Safer Micromobility: Technical Background Report

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International Transport Forum

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Foreword

In 2020, the ITF published *Safe Micromobility*, a report assessing the safety of micromobility and new mobility services. In the four years since publication, much has changed in terms of the evidence base regarding the safety of micromobility.

This report analyses current evidence on recent micromobility safety trends and risks. It provides safety recommendations for authorities and micromobility operators in line with the Safe System approach. It does not address safety issues related to fire risk from defective or damaged battery packs which is typically addressed via battery-specific standards and policies.

It is summarised in a policy document written by the same authors. That publication, entitled "Safer Micromobility" can be found here: https://www.itf-oecd.org/safer-micromobility.

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Executive Summary

What we did

The objective of this report is to comprehensively analyse and synthesize the most recent and key micromobility safety trends and risks and to formulate safety recommendations for both authorities and micromobility operators. Specifically, this report zooms in the safety implications of privately-owned or shared powered micromobility devices, with a particular emphasis on e-scooters and e-bikes. The safety analysis and recommendations are founded on the Safe System Approach, aimed at raising safety standards and effectively mitigating risks within the micromobility ecosystem, including road users, infrastructure, and vehicle design.

In the framework of this report an extensive review of scientific and "grey" literature to investigate key micromobility safety trends and risks was conducted, covering areas such as crash and injury trends, issues related to under-reporting of crashes, risk factors related to vehicles, users, and infrastructure, and the utility of surrogate safety data. A total of 145 relevant studies were identified, including peer-reviewed papers and reports from policy organizations, government agencies, and service providers.

A questionnaire was administered to five micromobility operators thoughtfully arranged in alphabetical order: Bolt, Dott, Lime, TIER Mobility, and VOI. This questionnaire served a dual purpose. Firstly, it was tailored to gather comprehensive insights into the safety aspects encompassing both the physical features and the increasingly vital digital facets, including app-based functionalities of micromobility vehicles. Secondly, it aimed to identify challenges and lessons-learned from the deployment of micromobility vehicles.

What we found

The introduction of powered micromobility vehicles, including e-scooters and e-bikes in many cities, has ushered in significant changes in urban transportation, presenting new and pressing challenges for policymakers and stakeholders. This transformation coincides with a growing public concern surrounding the upswing in micromobility-related crashes and their severity. Even though micromobility-related crashes attract publicity, they consist of a low percentage of the overall crashes inside and outside cities.

Most micromobility-related crashes are single-vehicle crashes of low severity, whereas collisions with larger motor vehicles lead to higher-severity injuries. Also, most reported micromobility crashes result in only minor injuries. Severe injuries comprise a small portion of total reported injuries, and a relatively small percentage of reported micromobility crashes lead to fatal injuries. E-scooterists presented to hospitals with a greater share of head, face, and neck injuries than cyclists. Injury severity is correlated to crash mechanisms, vehicle types and road users.

In addition to crash frequency, casualty risk reflects the probability of crashes and their severity. Overall, as shared e-scooter travel volumes outpace the growth of injuries requiring medical attention, e-scooter *risk* has diminished across various markets. However, good quality and representative data on e-scooter exposure and crashes is often not available, mainly for privately-owned e-scooters. Shared and especially privately-owned micromobility safety analysis would highly benefit from the existence of more consistent and available exposure and safety data to ensure more reliable risk estimations for injuries and crashes.

This report underscores the multifaceted nature of micromobility and, particularly, e-scooter safety. E-scooter-related incidents predominantly involve single road users, resulting in falls and collisions with stationary objects. Pedestrians are injured through collisions with either moving or stationary e-scooters. The gravest danger emerges from conflicts between micromobility vehicles and larger motor vehicles, often leading to fatalities.

Night-time riding, drug or alcohol-impaired riding, riding in traffic lanes or on sidewalks and encountering poorly maintained road surfaces all contribute to elevated crash and injury risk. Helmet use is low among injured e-scooterists, and this contributes to the frequency, severity and type of reported injuries. Vehicle design plays an important role in crash occurrence and severity with e-scooters displaying different and less stable characteristics than bicycles. Shared e-scooter designs have evolved rapidly to incorporate safety-improving features and make these available to riders.

E-scooter crashes disproportionately lead to head and facial injuries, particularly in the lower face region, compared to crashes involving conventional or electric bikes. Head injuries are significant in that they may involve serious and lasting trauma and related neurological complications – in this way, they are unlike other injury types and warrant special consideration. E-scooter crashes also often lead to fractures in the upper and lower extremities, particularly in the lower arm and wrist. Generally, injuries involving e-scooters are more severe than injuries involving conventional bikes and lighter than injuries involving e-bikes – likely linked to the more elevated travel speed of the latter.

In the case of micromobility safety, surrogate safety-based analyses are useful as they shed light to user behaviour and potential precursor factors and crash mechanisms (e.g. time to collision, harsh acceleration and deceleration, speeding, helmet use, double riding, etc.). Due to advances in modelling and technology, surrogate safety methodologies and analyses are expected to further grow.

What we recommend

Understanding the causes and mechanisms behind micromobility crashes and identifying risk factors implies that many of these incidents are preventable through coordinated efforts by the authorities and the micromobility operators. These recommendations are summarised below.

Safety Recommendations for Authorities

Safe Infrastructure

Proactively maintain micromobility infrastructure: To minimise the risk of micromobility-related crashes caused by potholes, debris etc., authorities should undertake regular maintenance of infrastructure, especially in high micromobility traffic areas.

Establish a dedicated and well-connected micromobility network: Authorities should develop a comprehensive urban plan that incorporates mixed and protected “light traffic lanes” for all micromobility modes, ensuring connectivity with existing transportation networks.

Establish and enforce micromobility parking policy and designate parking areas where needed: Authorities should formulate consistent micromobility parking guidelines that enhance its use. This includes establishing clearly marked and well-delineated parking zones for e-scooters and bicycles at the curb or on pedestrian or shared zones, mainly in core urban areas.

Safe Riders

Implement a 30km/h (or lower) speed limit in areas with high micromobility use: Authorities should default to 30 km/h (or 20 km/h) speed limits for car and truck traffic in areas with high micromobility traffic.

Establish low speed limits for micromobility vehicles on pedestrian or shared zones: In areas where micromobility users share pedestrian spaces, authorities should default to a safe speed limit (e.g. ~6-10 km/h) for micromobility modes, to reduce the conflicts between micromobility riders and pedestrians.

Take enforcement action against risky micromobility riding: Authorities should impose and enforce penalties for illegal micromobility riding including such as speeding, drug- or alcohol-impaired riding, underage riding, and double riding.

Promote the use of appropriate helmets: Authorities should encourage use of appropriate helmets for private and shared micromobility insofar as helmet promotion messages do not depress the use of active micromobility.

Introduce rider education in secondary schools: Micromobility training should be integrated into the curriculum of secondary schools.

Safe Micromobility Vehicles

Set universal technical requirements for e-scooter design: Establishing and converging technical standards for e-scooter is essential.

Adopt riding support systems in micromobility: Authorities should foster the adoption of riding support systems in micromobility vehicles including, for example, emergency braking assistance, audible speed warnings, ride condition detection technology, occupancy detection sensors, inappropriate parking notification, etc.

Safe Management

Establish and collect data on distinct micromobility categories in safety statistics: Creating distinct categories for each micromobility mode in road traffic casualty records, including police records and medical records, improves safety assessment.

Safety Recommendations for Operators

Safe Infrastructure

Establish collaborative partnerships with authorities for infrastructure condition reporting: Micromobility operators, armed with valuable data collected through in-vehicle sensors on potholes, falls, and near crashes, should play an active role in the proactive maintenance of urban infrastructure.

Integrate parking zones in shared micromobility apps and deploy smart docking in high-traffic areas: Shared micromobility apps should onboard designated parking areas and restrictions. Also, operators can reinforce responsible parking, e.g. by offering rewards for users who comply with parking requirements or in docks if these are available.

Safe Riders

Provide safety feedback via telematics data: Operators can use telematics data on speeding, acceleration/deceleration or distracted riding to provide riders with post-trip feedback. Real-time safety alerts to riders could also be considered where these do not contribute to rider distraction.

Provide economic incentives for safe riding: Shared micromobility operators may encourage helmet use with economic incentives such as providing free helmets or discounts to encourage safety-conscious ridership.

Implement mandatory initial rider training: To enhance rider safety, shared micromobility operators can require new riders to pass through in-app safe riding screens for the first few rides they make to help ensure that riders are familiar with local rules and guidelines before embarking on their e-scooter trips.

Verify age to start riding: Operators should implement age verification procedures to ensure riders meet the minimum age requirements defined in each city, ensuring compliance with local regulations and safety standards.

Safe Micromobility Vehicles

Ensure systematic maintenance of micromobility fleets: Operators should maintain their fleets in good repair and follow state-of-the-art maintenance protocols, emphasising regular checks and upkeep of essential components, including brakes, lights and batteries.

Enable context-dependent maximum speed control – geofencing: Shared micromobility operators can employ geofencing technology to dynamically lower maximum speeds in high-risk zones, such as pedestrian areas and junctions and during risky hours like nighttime.

Switch off e-scooter access if double riding or/and alcohol use is detected: Shared micromobility operators should be encouraged to incorporate in-vehicle sensors to detect double riding and introduce in-app tests to identify users under the influence of alcohol and drugs.

Implement riding support systems in shared e-scooters: Operators should be encouraged to implement riding support systems in e-scooters

Safe Management

Enable in-vehicle or in-app crash detection technology:

Shared micromobility operators can enhance the safety and user experience of their services and address the low micromobility crash data availability by integrating crash detection technology into their vehicles or mobile applications.

Safe Micromobility

The uptake of micromobility has been catalysed by the arrival of e-scooters and e-bikes – both privately-owned and shared. These vehicles and their use confers benefits to people and to cities but also raises challenges, particularly with respect to safety and their insertion in busy city spaces that are largely dominated by cars.

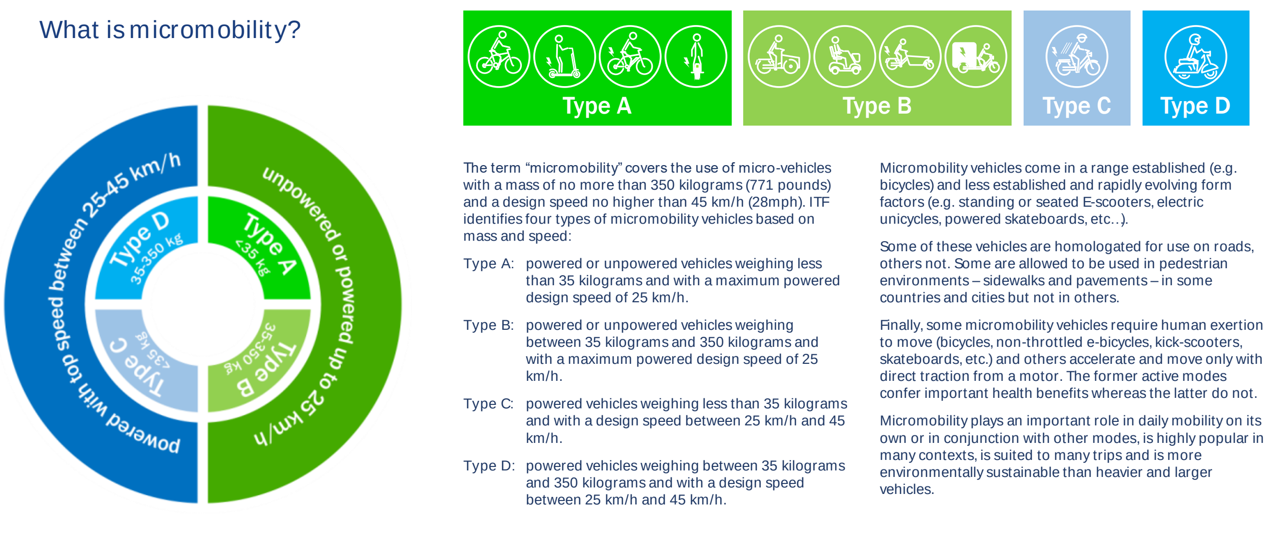
In 2020, the ITF published the report titled "Safe Micromobility" assessing the safety of micromobility and new mobility services (ITF, 2020). In the three years since publication, much has changed in terms of the evidence base (especially for safety) and changes in technology and operations.

The objective of this report is to comprehensively analyse and synthesise the most recent and key micromobility safety trends and risks and to formulate safety recommendations for both authorities and micromobility operators. These recommendations are led by the Safe System Approach and seek to contribute to the improvement of safety standards and mitigate risks associated with micromobility users, infrastructure and vehicles.

What is micromobility?

This report focuses on the safety impact of micromobility as defined by the ITF in the report “Safe Micromobility” (Figure 1- ITF, 2020) and specifically on e-scooters and e-bicycles (or e-bikes). Both shared (i.e., operated by riders on a for-hire basis) and privately-owned e-scooters and e-bikes are considered and, when possible and relevant, these are addressed separately.

Figure 1. Definition of micromobility



Source: ITF (2020)

Micromobility, safety and health

Physical activity is a crucial determinant of the overall contribution of safety to overall health. If safety is a concern for micromobility, it is because crashes and ensuing injuries negatively impact health and impose personal and societal costs. Exposure to air pollution also imposes a health burden on micromobility riders. Physically active forms of micromobility, however, confer significant health benefits across multiple health endpoints. Safety impacts from micromobility use must be considered in the overall context of health impacts. On balance, active travel's positive contribution to good health is orders of magnitude greater than the negative health impacts of crashes and air pollution (ITF, 2013; 2024).

From a health– perspective, active and passive forms of micromobility are not on the same footing. While micromobility modes like cycling and electrically-assisted cycling are physically active, other electrically powered micromobility modes, such as e-scooters, offer marginal benefits in terms of physical activity (ITF, 2024; Djokic et al., 2023; Haufe et al., 2022; Bourne et al., 2018; Bretones, A. and Marquet, O. 2023; Sanders et al., 2022). Nonetheless, e-scootering and other forms of non-active micromobility are generally associated with more active lifestyles, possibly linked to the greater use of micromobility in conjunction with public transport and other non-car modes. A key, context-based factor to consider when looking at micromobility-linked health outcomes is the extent to which non-active micromobility replaces walking and cycling versus highly sedentary car travel. Policy must seek to ensure the highest overall health outcomes, and thus, it must balance the positive health contributions of active micromobility modes versus the negative health outcomes of all micromobility when assessing safety and other policies.

Methodology

To investigate key micromobility safety trends and risks, an extensive review of the scientific and "grey" literature was conducted. This research explores the following aspects: 1. crash trends, 2. injury trends, 3. issues related to crash under-reporting and exposure data and their implications with the safety outcome, 4. risk factors related to vehicles, users and infrastructure, 5. findings and usability of surrogate safety data.

Findings at the international level regarding the two modes were summarised and synthesised. 145 relevant studies were identified and considered appropriate for this review. The year of publication of e-scooter studies range from 2018 and 2023. The majority of these studies are based on 2018-2021 data. Publications on e-bikes range from 2007 to 2022 and are based on data from the same period.

In addition, a questionnaire was developed and completed by a group of five micromobility Operators: Bolt, Dott, Lime, TIER Mobility, and VOI. This questionnaire served two purposes. Firstly, it was tailored to gather comprehensive insights into safety aspects encompassing both the physical and digital aspects of micromobility vehicles and services. Secondly, it aimed to identify challenges and lessons learned from the deployment of such vehicles.

Structure

The section "Key Micromobility Safety Trends " discusses studies that analysed crash and injury data to assess the safety of e-scooters and (e-)bikes. It analyses the findings from the literature on micromobility injury severity level and addresses types of crashes, crash and injury risk, and under-reporting and associated risk factors with riding behaviour, infrastructure, and vehicle design.

The section "Key Micromobility Risk Factors" synthesises the key risks associated with micromobility safety.

The section "Recommendations" presents targeted safety recommendations for both micromobility operators and local authorities, categorized into three critical areas: safe infrastructure, safe users, and safe micromobility vehicles.

Key Micromobility Safety Trends

This chapter presents the analysis of the findings from the literature on:
- e-scooter and e-bike crashes and injuries,
- risk factors considering various exposure measures related to users,
- risk factors related to road and cycling infrastructure,
- the design features of micromobility vehicles, that have been found to affect safety.

Micromobility crash and injury data

Micromobility crashes

The great majority of the literature on micromobility safety focuses on the injury outcomes of e-scooter and e-bike or conventional bike crashes. Table 1 presents the findings of recent studies on injury severity and injury type. Minor injuries emerge as the most prevalent severity level within reported micromobility-related crashes, while more severe injuries comprise a small portion of total reported injuries. With respect to all injuries, according to available data and studies, fatal injury rates are very low (<1%) and without clear difference between e-scooters, e-bikes, and conventional bikes (Table 1).

Considering only severe trauma injuries, the rates are higher (<10%) than rates reported for all-injury crashes. Considering only patients displaying severe trauma symptoms and accordingly admitted into major trauma centres in France, in-hospital fatality rates among severely injured patients are predictably higher than rates reported for all-injury crashes -- 9.2% for e-scooters, 10% for conventional bicycles and 5.2% for motorbikes (James et al., 2023). James et al. (2023) also registered a near tripling of e-scooter admissions (+185%) to major trauma centres from 2019 to 2022, compared to a 24% increase for bicycles (electric and conventional) and a 12% decrease for motorbikes. This growth indicates an increase in severe trauma-related e-scooter crashes in France. The relative shares of the overall trauma centre admissions for e-scooterists, cyclists and motorcyclists over the same period were 4%, 17% and 78%, respectfully (James et al., 2023). Furthermore, according to Clough et al. (2023), 2.7% of e-scooter riders and 1.7% of cyclists experienced major trauma leading to fatalities.

The severity of injuries is correlated with the crash mechanism, the vehicle type and road users involved (Kazemzadeh et al., 2023). E-scooter crashes mainly result in head and face injuries, as outlined in Table 1 and Figure 2, with a notable concentration of maxillofacial injuries observed in the lower third of the face (i.e., chin and jaw) (Benhamed et al., 2022; Grill et al., 2022; Kim et al., 2022; James et al., 2023;). Cyclists also present with maxillofacial injuries even when wearing helmets (Benjamin et al., 2019), albeit at lower rates than e-scooterists (Niemann et al., 2023). Severe trauma e-scooter and bicycle patients presented with traumatic brain injuries at double the rate of motorcyclists (22% for e-scooterists and 19% for cyclists vs. 11% for motorcyclists) (James et al., 2023).

Besides head/face injuries, upper and lower extremities injuries are also common among e-scooter crashes (Toofany et al., 2021; Serra et al., 2021; Stormann et al., 2020). Fractures, particularly involving the lower arm and wrist, are common among e-scooter riders, as is lower extremity trauma (Benhamed et al., 2022; Cicchino et al., 2021; National Academy, 2023). It is important to highlight that the majority of injury categories are not mutually exclusive, and numerous patients presented with more than one injury type or location.

The mechanics of e-scooter crashes explain some of these outcomes. E-scooter riders are free-standing and upright and present a high and forward centre of gravity. Loss of control crashes result in riders either attempting to hop off the e-scooter (contributing to lower extremity and foot injuries) or – in the case of forward obstacle crashes – being catapulted forward and over the handlebar and steering column. Such vaulting injuries result in upper extremity injuries as riders seek to break their fall or in a high incidence of face and head injuries as face- or head-first ground contact occurs before the rider can brace themselves (Arbel et al., 2022; Como et al., 2022; Chontos et al., 2023; Matt et al. 2022; Fournier et al., 2023; Paudel, 2019; Paudel and Yap, 2021; Serra et al., 2021; Wei et al., 2023). Alcohol consumption further suppresses reaction times, leading to a high incidence of head and face injuries for alcohol-inhibited e-scooterists (Shiffler et al., 2021).

Table 1 summarises recent studies describing e-scooter, conventional bike and e-bike injury types and severity. “No injury” events are crashes where the persons involved experience no injury at all. “Minor injuries” refer to injuries ranging from lacerations to minor wounds to hospital visits with no significant medical procedures (e.g., no hospitalization, imaging, surgery, etc.). Severe injuries refer to injuries that require significant medical attention and, in some cases, hospitalisation. A lack of common terminology describing injury severity level complicates analysis. Some records refer to Injury Severity Scores (ISS) or the Maximum Abbreviated Injury Scale (MAIS) code, while others simply note whether the patient arrived at the medical facility as a “walk-in” or by ambulance. E-scooter injuries have an ISS ranging from 1 to 5.5 (Toofany et al., 2021).

Table 1. Synthesis of the findings on e-scooter and e-bike injury severity and type

Injuries	Incident description	Vehicle Type	Effect	Source
Severity (% of casualties)	No injury (% of riders)	es	6-9%	Badia and Jenelious, 2021; Weidemann et al., 2022
	Minor injury	es	56-70%	Siman-Tov et al., 2017; Badia and Jenelious, 2021; PACTS, 2021; Weidemann et al., 2022; Tian et al., 2022; Stray et al., 2022
		eb	65-70%	Siman-Tov et al., 2017; Chen and Dai, 2018
	Severe injury	es	8-13%	Siman-Tov et al., 2017; Stray et al., 2022; Weidemann et al., 2022; Meyer et al., 2022; Vesselinov et al., 2023
		eb	5-17%	Siman-Tov et al., 2017; Chen and Dai, 2018; Meyer et al., 2022
	Fatality	es	<1%	PACTS, 2021 (1%); MMfE, 2021 (0.07%); Williams et al., 2022 (0%); Benhamed et al., 2022 (0.1%); Younes et al., 2023 (0.09%)
		eb	<1.3%	Qian & Shi, 2023 (1.3%); Younes et al., 2023 (0.15%)
		cb	<0.2%	Benhamed et al., 2022 (0.2%); Younes et al., 2023 (0.23%)

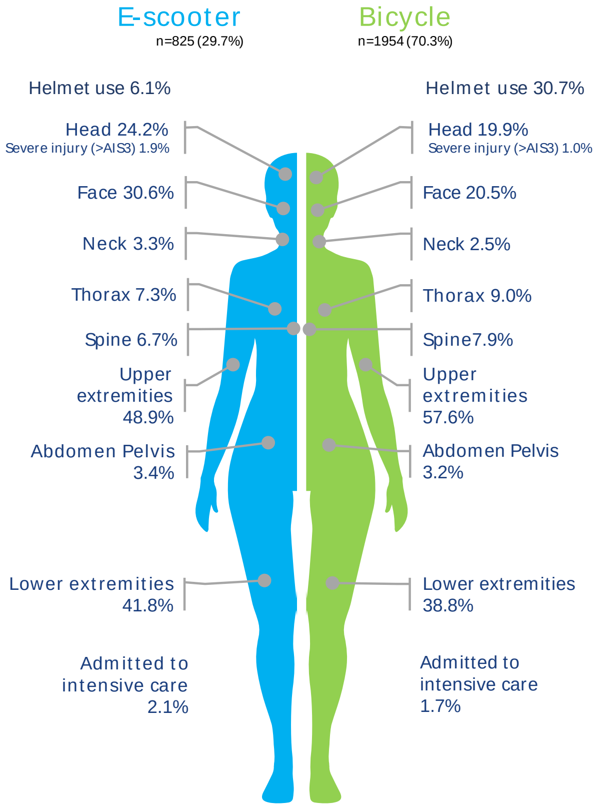
Injuries	Incident description	Vehicle Type	Effect	Source
Injured Body Region (% of casualties)	Upper extremity	es	25-55%	Alwani et al., 2020; PACTS, 2021; Stigson et al., 2021; Uluk et al., 2021; Benhamed et al., 2022; Orozco-Fontalvo et al., 2023; Leyendecker et al., 2023
	Lower extremity	es	23-45%	
	Head/ Face	es	Head: 18-41% Face: 30-60%	English et al., 2020; Alwani et al., 2020; Toofany et al. 2021; Stigson et al., 2021; Benhamed et al., 2022; Kleinerzt et al., 2021 & 2023; ; Leyendecker et al., 2023
		cb	Head: 20-24% Face: 20%	Benhamed et al., 2022; Laverdet et al., 2023
		eb	Head: 35%	Laverdet et al., 2023

*es: e-scooters, eb: e-bikes, cb: conventional bikes
*casualties: persons injured and fatalities

E-scooter injury patterns are different from the ones observed in the case of injured cyclists; conventional cyclists reported lower percentages in the above injury types and mainly in head/face and lower limbs (Stray et al., 2022; Benhamed et al., 2022; Clough et al., 2023; Laverdet et al., 2023; Niemann et al., 2023). E-scooter riders experience up to twice the incidence of severe head injuries and between 50% to 100% more maxillofacial injuries compared to conventional cyclists, potentially leading to a higher proportion of hospital admissions due to substantial trauma associated with e-scooter use (Benhamed et al., 2022; Clough et al., 2023; James et al., 2023). However, a comprehensive study analysing records from around 100 U.S. hospitals in 2021-2022 revealed that individuals with e-scooter injuries are more likely to be treated and released (85%) compared to e-bike (81%) or bicycle injuries (79%), albeit not by a significant margin. Despite variations in injury patterns, fatal incidents remain uncommon across micromobility modes, with a slightly higher proportion noted among cyclists based on 2021-2022 datasets (Younes et al., 2023).

Figure 2 illustrates the differences in injury types and severity between nearly 3,000 e-scooterists and cyclists presented to hospitals in the Rhône Department of France. E-scooterists presented with a greater share of head, face, and neck injuries than cyclists. This may partly be explained by the much lower incidence of helmet use amongst e-scooterists, though helmets generally do not prevent head, face and neck injuries. A higher incidence of alcohol-involved crashes for e-scooterists may also help explain these differences. Injuries to lower extremities are more prevalent in this population for e-scooterists as compared to cyclists – possibly reflecting injuries sustained as e-scooterists hopped off their e-scooter just before, or at the moment at which, they lost control.

Figure 2. Comparative description of e-scooter and bicycle riders' injuries (AIS≥1) as a percentage of patients presenting with injuries to hospitals in the Department of the Rhone in France in 2019



E-bike injury patterns are also distinct from e-scooter and conventional bicycle injury profiles. E-bike riders are more likely to suffer internal injuries compared to e-scooter riders, whose injuries are nearly three times more likely to result in concussion (DiMaggio et al., 2022). Several studies conclude that injuries involving e-bikes were more severe than injuries involving e-scooters, with the higher relative speed of travel cited as a contributory factor (Arbel et al., 2022; Cicchino et al., 2021; Hamzani et al., 2021; DiMaggio et al., 2022). Laverdet et al. (2022) present a contrary finding that e-scooter injury severity was higher compared to e-bike and conventional bike injury severity. However, a study in the United States concludes that injuries associated with e-scooters exhibited greater similarities to injuries related to conventional bikes rather than to those related to e-bikes (National Academy, 2023).

The literature on the safety of e-bikes compared to conventional bikes is relatively sparse and mainly covers the pre-pandemic era. Existing studies tend to be concentrated in certain European countries, some US states, and China. Several studies in European countries where e-bikes are allowed to offer pedal assistance up to 25 km/h showed that e-bike crashes are, in general, equally severe as conventional bike crashes (Schepers et al., 2014; Weber et al., 2014; Weiss et al., 2018; Fyhri et al., 2019; Schepers et al., 2020).

Micromobility crash risk

While crash data provide valuable insights into the absolute frequency and severity of crashes, a comprehensive safety assessment involves understanding crash risk. Risk reflects both the crash severity as well as the probability of its occurrence. It is characterised as the number of crashes or casualties(fatal crashes, crashes with hospitalised or fatally injured victims, fatalities, persons injured) over a metric of exposure (such as the overall distance travelled). Crashes may be captured in aggregate but a policy-relevant expression of crash risk should account for disaggregate crash characteristics. Accordingly, crashes may be characterised according to severity, type or type of injured party. Exposure metrics can vary as well – when no trip-related data is available, risk may be expressed as a crash rate per population. More policy-relevant exposure metrics capture either trip numbers, distances travelled or commuting duration. Distance-based metrics are appropriate for exposure of motorized vehicles, but they are not ideal for comparing motorized and non-motorized modes (e.g., bikes) as the latter tend to have trips of a shorter length (Vanparijs et al., 2015). Crash risk in this study is expressed as a rate of crashes (or varying severity) per number of trips or, alternatively, per vehicle kilometres travelled.

Policy should seek to avoid all crashes and eliminate all severe or fatal injury ones. Paradoxically, however, exposure-adjusted crash risk may diminish even with a rise in absolute crash numbers if trips or distances travelled increase at a higher rate than crashes. According to Safe System frameworks, there is a clear difference between measuring crash risk and its evolution and the formulation of policy objectives –these should not be conflated. It is one thing to note that increased crashes are accompanied by a reduction of overall crash risk, but quite another to target decreased crash risk as an objective, even when this is delivered despite a concomitant increase in crashes. Policy targets should not solely target incremental crash risk improvements but, rather, should primarily aim to eliminate the risk of severe or fatal crashes.

Challenges persist in determining whether observed micromobility safety trends result due to changes in safety or exposure. Addressing these challenges requires improved collection of micromobility-related crash data, particularly for light-injury and non-injury crashes, from hospital/health authorities and the police, ensuring proper vehicle coding in crash/injury reports and more detailed data on micromobility exposure, categorized by vehicle type. These processes are distinct and involve different authorities.

Available evidence indicates that, as shared e-scooter travel activity outpaces the growth of injuries requiring medical attention, shared e-scooter risk has diminished in Europe and the US. The following table provides a comparative overview of casualties requiring medical treatment (on-site emergency or hospitalisation) per million shared e-scooter trips across various markets (MMfE, 2023), highlighting changes between 2022 and 2021, together with existing micromobility regulations in each market (ETSC, 2023). As this data refers to commercial shared e-scooter services involving certain types of vehicles, users, experience levels and uses, these findings do not reflect the evolution of overall e-scooter risk-taking also into account not negligible underreporting, especially of single-vehicle crashes.

Table 2. Shared e-scooter risk and e-scooter safety regulations across European markets

	Shared e-scooter casualties requiring medical treatment per Mio trips			E-scooter Safety Regulations						
Market	2021	2022	YoY%	Min age (y/o)	Max speed (km/h)	Max power (w)	Ride on pavements?	Drink-ride limit	Helmet required	Mandatory insurance
Austria	4.1	1.5	-63.6%	12	25	600	No[1]	0.8	<12 y/o	No
Belgium	7.1	7	-1.8%	16	25	NA	No	Same as car	No	No
Bulgaria	NA	NA	NA	16	25	NA	Yes[1]	NA	<18	No
Cyprus	NA	NA	NA	14	20	NA	Yes[1]	0.5	Yes	No
Czech Rep	9.2	15.6	69.3%	NA	25	250	>10 y/o	No	<18	No
Denmark	8.6	14.8	72.3%	15	20	NA	No	Same as mopeds	Yes (>Jan 2022)	Yes
Finland	5	2.9	-41.6%	No	25	1000	No	No	Yes - as bikes	No
France	9	12.1	34.8%	12	25	NA	No[1]	Forbidden to ride	Recommended	Yes
Germany	4.3	4	-7.7%	14	20	500	No[1]	Same as car	No	Yes
Greece	NA	NA	NA	15	25	NA	Yes[1]	No	Yes	No
Italy	12.1	4.4	-63.3%	14	20[2]	500	No	NA	<18	No[5]
Norway	3.2	2.7	-17.5%	12	20	NA	No	Same as cars	<15	No
Poland	4.9	4.5	-8.0%	10	20	NA	Yes[1]	Forbidden to ride	No	No
Portugal	22.3	25	12.0%	No	25	1000	>10 y/o	Same as cars	No	No
Slovenia	NA	NA	NA	14[4]	25	NA	No	0.5	<18	No
Spain	22.4	14.8	-34.1%	14-16	25	1000	No	Same as cars	Yes (>March 2022)	No[5]
Sweden	5.2	5.3	0.5%	NA	20	250	NA	NA	<15 - as bikes	NA
Switzerland	2.2	4.4	100.3%	16[3]	20	500	No[1]	Same as cars	No	No
UK	31.9	20.6	-35.5%	16	25	500 (trials)	No	Same as cars	No	Trial[5]
		Cumulative	-25.7%							

[1] "local" authorities can make exceptions (e.g., if no cycling lane, travel speed up to 6 km/h, if the road speed limit is <30km/h or <50 km/h, riders aged 14-16 should only ride them on bicycle lanes etc.).
[2] 6km/h in pedestrian areas.

[3] 14 with moped license.
[4] 12, with cycling licence.
[5]required for sharing providers.
Sources: MMfE, 2023; ETSC, 2023

Table 2 reveals a wide variation in micromobility regulations across European markets, reflecting the evolving nature of e-scooters as a travel mode. Safety regulations like helmet requirements and age limits exhibit considerable variation based on the market, type of micromobility vehicle, and whether they are privately-owned or shared. Shared e-scooter casualty risk has fluctuated across markets, with some seeing substantial increases (e.g., Denmark and Switzerland) and others experiencing decreases (e.g., Austria and Italy). The decrease of shared e-scooter risk can be partly attributed to increased attention to safety and the uptake of a "safety culture" among operators and users. Italy's remarkable safety performance can also be credited to the recent mandatory enhancements in e-scooter features, such as the incorporation of front and rear brakes along with direction indicators (yellow flashing lights, both front and rear). These specifications are required for all new e-scooters introduced to the market since October 2022 (European Consumer Centre Germany, 2023). It is noteworthy that these safety regulations collectively contribute to the cumulative e-scooter casualty risk reduction across markets (-25.7%).

In markets where a reduction in shared e-scooter casualty risk is observed, several common regulatory measures were taken aiming to improve risk, yet further investigation is required to provide clarity on their specific road safety impact. These include the enforcement of minimum age requirements for riders, the imposition of maximum design speed limits and helmet use.

MMfE also reports that the risk of injury requiring medical treatment is comparable between shared e-scooters and shared e-bikes (MMfE, 2023a). Furthermore, the insurer AXA's findings for the period between 2019 and 2022 highlight that the crash risk of shared e-scooters in Europe is 20 times lower compared to mopeds (MMfE, 2023b). However, an analysis of the UK Department for Transport STATS19 data on shared e-scooters reveals a provisional rate of 13 casualties per million miles, approximately three times higher than the rate for pedal cycles (DfT, 2022). In alignment with these findings, a study by Cicchino et al. (2021b) indicates that the estimated Emergency Department (ED) visit rates per million miles travelled were higher among e-scooterists compared to cyclists (E-scooters: 20.7 emergency department visits per million miles travelled, Bikes: 5.5 Emergency Department visits per million miles travelled). Finally, it should be noted that e-scooters are riskier than cars for their users (Rix et al., 2021) even if cars are a much greater source of danger to other traffic participants.

Collision types

E-scooter-related crashes differ from other modes in that their great majority involve the rider and no other road user. Toofany et al. (2021) refer to those events as single-road user collisions and found that they account for almost 93% of all reported e-scooter-related injuries. Single road user collisions usually refer to falls, collisions with stationary objects, loss of vehicle control etc. In addition, it is essential to acknowledge the potential risk of collisions involving e-scooters tripping over pedestrians.

As shown in Table 3, several studies and analyses have quantified the number of single-road user collisions as a percentage of the total e-scooter-related crashes and injuries. Lime analysed data from their records and found that in Paris and New York City, single road user collisions accounted for 79% and 80% of all recorded crashes of their shared e-scooters (Lime, 2022). Looking at police-recorded crash statistics, Heydari et al. (2022) found that only 4% of all police-recorded crashes in the UK were due to single-road user collisions compared to 79% involving other motorised vehicles and other parties and 17% involving pedestrians. The low-fall rate in the UK data likely reflects a known bias in police records towards crashes involving motor vehicles or crashes resulting in serious injuries, and thus UK data under-represents overall single-road user collisions since these generally do not involve motor vehicles and result in injuries that are generally less severe.

E-scooter-related casualties resulting from falls constitute a substantial proportion of overall e-scooter-related casualties(64-85%). This range compares with the respective percentage of cyclists' casualties due to falls (75%; Kleinertz et al., 2021). Also, Benhamed et al. (2022) confirm that most e-scooter and bicycle road collisions are consequent to a fall or loss of vehicle control. Single road user collisions also involve collisions with stationary objects. Compared to falls, the latter concerns a lower percentage of all e-scooter-related injuries, as shown in Table 2.

Several studies have analysed injuries and fatalities data to assess the impact of motor vehicles on e-scooter safety. Across these studies, injuries resulting from e-scooter-motor vehicle collisions account for 8-19% of all e-scooter-related injuries, a slightly higher proportion than bicycle injuries stemming from collisions with motor vehicles. In the United States, multiple studies conclude that motor vehicle collisions are greatly responsible for e-scooter-related fatalities (NTSB, 2022), accounting for more than 80% of e-scooter fatalities. This percentage is comparatively smaller than bicycle fatalities attributed to motor vehicle collisions, which range from 93 to 96% based on National Highway Traffic Safety Administration (NHTSA) statistics from 2020 and 2019, respectively (NHTSA, 2022; NHTSA, 2021). Shah et al. (2021) note that 1 in 10 reported motor vehicle crashes with e-scooters or bicycles result in the injury or death of the e-scooterist or cyclist.

Pedestrians are uniquely exposed to e-scooter crash risk. This is partially because, in some countries, e-scooters operate legally or illegally on the sidewalk in the presence of pedestrians, especially in the absence of bicycle infrastructure (Badia and Jenelius, 2021). Additionally, pedestrians are affected by illegally or poorly parked e-scooters (Zuniga-Garcia et al., 2021; Brown et al., 2020; James et al., 2019). The co-existence of pedestrians and e-scooterists results in pedestrian injuries (1 to 10% of all e-scooter-related casualties). Pedestrians are injured through a collision (30%) or by tripping over a parked e-scooter (59%).

Table 3. Micromobility collision types.

Collisions		Vehicle type	Effect	Source
Involved road users (% of casualties)	Single road user	es	93%	Toofany et al. 2021
	Multiple road users	es	7%	
Falls	% of tot. crashes	es	79-90%	Badia and Jenelious, 2021; Heydari et al., 2022; Lime, 2022
	% of casualties	es	64-85%	Bloom et al. 2020; English et al., 2020; Kleinertz et al., 2021; Azab et al., 2022
		cb	75%	
with objects	% of casualties	es	1-39%	Kleinerzt et al., 2021; Weidemann et al., 2022; Neuroth et al., 2022
with motor vehicles	% of casualties	es	8-19%	Bloom et al. 2020; Cicchino et al., 2021b; English et al., 2020; Lavoie-Gagne et al., 2021; Schisman et al., 2021;
		cb	10%	

Collisions		Vehicle type	Effect	Source
				Shah et al., 2021; Neuroth et al., 2022
	% of tot. fatalities	es	>86% (24% hit-and-run)	Karpinski et al. 2022a NTSB, 2022; NHTSA, 2021 & 2022
		cb	93-96%	
with pedestrians	Involved pedestrians (% of tot. crashes)	es	4-17%	Badia and Jenelius, 2021; Heydari et al., 2022
	Injured pedestrians (% of casualties)	es	1-10%	APH, 2019; Portland Bureau of Transportation, 2019; Trivedi et al., 2019; Weidmann et al., 2022; PACTS, 2021; Stigson et al., 2021
	tripped over (of non-rider casualties)	es	30%	Toofany et al. 2021
	Struck (of non-rider casualties)	es	59%	Toofany et al. 2021

*es: e-scooters, cb: conventional bikes
*casualties: persons injured and fatalities

Crash and injury under-reporting

E-scooter crashes (like bicycle-involved crashes) generally suffer from under-reporting. Two factors contribute to this:

- Differences in the total number of recorded injuries and crashes among different databases.
- Under-reporting of non-injury or mild injury crashes/incidents.

A recent study by the National Traffic Safety Board (NTSB) compared their findings on fatalities reported in media reports to the recorded fatalities in three databases and found that the records in the databases always showed fewer fatalities (NTSB, 2022). This suggests that when analysing fatalities and injury data, some records might be missing.

Indirect evidence for crash under-reporting is the fact that most of the scientific literature focuses on hospital, emergency room, or trauma centre data when assessing the safety impacts of e-scooters. These records only cover incidents that resulted in injuries requiring immediate medical treatment. On the other hand, studies that analyse falls and collisions of e-scooterists of all injury severity types are survey-based (e.g., Department for London, 2022). No- or light-injury bicycle crashes face similar under-reporting as well (De Mol and Lammar, 2006; Shinar et al., 2018). In some US states, the police only record crashes that involve significant injuries or property damage. In certain states (e.g., Oregon), crashes can be self-reported, so it is likely that crash datasets are more representative of the actual situation.

Studies looking to document the magnitude of under-reporting in micromobility crashes and injuries compare hospital and police crash records. They notably reveal a strikingly low overlap, with only 3 to 12% of e-scooter patients documented in both hospital and police records (PACTS, 2021; Tian et al., 2022; Laverdet et al., 2023). Among reported crashes in the USA, data on helmet use was only recorded in 42% of bicycle-related cases (Tian et al., 2022) and from 40% to 85% of e-scooter-related cases (National Academies, 2023). Another additional aspect concerns the misreporting of crashes. A crash is recorded, but the road users involved are misclassified. NTSB (2022) discusses this issue as a US-wide phenomenon.

Safe infrastructure

The type and quality of the road infrastructure have been found to affect e-scooter collisions (Table 4). Poor road infrastructure (e.g. where the surface is poorly maintained and has potholes and other discontinuities) has been found responsible for 30-40% of e-scooter crashes. Unpaved versus paved surfaces have been associated with higher crash risk. Surface quality for cycling infrastructure is equally important, as poor quality has been found to be associated with single road user crashes, particularly for e-scooters.

Both pavements/sidewalks and higher-speed traffic lanes have been found to be the least safe locations to ride, while separated bicycle tracks prove to be the safest location and are associated with a lower injury risk (Table 4). Several studies suggest that e-scooter incidents occur primarily on roadways and secondarily on pavements/sidewalks (APH, 2019; Bloom et al., 2022; English et al. 2020), while other studies conclude to the opposite finding (Cicchino et al. 2021). This difference may be linked to the prevalence of riding on pavements/sidewalks and the presence of bicycle infrastructure. Ma et al. (2021) find that e-scooter travel conditions are better on the roadway or on cycling infrastructure than on pavements/sidewalks that are characterised by more obstacles and vibration-inducing discontinuities. In the US, e-scooterists generally ride on bike infrastructure when it is present (27-67%), on the road (20-49%) and on the sidewalk (10-36%). In Europe, the trend is similar, although the shares are different, with a higher prevalence of bicycle infrastructure use up to 93%) compared to traffic lanes (11-36%) and pavements/sidewalks (4-24%) (Badia and Jenelius, 2021).

When it comes to geometry, a narrow lane width can elevate the risks for micromobility users, increasing the likelihood of collisions (Sabbaghian et al., 2023). Ma et al. (2021) investigated obstacle proximity to e-scooter riders, emphasising the critical importance of evaluating the surrounding environment of e-scooters to ensure safety.

Table 4. Risk factors related to infrastructure associated with micromobility safety

<table>
<tr><th>Risk factor</th><th>Vehicle type</th><th>Effect</th><th>Source</th></tr>
<tr><td>Poor road infrastructure (% of tot. crashes)</td><td>es</td><td>30-40%</td><td>Badia and Jenelius, 2021; Ma et al. 2021; DfT, 2022</td></tr>
<tr><td>Paved vs unpaved road</td><td>es</td><td>2.66 greater crash risk</td><td>Tian et al., 2022</td></tr>
<tr><td rowspan="7">Road environment</td><td>es</td><td>Traffic lane: 23-55% (all)</td><td rowspan="3">Badia and Jenelius, 2021; APH, 2019; Cicchino et al., 2021a; Cicchino et al., 2021b; Bloom et al., 2022</td></tr>
<tr><td>es</td><td>Sidewalk: 17-58% (all)</td></tr>
<tr><td>es</td><td>Bike lane: 0.04-25% (all)</td></tr>
<tr><td>es</td><td>Intersection: 65% (% of tot. fatalities)</td><td rowspan="2">Karpinski et al. 2022b</td></tr>
<tr><td>cb</td><td>Intersection: 67% (% of tot. fatalities)</td></tr>
<tr><td>es</td><td>Non-junction: 17% (% of tot. fatalities)</td><td rowspan="2">Karpinski et al. 2022b</td></tr>
<tr><td>cb</td><td>Non-junction: 17-27% (% of tot. fatalities)</td></tr>
</table>

*es: e-scooters, cb: conventional bikes

Two studies in China and one in Germany have assessed the safety of e-bikes at signalised intersections (Huang et al., 2020; Bai et al., 2013; Petzoldt et al., 2017). According to these studies, the conflict rate of e-bikes is higher than that of conventional bikes irrespective of fault. According to Bai et al. most observed conflicts were caused by the dangerous driving behaviour of car drivers. Liang et al. (2021) observed that on pavements/sidewalks and bike lanes, the probability of traffic conflicts is highest between e-bikes and pedestrians and lowest between two conventional bicycles.

Safe Riders

This section analyses micromobility crash outcome and crash risk, considering various factors related to users. Specifically, factors associated with micromobility crashes, injuries and/ or a particular injury level or type are presented. Crash and injury risk factors associated with bicycles are quite different to those of e-scooters, namely, nighttime riding, alcohol consumption, and helmet use. There is a broad convergence across the international literature on micromobility and e-scooter crash risk factors. These are summarised in Table 5.

Surrogate safety studies can provide information on road user behaviour and rules compliance, aspects that have been found associated with crash and injury risk. Nighttime and reduced lighting conditions are positively correlated with both injury and fatal crashes. Riders under the influence of alcohol are more likely to be involved in injury collisions (Arbel et al., 2022; Shiffler et al., 2021; Benhamed et al., 2022; James et al., 2023; Kobayashi et al., 2019; Hennocq et al., 2020). Haworth et al. (2021) observed the following types of illegal riding behaviour among e-scooter riders in Brisbane, Australia: no helmet use (35.6% of all observed users- helmets are required by law in Australia), more than one rider per e-scooter (2%), underage riding (6.7 to 10.3%), and riding on the road (which is illegal in Brisbane). Illegal behaviours were significantly higher for shared e-scooter users. Hong et al. (2022) observed that 96% of shared e-scooter riders on the Virginia Tech University campus in the US were helmetless. Low levels of helmet use, ranging from 0.4% to 10.9% for shared e-scooter riders, has also been observed in several other international studies (Hayworth, et al., 2022). Many e-scooterists also occasionally ride with an additional passenger (dual riding). According to a Berlin-based survey, 42% of people who have ridden an e-scooter before said they had at one point ridden with two people onboard (Siebert et al., 2021a). Observational studies of dual-use riding find that between 2% and 5% of all observed trips involve two riders on a single e-scooter (Siebert et al., 2021b).

Helmet use, which is very low among injured e-scooter riders, could help reduce head injuries, which are common among e-scooter injuries (English et al., 2020; Toofany et al., 2021; Cicchino et al., 2021b; Bloom et al., 2022). However, several studies conclude that while current bicycle helmet standards (ASTM F1447-18, 2018; NF EN 1078) are well adapted to evaluate helmets for linear impacts, there is a need to address oblique impact conditions and the evaluation of head rotation injuries (Bourdet et al., 2021; Fournier et al., 2023; Wei et al., 2023) which are common during e-scooter riders' falls. Also, considering that a large proportion of the impacts are to the face (Table 1; Posirisuk et al., 2022; Kim et al., 2022), the use of risk-appropriate helmet protection should be incentivised for e-scooter riders.

Mobile phone use while riding an e-scooter (Siebert et al., 2021) and cycling (Huemer et al., 2022) is a distraction that can impair a rider's focus and reaction time. The act of using a mobile phone while riding diverts a rider's focus from their immediate surroundings, potentially leading to reduced situational awareness and an increased likelihood of crashes.

Table 5. Risk factors related to users associated with micromobility safety

Risk factor	Vehicle type	Effect	Source
Nighttime (% of fatal crashes)	es	82%	Karpinski et al., 2022b
	eb	48%	
	cb	57%	
	es	43%	Yang et al., 2020
Nighttime & Reduced lighting (% of casualties)	es	30-44%	Weidemann et al., 2022; Kleinertz et al., 2021; Kleinerzt et al., 2023; Laverdet et al., 2023
	cb	14-28%	
	eb	18%	
Nighttime crash risk	es	4.8 crashes per 100,000 trips **vs** 2.2 for daytime crashes	Shah & Cherry, 2022
Helmet use (% of casualties)	es	0-7%	Harbrecht et al., 2021; Cicchino et al., 2021b; Grill et al., 2022; English et al., 2020; Bloom et al., 2022; Stray et al., 2022; Meyer et al., 2022; Laverdet et al., 2023; Clough et al., 2023; Leyendecker et al., 2023
	cb	16-64%	
	eb	53%	
Alcohol	es	Fatalities: 41%	Karpinski et al. 2022b
	es	Casualties: 7-53%	Weidemann et al., 2022; Puzio et al., 2020; Grill et al., 2022; Bekhit et al., 2020; Harbrecht et al., 2021; Kleinerzt et al., 2021; Neuroth et al., 2022; Leyendecker et al., 2023
	cb	Casualties: 6-13%	
Double riding (% of casualties)	es	14-17%: >one riders/ vehicle	Weidemann et al., 2022 Hennocq et al, 2020
Experience	es	24-37% of injured riders were injured during their 1st ride	Austin Public Health, 2019; Cicchino et al., 2021; Williams et al., 2022; Sexton et al., 2023
	es	78% of crashes involved riders with low riding rates	DfT, 2022

*es: e-scooters, eb: e-bikes, cb: conventional bikes
*casualties: persons injured and fatalities

When e-scooterists travel on bicycle infrastructure, their speed has been found to be comparable to, but slightly higher than, that of conventional cyclists (~15.4 km/hour) (Pazzini et al., 2022). During overpassing manoeuvres, e-scooter speed has been found to increase, especially for close-distance interactions (e.g., <50 cm); this might affect cyclists', and other users' perceived safety. Excessive speeding has been identified as a significant risk factor contributing to e-scooter injuries, with statistics from the US Centers for Disease Control and Prevention (CDC, nd) suggesting it plays a role in approximately 30% of such incidents. Lastly, Almannaa et al. (2021) concluded that the average speed of e-bikes is higher than the average speed of e-scooters, leading potentially to a higher severity of injury.

The research on surrogate safety for e-bikes is limited and mainly based on old research without a common methodological framework. The majority of the studies in the literature and under consideration aim to investigate the safety performance of e-bikes, comparing it with the safety performance of conventional bikes. The travel speed of e-bikes is a significant factor influencing safety performance. Hertach et al. (2018) conclude that speeding typically occurs before recorded e-bike crashes. Cherry & MacArthur (2019) reviewed eight studies investigating the average operating speed of e-bikes compared to conventional bikes, finding that e-bikes travel about 3.0 km/h faster than conventional bicycles. A similar margin was also found in a naturalistic study of German cyclists (Schleinitz, K. et al., 2017). In China, three studies found that e-bikes travel speeds were 40–50% faster than conventional bicycles, reflecting the larger share of throttled e-bikes able to operate above 25km/hr (Cherry & He, 2010; Lin et al., 2008; Yang et al., 2014). Similarly, speed-pedelec speeds (able to travel up to 45km/hr) in Germany were found to be 62% higher than conventional bicycles (Schleinitz, K. et al., 2017). Finally, red light violations are observed to be the same between e-bikes and conventional bikes (Cherry and MacArthur, 2019).

In several injury-related studies, there is a discussion on the gender of the rider and e-scooter crash outcomes. E-scooter riders are mostly younger males, as found in various demand-related studies (e.g., Laa & Leth, 2020; Christoforou et al., 2021; Department for London, 2022). With driving and cycling, younger males are associated with higher incidences of risky behaviour, crash rates and severe crash outcomes (Prati et al., 2019). However, evidence to-date indicates that male and female e-scooterists have been found to have the same injury and crash probabilities (Harbrecht et al., 2010; Cicchino, Kulie, and McCarthy, 2021).

Similarly, seasonality of e-scooter injuries and fatalities has not been found to be a significant risk factor. The higher number of collisions during the spring and mostly summer months is due to the increase in ridership. This trend is similar to bicycle crashes (NHTSA, 2021; NHTSA, 2022) and is explained by increased seasonal riding (Fournier et al., 2017).

Evidence suggests that experience operating micromobility vehicles improves safety performance. This has been found to be the case with cycling – for example, Branion-Calles et al. (2020) found that crash rates decreased with increased rider cycling frequency in seven European cities. For the case of e-scooters, two types of inexperience should be considered: users who have not completed many rides and users who are not familiar with the local context. The latter is particularly relevant to shared e-scooter use, as in many cities, it has been found that shared e-scooters are used by a considerable number of non-residents or tourists (Laa & Leth, 2020; Christoforou et al., 2021; Austin Public Health, 2019). A study in Austin, Texas, found that 33% of the injured e-scooterists were not Austin residents, and 21% were not even Texas residents (Austin Public Health, 2019). Collisions are predominantly linked to infrequent riders, with 78% of crashes involving this group, while first-time renters face a threefold higher risk compared to experienced users who have rented e-scooters over 20 times, emphasizing the importance of safety for newcomers (DfT, 2022).

There is some research on user frequency between privately-owned and shared e-scooter riders. A study in Belgium surveyed e-scooterists six months after the introduction of shared e-scooters and found that shared e-scooter riders rode less frequently than riders using their own e-scooter (Lefrancq, 2019). In a six-month period, 46% of shared e-scooter riders had ridden less than 10 times, and only 16% of them had ridden more than 50 times. Twenty-nine per cent (29%) of e-scooter owners had ridden up to 10 times, while most of them (41%) had ridden more than 50 times. Similar are the findings from the survey of Laa and Leth (2020) in Vienna. Therefore, it can be assumed that e-scooter owners are more frequent riders and, so, have acquired better riding skills.

Brownson et al. (2019) note that most of the hospital admissions (93%) for e-scooter-related injuries in Aukland, New Zealand, involved shared e-scooter riders, while only 1% of the patients were e-scooter owners. Additionally, an Australian study by Haworth et al. (2021) observed e-scooters in Australia in February 2019, revealing that illegal and risky driving behaviour, such as not wearing a helmet, riding on the road, or double riding, were more prevalent among shared e-scooter riders compared to owners (49.6% for shared e-scooters vs. 12.2% for privately-owned e-scooters).

Safe vehicles

In ever-evolving urban landscapes, powered micromobility solutions like e-scooters and e-bikes have reshaped urban transportation. However, their rapid uptake has brought forth an array of safety concerns linked to vehicle design. E-scooters and e-bikes – as well as conventional bikes -- differ greatly in their design, stability, and speed (Arbel et al., 2022). This chapter extends the discussion, delving into various vehicle design elements and their broader implications for enhancing micromobility safety, such as the vehicle’s maximum design speed, wheels’ size, brake mechanism, lights and bells.

A key distinction between e-scooters and bicycles lies in the rider's position. Unlike bicycles, e-scooter users stand on the vehicle while riding and can fall freely from the vehicle, absorbing the full impact of the fall (Arbel et al., 2022). The standing posture on e-scooters has been identified as risky, particularly during braking to manoeuvre around or away from obstacles. Conversely, the seated posture offers improved braking and handling performance for both seated e-scooters and bicycles.

The maximum design speed of powered micromobility vehicles remains a pivotal determinant of safety. The European Committee for Standardisation has issued EN 17128: 2020, which establishes design standards for personal light electric vehicles (PLEV), including e-scooters. The standard mandate restricts the maximum speed of e-scooters to 25km/h or less and does not apply to powered light vehicles having a maximum design speed above 25 km/h. Though there are no universal guidelines for its application, most European countries adhere to EN 17128: 2020.

Several studies highlight that the reduction of e-scooter riding speed can lead to a significant reduction in the mean head-ground impact speed (Posirisuk et al., 2022; Fournier et al., 2023). A study investigating differences in vehicle kinematics among standing and sitting e-scooters and 26-inch wheel bicycles, concluded that seated e-scooter stability begins at a relatively higher riding speed, becoming stable when speed exceeds 20 km/h, while certain standing posture designs, though stable in lower riding speeds, still fall short of the stability achieved by the reference 26 inch-wheel bicycle (Paudel and Yap et al., 2021). Enhancing the current e-scooter design could address stability challenges faced by riders during low speeds, simultaneously improving rider and overall safety.

Standing e-scooters feature a central column with handlebars to ensure stability and facilitate steering, complemented by a foot platform for the standing rider (SAE International, 2019). As with bicycles, changing the fork-steerer column angle (e.g. fork offset) impacts front wheel handling characteristics and shifts the rider/vehicle centre of mass – in some instances, bringing it nearer to the self-stability range of a larger-wheeled bicycle. Likewise, shifting the angle of the steering column with respect to the headtube/fork angle also has an incidence of the centre of gravity and steering performance.

Paudel (2019) and Paudel and Yap (2021) have highlighted that the vertical location of the centre of mass for bicycle riders and standing e-scooterists is comparable, though slightly higher for the latter for the same rider. The horizontal position of the centre of mass for e-scooters with a rider is more forward than for bicycles or seated e-scooters (Paudel, 2019). Compared to bicycles, the slightly higher and more forward-facing centre of mass has an incidence on forward obstacle crashes for e-scooters. In these instances, e-scooter riders exerting weight on the steering bar and column can induce a fulcrum effect, potentially leading to over-the-handlebar vaulting (Arbel et al., 2022; Como et al., 2022; Chontos et al., 2023; Matt et al. 2022; Fournier et al., 2023; Paudel, 2019; Paudel and Yap, 2021; Serra et al., 2021; Wei et al., 2023). Dynamically or statically shifting the centre of mass backwards and downwards improves the self-stability range of e-scooters, especially at lower velocities, just as shifting it forward degrades stability (PACTS, 2021; Paudel, 2019; Paudel and Yap et al., 2021). Many recent-generation shared scooters accordingly place weight lower and to the rear of the e-scooter, thus, alongside the adoption of larger front wheels (see below), improving stability (National Academies, 2023). These considerations underscore the significance of understanding the dynamic interplay between design features and rider behaviour in shaping the safety outcomes of e-scooter operation.

Wei et al. (2023) find that head-ground impact velocities during e-scooter falls align with those observed in bicycle falls, though the difference in injury characteristics discussed earlier suggests dissimilar head-ground impact configurations, as noted by Matt et al. (2022). Fournier et al. (2023) note that critical factors influencing the risks of head injury from e-scooter crashes include the initial speed of the device, its inclination with respect to obstacles, and the size and weight of the rider.

The width of the foot platform determines the stability of the e-scooter rider (Masquelet et al., 2023). Shichman et al. (2023) observe that the prevalent narrow-based design of e-scooters is more hazardous than a wider foot platform, with orthopaedic fracture rates significantly higher in the more commonly used "foot-behind-foot" riding position compared to a ”side-by-side“ position.

The size of wheels and tyres in micromobility vehicles has a substantial impact on safety, with larger wheels emerging as a salient safety feature, preventing deflection, improving obstacle clearing and providing gyroscopic stability. Bicycles have larger wheels (16” to 29”) that generate stabilising gyroscopic forces and generally employ shock-absorbing tubed or tubeless tyre designs. E-scooters have much smaller wheels (6” to 12”) and more solid and less forgiving tyres (García-Vallejo et al., 2020; PACTS, 2021). Bicycle wheels have a shallower angle of attack than smaller e-scooter wheels and are thus more stable when encountering obstacles of the same height (Paudel, 2019). E-scooters with smaller wheels have been linked to a higher likelihood of falls, elevating the risk of head injuries for riders. A noteworthy finding underscores that increasing e-scooter wheel size decreases the likelihood of falls caused by potholes, with a critical pothole depth range estimated to be between 3 and 6 cm for 10-inch wheel e-scooters (Posirisuk et al., 2022). Therefore, larger wheels offer more stability and safety.

Moreover, the choice of wheel type is a crucial consideration, with air-chambered wheels being found to confer more stability than solid rubber or honeycomb ones (Leoni et al., 2022). These air-chambered wheels can absorb vibrations and shocks better, thereby enhancing overall ride comfort and safety. Many e-scooters – especially those designed for shared use – compensate for the relative lack of passive shock absorption with active front-fork suspension systems.

Braking systems represent a critical aspect of micromobility vehicle design, and their diversity warrants attention. The types of braking systems for e-scooters and e-bikes vary widely depending on the specific model and manufacturer. Nonetheless, there are some common types used internationally. Notably, most e-scooters are equipped with two independent braking systems (in some cases, this is a legal requirement). Some models feature two-hand lever brakes, while others incorporate a foot-brake in addition to a single left-hand brake (Siebert et al., 2021). This diversity highlights the need for establishing a universal mental model for lever-to-brake coupling, mitigating potential confusion surrounding lever and front/back-wheel-brake coupling.

Dozza et al. (2022A) investigated the distinct braking and manoeuvrability characteristics of e-scooters and bikes, concluding that e-scooters typically require a longer braking distance compared to bikes. Recent research by Li et al. (2023) emphasises that braking performance, measured in terms of deceleration and jerk, exhibits variations across different vehicle types. Notably, e-scooters show lesser efficacy in braking compared to bicycles. For standing e-scooters, the maximum allowable deceleration to prevent flipping over is approximately 5 m/s^2, significantly lower than for seated e-scooters (6.7 m/s^2) or bicycles (7.5 m/s^2) (Paudel and Yap, 2021). These findings are crucial in comprehending the dynamics of road interactions, as it implies that e-scooters have a lower probability of safely stopping in emergency situations compared to bicycles. However, e-scooters exhibit superior performance in steering manoeuvres, attributed to their shorter wheelbase and the absence of a pedalling requirement (Paudel and Yap, 2021). Li et al. (2023) conclude that steering could be a more efficient collision-avoidance strategy for e-scooters than braking in a front collision scenario.

E-scooters and bicycles also display different acceleration profiles. Throttled acceleration as found on most e-scooter models, is more rapid and responsive than pedal-powered acceleration, even in cases where it is motor-assisted. In most cases of the latter, pedal torque-input linked acceleration is smoother and less sudden than torqueless motor engagement.

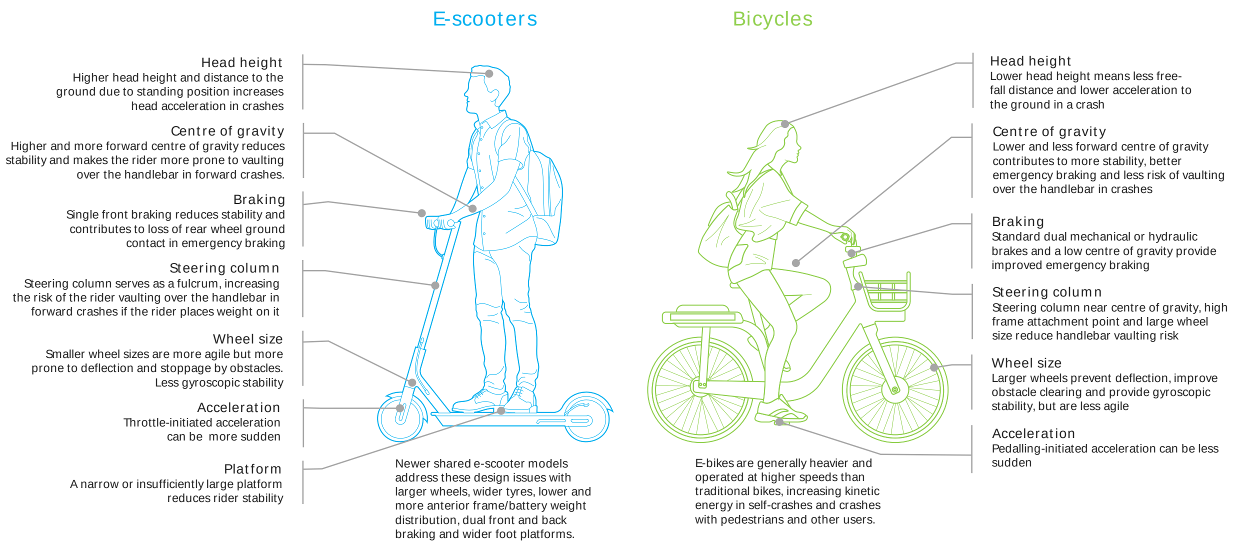
Ensuring visibility and audibility on the road is paramount for the safety of both micromobility riders and pedestrians. Bikes often come equipped with front and rear lights, offering visibility in various lighting conditions, while pedal and wheel reflectors offer extra visibility. In contrast, e-scooters often feature just a single headlight, and due to their small wheel size, side reflectors show small movement. Without turn indicators on most e-scooters, riders risk instability when resorting to hand signals, unlike bike riders who maintain stability during such manoeuvres due to the gyroscopic effect of the larger wheels. This discrepancy underscores the importance of a well-lit path for safe e-scooter operation and accentuates the need for robust lighting standards across micromobility vehicles. Furthermore, both e-bikes and e-scooters should incorporate auditory signalling devices, such as bells, to alert other road users to their presence, enhancing overall road safety.

In addition to the above design features, it is essential to consider the impact of combined vehicle-rider weight on micromobility safety. Considering the standing riding position of the e-scooter rider and the fact that the overall average weight of the scooter (15-30 kg for private and up to 55 kg for rental (PACTS, 2021) is less than the average weight of the rider, the position of the rider drastically impacts the centre of gravity of the vehicle (Garman et al., 2020). Leoni et al. (2022) suggest that, when riding on the same surface with a similar road profile, a vehicle's weight plays a critical role in dampening vibrations and enhancing stability. E-scooters with the same wheel size but greater weight are found to be more stable. Also, a heavier e-scooter (31.5 kg) demonstrates superior braking performance when compared to its lighter counterpart (11.3 kg) (Li et al., 2023). This underscores the significance of engineering considerations that balance weight and performance to ensure a safe and comfortable riding experience.

The collective findings imply that a holistic consideration of multiple factors, including rider size, vehicle dynamics, and environmental conditions, is crucial for understanding and mitigating head injury risks in micromobility.

Finally, it should be noted that standing e-scooters usually pose physical accessibility challenges for those with mobility-related disabilities as compared to seated e-scooters, bicycles and tricycles, but for some people, they may be more easily accessible. Ongoing debates surround the regulatory classification of seated e-scooters, with additional intricacies arising when considering distinctions between fixed and removable seats (National Academies, 2023).

Figure 3. Various e-scooter and bicycle characteristics and safety



In conclusion, this chapter underscores the paramount importance of safety in micromobility and extends the discussion to encompass the broader implications of vehicle design features. Compliance with established standards, the incorporation of larger (front) wheels and both active and passive suspension and wider e-scooter foot platforms, optimisation of braking systems, and the implementation of effective lighting and auditory signalling mechanisms all play crucial roles in enhancing the safety of e-scooters and e-bikes. These measures are vital for fostering the responsible growth of micromobility in urban environments, ensuring that these modes of transportation contribute positively to modern urban mobility while minimising risks to riders and all road users alike.

Summary of Key Micromobility Risk Factors

This section provides a **comprehensive synthesis of the key risk factors** associated with micromobility, shedding light on the multifaceted challenges that must be addressed to ensure the safe integration of micromobility options into urban landscapes. A systematic analysis of key factors, behaviours, and regulatory considerations provides a holistic understanding of the safety landscape, paving the way for effective recommendations and informed decision-making.

Speeding (Fu1) emerges as a significant concern, as excessive travel speed of both micromobility modes and other vehicles (in particular trucks, vans and cars) has been identified as a key risk factor for e-scooter and e-bike injuries. Riders who exceed safe speed limits are more susceptible to crashes, making it crucial to address this issue for reasons of fairness, particularly in privately-owned micromobility devices (but also in all vehicles) lacking geofencing technology present in shared counterparts. Managing speeds of other vehicles is essential for reducing micromobilty crash risk. The **use of helmets** (Fu2) and, in particular – the use of appropriate helmets for e-scooter riders is another critical factor. Additionally, the **influence of alcohol and drugs** (Fu3), mainly among e-scooter riders, is a significant concern, as riders under the influence are more likely to be involved in injury collisions and are more likely to suffer serious injuries.

Visibility (Fu4) also emerges as an essential safety factor, with nighttime and reduced lighting conditions being positively correlated with both injury and fatal crashes. **Low rider experience** (Fu6) is a recurrent factor in e-scooter collisions, contributing to most crashes, with falls being a prevalent consequence. Furthermore, **mobile phone use** (Fu7) while riding is a distraction that can impair a rider's focus and reaction time. **Rider stability** (Fu8) is a key contributory factor to crashes and falls and is linked to parameters such as the rider's position, vehicle dimensions and riding experience.

Poorly maintained roads and unpaved surfaces (Fi1) are linked to a heightened crash risk. Particularly concerning is that these infrastructure-related issues often result in falls, further emphasizing the need for infrastructure improvements to bolster rider safety. The **riding location** (Fi2) can also influence crash probability, with intersections and sidewalks the least safe locations due to high conflict rates, indicating the necessity for urban planning and regulations that address the integration of e-scooters into pedestrian-dense areas. Lastly, the risk for other road users is heightened by e-scooters being **parked inappropriately** (Fi3).

Larger wheels (Fv1) contribute to stability and vehicle control, as does centring weight lower and further back. **Optimized braking systems** (Fv2) enhance a rider's ability to slow down or stop safely. Setting appropriate **maximum speeds** (Fv3) for e-scooters and e-bikes helps prevent excessive travel speed, a significant risk factor for e-scooters, e-bikes and pedestrian injuries. Shared micromobility incorporates geofencing technology, capping shared e-scooters and e-bike speeds to a defined maximum threshold (20/25 km/h in the EU) in designated "low-speed zones". The existence of effective **lighting and auditory signalling** mechanisms (Fv4) ensures visibility and communication with other road users, reducing the risk of crashes in low-light conditions or situations where awareness is critical. Finally, optimizing the width of the e-scooter's **foot platform** (Fv5) can greatly enhance safe riding by providing improved stability.

Additionally, the **availability of micromobility safety data** (Fm1) and **exposure data (kilometre or time travelled)**is crucial for informed decision-making and effective policymaking. Consistently gathering and analysing data on micromobility crashes, injuries, and near-miss incidents can provide valuable insights into the root causes and patterns of these events and address the under-reporting. Promoting **post-care** (Fm2) for micromobility riders can offer a safety net in case of crashes.

In summary, a **holistic approach** that combines safe riding behaviour, improved infrastructure, vehicle design standards, and safety data collection is essential to mitigate the crash risks associated with micromobility in our urban environments.

The table below outlines these main risk factors primarily associated with e-scooter riding and to some extent, with e-bikes as well. It also underscores the **correlation** between these risk factors and road users, infrastructure, and micromobility vehicles.

Table 6. Key micromobility risk factors.

Code	Risk Factors	Safe Users	Safe Infrastructure	Safe Vehicles
Fu1	Speeding	● high	● medium	● high
Fu2	Helmet use	● high	● low	● medium
Fu3	Under the influence	● high	● low	● low
Fu4	Visibility	● high	● high	● high
Fu5	Double riding	● high	● low	● low
Fu6	User experience/ Riders age	● high	● medium	● high
Fu7	Mobile phone use	● high	● low	● medium
Fu8	Rider's stability	● high	● high	● high
Fi1	Poor road infrastructure	● low	● high	● low
Fi2	Riding location	● medium	● high	● low
Fi3	Parking	● high	● high	● low
Fv1	Wheel size	● low	● low	● high
Fv2	Maximum design speed	● low	● low	● high
Fv3	Braking system	● low	● low	● high
Fv4	Lights and auditory	● low	● low	● high
Fv5	E-scooter foot platform	● low	● low	● high
Fm1	Micromobility safety data availability	● high	● high	● high
Fm2	Post - care	● high	● high	● high

●high correlation, ●medium correlation, ●low correlation

Recommendations

Safety Recommendations for Authorities

Safe Infrastructure

Establish micromobility parking policy and designate parking areas where needed

Authorities should formulate consistent micromobility parking guidelines that enhance its use. This includes establishing clearly delineated parking zones for e-scooters and bicycles in high-traffic areas. These should be placed at the curb or, where legal and where it does not impede pedestrian activity, in pedestrian or shared zones. Their implementation requires uniform and systematic enforcement. It also involves careful planning and traditional and digital signage to guide riders to these designated zones. This ensures that parked micromobility vehicles do not impede pedestrians, contributing to safer urban environments. Authorities should simultaneously enforce motor vehicle parking policy to ensure micromobility infrastructure and parking zones are not encumbered by illegally parked cars, vans and trucks. Shared micromobility parking should allow sufficient access for operators' support cargo bikes and vans. Safe Infrastructure

Proactively maintain micromobility infrastructure

Authorities should implement proactive and regular maintenance for micromobility infrastructure, shared paths and road surfaces, with priority in high micromobility traffic areas. Proactive maintenance ensures that infrastructure elements like bike tracks, sidewalks and roads remain in good condition. This minimises the risk of crashes caused by potholes, debris or poorly maintained surfaces. Prompt reporting of infrastructure issues by road users and near-crash hot spots by micromobility operators contributes to efficient, proactive maintenance. Implementing this measure could reduce falls, a major contributor to e-scooter and (e-)bike-related injuries, and facilitate a smoother learning curve for inexperienced e-scooter riders.

Establish a dedicated and well-connected micromobility network

Authorities should develop a comprehensive urban plan incorporating mixed and protected micromobility infrastructure, ensuring connectivity with existing transportation networks. Specific focus should be given to junction treatments to ensure increased visibility and awareness for car and truck traffic. Seamless connections with public transport, sidewalks and shared mobility services should be encouraged to create a well-connected micromobility network. The effective implementation of this recommendation can reduce collisions of micromobility vehicles with motor vehicles (especially in junctions) and pedestrians on sidewalks.

Safe Riders

Implement a 30km/h (or lower) speed limit in areas with high micromobility use

Authorities should default to a 30 km/h (or 20 km/h) speed limit for car and truck traffic in areas with high micromobility traffic. Lowering the speed limit to 30 km/h or lower provides a crucial safety buffer, allowing motorists to react more effectively to unexpected situations and reducing the severity of potential micromobility vehicle-motor vehicle collisions.

Establish low-speed limits for micromobility vehicles in pedestrian or shared zones

In areas where micromobility riders legally can or must share pedestrian spaces, authorities should default to establishing a safe (~6-10 km/h) speed limit for micromobility modes to enhance pedestrian safety. Implementation involves clear signage, providing access to geospatially-referenced speed control zones. It also involves educating road users on speed limitation rules and enforcement to reduce the risk of crashes and conflicts. This ensures a safe co-existence between micromobility riders and pedestrians.

Take enforcement action against risky micromobility riding

Authorities should impose penalties for illegal micromobility riding, including:

- speeding for micromobility vehicles in speed-restricted zones,
- riding under the influence of drugs and alcohol,
- riding under the age limit,
- riding with two or more people,
- riding on sidewalks when it is forbidden,
- riding outside designated infrastructure where its use is obligatory,
- illegal parking.

Authorities should define a common limit for alcohol and drug levels and establish minimum age requirements for micromobility.

Promote the use of appropriate helmets

Authorities should encourage helmet use for private and shared micromobility in a way that does not discourage using active micromobility, which would diminish overall health benefits. Further research is needed regarding closed-face helmets or equivalent protection to protect against maxillofacial injuries common in e-scooter crashes. Authorities should require adapted helmets for riders of high-speed e-scooters and e-bikes (e.g. with a maximum speed between 25 km/h and 45 km/h and above).

Introduce rider education in secondary schools

Micromobility training should be integrated into the curriculum of secondary schools. Introducing micromobility training at this level equips students with the knowledge and skills necessary for safe and sustainable urban mobility. Implementation should involve developing age-appropriate micromobility training modules, training qualified instructors, and integrating these lessons into the school curriculum to ensure students are well-prepared for micromobility usage.

Safe Vehicles

Set universal technical requirements for e-scooter design

- Establishing and joining technical standards for e-scooters is essential. E-scooter standards should account for the following:
- maximum speed (e.g. <20/25 km/h. Vehicles operating at higher speeds would be regulated differently and more stringently)

- maximum power (e.g. <250-500 W. Vehicles with higher power should be regulated differently and more stringently)
- minimum wheel size (the larger, the better)
- foot platform area (e.g. at least 150 cm2)
- dual, separate and hand-initiated braking systems
- independent front and rear lights
- indicator lights (due to the difficulties of using hand signals)
- reflective markings
- phone attachment feature.

Further investigation into the impact of weight on e-scooter safety is needed due to the limited current data and potential implications on collision energy.

Adopt riding support systems in micromobility vehicles

Authorities should foster the adoption of riding support systems in micromobility vehicles, including automatic emergency braking assistance, audible warning devices providing alerts when speeding, detection technology capable of assessing factors like unsteady movement, occupancy detection sensors and alerts when inappropriately parking.

Safe management

Establish and collect data on distinct micromobility categories in safety statistics

Creating distinct categories for each micromobility mode (i.e., conventional bikes, e-bikes, e-scooters, speed e-scooters/e-bikes, monowheels/e-unicycles) in road traffic casualty records, including police records and medical records, improves safety assessment. Micromobility-related incidents are often grouped under broad categories, making it challenging to track and understand the specific risks and injuries associated with these modes. Additionally, collecting exposure data for each category is essential to calculate casualty risk accurately.

Safety Recommendations for Operators

Safe Infrastructure

Establish collaborative partnerships with authorities for infrastructure condition reporting

Micromobility operators collect valuable data on potholes, falls, and near-crashes through in-vehicle sensors. They should use this information to help authorities proactively maintain urban infrastructure by identifying and reporting areas with subpar road conditions. This effort, fuelled by data-driven insights, contributes to maintaining and improving micromobility infrastructure, ultimately enhancing overall safety for riders and pedestrians. Additionally, operators should initiate programs to evaluate the effectiveness and costs of this reporting.

Integrate parking zones in shared micromobility apps and deploy smart docking in high-traffic areas

Shared micromobility apps should onboard designated parking areas and restrictions. Deploying smart docking and charging stations in high pedestrian or vehicular traffic zones can reduce obstruction on sidewalks. This ensures convenient access to charged shared micromobility vehicles. Such hubs could also minimise the use of vans or other vehicles for re-positioning, swapping batteries or otherwise re-charging shared micromobility fleets, which may impose additional risks on all road users. Also, operators can reinforce responsible parking, e.g. by offering rewards for users who comply with parking requirements or in docks if these are available.

Safe Riders

Provide safety feedback via telematics data

Operators can use telematics data on speeding, acceleration/deceleration or distracted riding to provide riders with post-trip feedback. This feedback gives riders insights into their habits and opportunities for operators or insurers to incentivise safe behaviour. Real-time safety alerts to riders could also be considered where these do not contribute to rider distraction. These alerts detect risky riding behaviours and notify riders of speed limits, especially in high-risk areas like sidewalks and junctions. Operators should explore how real-time safety alerts impact micromobility safety.

Provide economic incentives for safe riding

Shared micromobility operators may encourage helmet use with economic incentives such as providing free helmets or discounts to encourage safety-conscious ridership. They can also discourage inappropriate parking and alcohol- or drug-impaired riding with incentives or automatic vehicle locking, pending a better understanding of the necessary costs and potential public and private funding schemes.

Implement mandatory initial rider training

To enhance rider safety, shared micromobility operators can require new riders to pass through in-app safe riding screens for the first few rides they make to help ensure that riders are familiar with local rules and guidelines before embarking on their e-scooter trips.

Verify age to start riding

Operators should implement age verification procedures to ensure riders meet the minimum age requirements defined in each city, ensuring compliance with local regulations and safety standards.

Safe Vehicles

Ensure systematic maintenance of micromobility fleets

Operators should maintain their fleets in good repair and follow state-of-the-art maintenance protocols, emphasising regular checks and upkeep of essential components, including brakes, lights and batteries. This approach ensures the vehicles' continued safety and optimal performance, enhancing the micromobility service's overall reliability.

Enable context-dependent maximum speed control using geofencing

Shared micromobility operators can employ geofencing technology to smoothly and dynamically lower maximum speeds to designated speed limits in high-risk zones, such as pedestrian areas or during risky hours like nighttime, prioritising safety for all road users.

Restrict e-scooter access if tandem riding and/or alcohol use is detected

Shared micromobility operators should be encouraged to incorporate in-vehicle sensors to detect tandem riding and introduce in-app tests to identify users under the influence of alcohol and drugs. If violations are detected, e-scooter access can be disabled, ensuring responsible and sober usage.

Implement riding support systems in shared e-scooters

Operators should be encouraged to implement safe riding support systems in e-scooters, including automatic emergency braking assistance and detection technology capable of assessing factors like unsteady movement, tandem riding and inappropriate parking.

Safe management

Enable in-vehicle or in-app crash detection technology

Shared micromobility operators can enhance the safety and user experience of their services and address the low availability of micromobility crash data by integrating crash detection technology into their vehicles or mobile applications. In cases where the technology detects a potential crash and the user does not respond within a specified timeframe, the app can automatically notify emergency services (e-call). Micromobility operators can establish partnerships with local emergency services, medical facilities or roadside assistance providers to ensure a swift response to detected crashes and improve the effectiveness of this app feature. However, it is crucial to conduct research and pilots to prevent the overexposure of false calls to emergency services.

Conclusion

This report examines and synthesises the most recent and key micromobility safety trends and risks and formulates safety recommendations for both authorities and micromobility operators regarding both privately owned and shared micromobility vehicles, with a particular emphasis on e-scooters and e-bicycles (e-bikes). The analysis and formulation of safety recommendations are guided by the principles of the Safe System Approach, with the primary goal of enhancing safety standards and proactively addressing the inherent risks associated with the entire micromobility ecosystem. This comprehensive approach encompasses all facets, including riders, infrastructure, and vehicle design, ensuring a holistic and effective strategy to mitigate safety challenges.

The uptake of micromobility vehicles, including e-scooters and e-bikes in many cities, has ushered in significant changes in urban transportation, presenting new and pressing challenges for policymakers and stakeholders. This transformation coincides with a growing public concern surrounding an increase in micromobility-related crashes. Crashes involving e-scooters and e-bikes are increasing, though so is their use. Injuries from these crashes are also increasing and are sometimes serious or fatal. E-scooter, and in some instances, e-bike crashes and injuries are different from those involving conventional bicycles, suggesting the need for targeted safety measures. Nonetheless, a relatively small percentage of micromobility collisions results in severe injuries or fatalities. Where good quality data on both crashes and exposure exist, e-scooter crash risk has diminished as e-scooter travel volumes outpace the growth of injuries requiring medical attention. This is especially the case for shared e-scooters, whose speeds are capped at 20-25 km/h. Generally, however, comprehensive and comparable data across both shared and privately owned e-scooters (including those that can travel up to 45 km/h) is not largely available. Private and shared micromobility safety analysis would highly benefit from the existence of more consistent and available exposure and safety data to ensure more reliable risk estimations for injuries and crashes – especially for e-scooters and e-bikes.

This report underscores the multifaceted nature of micromobility and, particularly, e-scooter safety. E-scooter-related incidents predominantly involve single road users, resulting in falls and collisions with stationary objects. Pedestrians are injured through collisions with either moving or stationary e-scooters. The gravest danger emerges from conflicts between micromobility vehicles and larger motor vehicles, often leading to fatalities. All of these factors contribute to depressing potential demand for travel by e-scooter or other forms of micromobility, even though a relatively small percentage of micromobility crash injuries are severe and require hospitalisation. Nighttime riding, drug or alcohol-impaired riding, riding in traffic lanes or on sidewalks and encountering poorly maintained road surfaces all contribute to elevated crash and injury risk. Helmet use is low among injured e-scooterists, and this contributes to the frequency, severity and type of reported injuries. Vehicle design plays an important role in crash occurrence and severity, with e-scooters displaying different and less stable characteristics than bicycles. Shared e-scooter designs have evolved rapidly to incorporate safety-improving features and make these available to riders.

When it comes to e-bikes, much of the safety data concerns Europe, where multiple studies conclude that there are no significant differences in the overall safety of e-bikes compared to that of conventional bikes, though the increased speed at which they are operated has been seen to be a factor in the types of injuries that have resulted from crashes.

In the case of e-scooter safety, surrogate safety-based analyses have proven very useful as they shed light on user behaviour and provide kinematics data on unsafe behaviours (e.g., helmet use). Surrogate safety studies have the potential to provide additional datasets to assess micromobility safety. Reviewed studies on both micromobility modes provided insightful information on unsafe behaviours, while they also have the potential to provide exposure-related information. Due to advances in technology, surrogate safety methodologies and analyses are expected to further grow.

The type and mechanism of micromobility collisions, in addition to the identified risk factors, suggest that many crashes and injuries are preventable if appropriate actions are taken by authorities and micromobility operators. In this context, this report outlines specific safety recommendations for both micromobility operators and local authorities, which are classified into four pivotal domains: safe infrastructure, safe riders, safe micromobility vehicles, and safe management.

Authorities bear a crucial responsibility in fostering the safety of micromobility users and integrating micromobility seamlessly into urban transportation systems. By prioritising safe infrastructure, authorities can enhance micromobility safety by implementing proactive maintenance, creating dedicated, safe and connected micromobility networks, and establishing designated parking areas for micromobility vehicles. These measures not only reduce infrastructure-related risks but also promote safer coexistence between micromobility users and pedestrians. Traffic rules enforcement, including lower speed limits for motorised traffic and for micromobility modes on pavements/sidewalks (where allowed), enhances safety. Helmet use promotion and rider education in secondary schools contribute to safer riding. Furthermore, setting universal technical requirements for e-scooter design and promoting the adoption of riding support systems in micromobility vehicles can significantly reduce risks. Creating a distinct micromobility category in road traffic casualty records improves data collection and accountability. In collaboration with micromobility operators, authorities play a pivotal role in creating safer and more sustainable urban environments.

Micromobility operators play a significant role in ensuring the safety of micromobility users and enhancing the overall urban mobility experience. By embracing a proactive approach, operators can actively contribute to micromobility safety through measures such as infrastructure condition reporting, promoting the use of parking corrals, deploying smart docking and charging stations, and offline safety feedback via telematics. These strategies not only promote safer riding practices but also enhance user convenience. Moreover, by offering economic incentives for safe riding, mandating rider training, and employing geofencing technology, operators can substantially mitigate risks associated with micromobility usage. The adoption of riding support systems in shared micromobility vehicles further bolsters safety efforts. Lastly, by integrating crash detection technology into their applications, operators can swiftly respond to incidents, ensuring timely assistance when needed. Micromobility operators are key partners in shaping a safer, more efficient urban mobility landscape.

While the literature on e-bikes is relatively sparse and does not fully reflect current levels of e-bike usage, much of what improves the safety of e-scooters and conventional bikes will also improve the safety of e-bikes as well (e.g., the presence of bike lanes, the presence of lighting, speed control software, etc.).

Effective application of these recommendations for safer micromobility must always be context-dependent and address local needs and desires. With a concerted effort from all stakeholders, micromobility safety can be improved.

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