars (*Urban Mobility Next…*, 2021, p. 8). Such data are often carried by mobile phones, often used to access shared services. Some operators gatekeep their services behind credit card registration requirements. Schumann *et al*. (2023) report the possibility of using passive data generated for the development of micro-mobility, including data from fixed sensors (e.g., digital cameras and counters) and mobile sensors (data from mobile phones and GPS systems). Harari (2020) highlights the problems of privacy protection and data security (including data on habits or personality traits), including:

– how secure are user data,
– which data are used and which are shared,
– who uses them and for what purpose?

Data generated for micro-mobility purposes can be a valuable source of information, used by operators managing public space and transportation in cities for purposes such as accessibility planning, lawmaking and enforcement (ensuring the safety of micro-mobility users and urban traffic participants)

(Chitturi & Puentes, 2023, p. 12, 13). On the other hand, there are concerns that personal data can be stolen. Operators can obtain data only to the extent provided by the privacy policy and personal data protection rules (see Tab. 3). The data can be provided by users, collected automatically when using service access applications, or sourced from external companies (based on user interactions with the service provider). Data is most commonly stolen from users' phones and the operators' data cloud. Finding vulnerabilities allows operators to introduce safeguards on their end to protect customer data from possible interception by unauthorized parties. However, micro-mobility users (phone owners themselves) must also commit and do their part to protect their own data.

Table 3

Types of user data acquired under privacy policies (according to operators)

Operator	User-provided data				Data collected automatically by operator			Data from external sources (Facebook, Google, etc.)
	contact info	billing info	Identification info	demographic info	device info	location and vehicle info	analytics	user interactions related to the service provider
Bird	✓	✓	✓	✓	✓	✓	✓	✓
Lime	✓	✓	✓	✓	✓	✓	✓	✓
Razor	✓	✗	✓	✗	✓	✓	✓	✓
Lyft	✓	✓	✓	✓	✓	✓	✓	✓
Jump	✓	✓	✓	✓	✓	✓	✓	✓

Source: based on Vinayaga-Sureshkanth *et al.* (2020, p. 4).

Conclusions

MMVs are certainly an asset that can be incorporated into green city strategies. Micro-mobility is an important facet of SUMP in cities that also aspire to be friendly and, above all, safe places to live. The systematization of safety is, in this case, an interdisciplinary effort. Safety vis-a-vis micro-mobility extends to:

– responsible conduct of users, including as regards data protection,
– infrastructure accessible to all social groups and their vehicles,
– data obtained by operators,
– formal and legal measures to foster improvements in traffic safety (roadworthiness standards and traffic rules).

Micro-mobility is a challenge for modern cities. Nevertheless, it also falls perfectly in line with the push towards SUMP and greener transportation. New MMVs are introduced as the technology advances, and safe infrastructure needs to be established to keep up. On the one hand, the demand for MMVs (private and shared) is rising, on the other, this coincides with increased accident rates. Micro-mobility can be a boon for cities willing to harness it for sustainable development and greener transportation. MMVs are increasingly in demand and highly popular, and this trend may help effect a real shift in the modal split of urban travel towards clean and zero-emission vehicles. The achievement of this goal can be facilitated by ensuring conditions for growth. And indeed, safety is one of such conditions, the provision of which will pose a major challenge and organizational/financial effort for cities.

The purpose of this paper was to serve as an introduction to systematization of micro-mobility safety and to highlight selected aspects thereof. The author acknowledges that aspects of MMV safety are broader still, including security of operating systems (hacking attacks affecting GPS coordinates, motors and braking systems), regulations on active and passive safety of MMV users and other traffic participants, accident severity or "economics" of safety (taking into account external costs of accidents involving MMVs) – aspects which can serve as a jumping-off point for further considerations and research on the safety of urban micro-mobility.

Translated by Joanna Molga

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