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E-Micromobility Safety Assessment

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1 Introduction

The emergence of micromobility, a new transportation mode based on small personal mobility vehicles, can contribute notably to urban transportation sustainability, by decreasing conventional traffic congestion and associated pollution problems, providing a better access to public transportation and allowing an energy efficient mobility. However, the sudden introduction of micromobiles in large cities, notably electric kickscooters delivered by sharing service companies, has created some integration and safety problems in the urban space. Safety is one of the micromobility concerns influencing its social acceptance and long-term growth. For this reason, a micromobility safety analysis has been included among MOBY project tasks. Although micromobility includes different types of vehicles such as bicycles, small cargo and single wheel vehicles, the safety study has been focused on electric kickscooters, also known as e-kickscooters or simply e-scooters, since it is the vehicle experiencing the fastest growth ever seen in the urban scene [1]. Moreover, little knowledge on e-kickscooters safety is available in comparison with more experienced vehicles such as bicycles. Micromobility safety depends on many aspects such as, among others, regulations, vehicle design, users' protection and urban infrastructure, including urban road/lane design but also specialized telecommunications and signalling concepts known as Intelligent Transportation Systems (ITS). In addition, several available techniques and technologies can be used to offer additional safety protection.

For these reasons, the Safety Analysis Task has addressed three main objectives:

- Analyse and better understand the safety problems of micromobility, particularly those related to the e-kickscooters, with intrinsic safety problems compared to the case of more experienced vehicles such as bikes or mopeds.
- Assess the impacts of urban infrastructure on micromobility safety, considering both urban space such as road/lane design, including also Intelligent Transportation Systems (ITS) signalling and telecommunications infrastructures
- Assess the available technologies with high Technology Readiness Level (TRL) that can be used to effectively enhance the micromobility safety

The present output report contains the results of micromobility safety analysis, infrastructure assessment and the review of the available technologies considering the safety main priorities, allowing the proposal of effective safety measures.

A large number of documents has been compiled and reviewed in the micromobility safety analysis resulting in the Safety Knowledge Data Base with more than 400 references. The basic sources of micromobility safety information have been: specialised reports, scientific papers, news, official accident statistics, regulations, norms and standards, e-scooter sharing companies reports and surveys. Additional surveys have been prepared and distributed among mobility users, traffic accident investigation experts and urban mobility experts, providing additional information and better hazard recognition and understanding.

In addition, a group of experts on urban design, Intelligent Transportation Systems (ITS), vehicle design and production, vehicle power plant control, optical and radar sensors and software applications have contributed to the urban infrastructure assessment and the technologies review considering possible applications to micromobility safety.

From the safety analysis priorities, a set of safety enhancement measures has been proposed, considering the possibilities offered by recent technical advances.

2 Analysis of safety data

The analysis of safety data has been based on several sources of information. An extensive compilation of published data about e-micromobility safety has been carried out, which resulted in the MOBY Safety Knowledge Data-Base. The usual micromobility safety documents are: regulations at city or national levels, accidents and injuries statistics, reports from different traffic related bodies, scientific papers from transport researchers and news in newspapers and journals that pay special attention to micromobility, due in part to its novelty in comparison to conventional transport modes

Statistical information often does not reflect minor accidents and light injuries not requiring the involvement of Police or Medical treatment. For this reason, user surveys are valuable complementary sources of information allowing to reflect the users' safety perceptions with strong influence in the evolution of micromobility. In the MOBY project a user survey has been carried out in Task 2002 which contained several safety related questions proposed in the Safety Analysis Task. In addition, a police survey was designed to better understand the main causes of accidents and severity of injuries. From this information, the main accident types and related injuries have been categorized, identifying the main causes and related factors. Finally, the participation in the European City Dialogue on Micromobility Workshop allowed to present the main MOBY safety analysis results and obtain the opinions of participants on several safety related aspects. The most relevant outcomes are presented in the following sections.

2.1 Present safety regulations

From 2018 urban traffic regulations issued by national, regional and municipal authorities had to quickly adapt to the challenges and conflicts created by the fast increase of micromobility, especially e-kickscooters in urban areas. Without previous experience or guidelines and little time to evaluate pros and cons, every country/city adopted very different strategies on micromobility regulations, from tolerance with simple informal instructions based on existing bicycle rules to more formal regulations including a strict control on vehicle characteristics and restrictions on the use of urban public space. The safety impact of regulations is evident since many aspects are regulated with the purpose to increase the safety of riders, pedestrians and users of other types of vehicles.

Regulations have special provisions for each type of vehicle. We will analyse the regulatory diversity of e-kickscooters, since the vast majority of present micromobility vehicles belong to this class. Table 2.1 and Table 2.2 show the comparison of basic safety regulations including **Minimum age**, **Plate/Insurance requirement**, **Maximum speed of vehicle** (electronically limited), **Vehicle Certification**, **Allowed lanes** and

Helmet use. It has been observed that regulations are permanently under discussion and as a consequence, they are frequently revised. Relevant examples of regulatory changes are the introduction of compulsory use of helmets and insurance/plate in Tel Aviv along the year 2020, the authorization of first e-kickscooter trials in UK from July 2020 [7] and the recent decision to exclude e-kickscooter services and parking from Copenhagen city centre from January 2021 [8].

Regulation	Germany (Munich)	Spain (Barcelona)
Minimum Age	The minimum age for driving vehicles type A (scooter with handlebar and no seat) is 14 years old.	The minimum age for driving PMVs or cycles is 16 years in all cases.
Plate/Insurance	An insurance is mandatory and a sticker with identification code must be visible in rear side of vehicle.	If the use of the vehicle is personal, the insurance is not mandatory but recommended.
Maximum speed	The maximum speed of type A and B VMPs is 20 km/h in all cases.	Type A and B maximum speed is 25 km / h
Vehicle Certification	Vehicle types must be certified according to the German Personal Light Electric Vehicles Ordinance (eKFV), including stability, braking, max. speed and other tests.	Not specified. Recommended reflective elements, lights and bell
Allowed lanes	Sidewalks and pedestrian areas not allowed	Type A No allowance on sidewalks except on painted bicycle lanes at max. 10 km/h. Use bicycle lanes on roads when available, pedestrian areas and parks allowed at max 10 km/h, allowed on streets limited to 30 km/h.
Helmet use	Helmet is recommended	Helmet is recommended

Table 2.1 Safety related regulations comparison between Munich [4] and Barcelona [3]

Regulation	Denmark (Copenhagen)	Israel (Tel Aviv)
Minimum Age	15 years old	16 years old
Plate/Insurance	Recommended but not required	Sharing companies must provide insurance and identification plates.
Maximum speed	20 km/h	25 km/h maximum speed. In some areas the maximum speed allowed is 15 km/h.
Vehicle Certification	CE Certified. Reflective elements, white and red lights and reflectors on front/back parts sides. Yellow or white reflector on vehicle sides.	Reflective elements, lights and bell
Allowed lanes	Bicycle rules apply in general. Use cycle paths if available. Riding on sidewalks, city centre, footpaths and pedestrian areas is not allowed	Riding on sidewalk is not allowed. Riding is only permitted on the right side of the road (if no bicycle lanes are available)
Helmet use	Helmet is recommended	Helmet is mandatory, reflective vest must be used in dark conditions

Table 2.2 Safety related regulations comparison between Copenhagen [5] and Tel Aviv [6]

A very relevant regulatory step has been the publication of the Personal Light Electric Vehicle Ordinance (eKFV or PLEV) from German Ministry of Transport (BMVI) which is available in English as an EC Notification [4]. The Ordinance, besides basic use regulations, include a complete list of technical requirements such as dimensions, weight, power, speed range, braking capability, lights, optical reflectors, characteristics of insurance plate and a set of stability tests in front of surface alterations and kerbs that the vehicle must pass to become certified for legal circulation in German public space. This Ordinance has inspired other countries requirements for e-kickscooters technical requirements, like recent e-scooter trials UK guidance [7] and may become the basis for a future European safety standard for these vehicles.

One of the problems of micromobility regulations is to achieve appropriate diffusion and knowledge among users. To achieve a better comprehension from public, some administrations have issued infographic descriptions of the essential regulations [3], [9]. Fig. 2.1 reproduce infographic information of essential micromobility regulation in Germany.

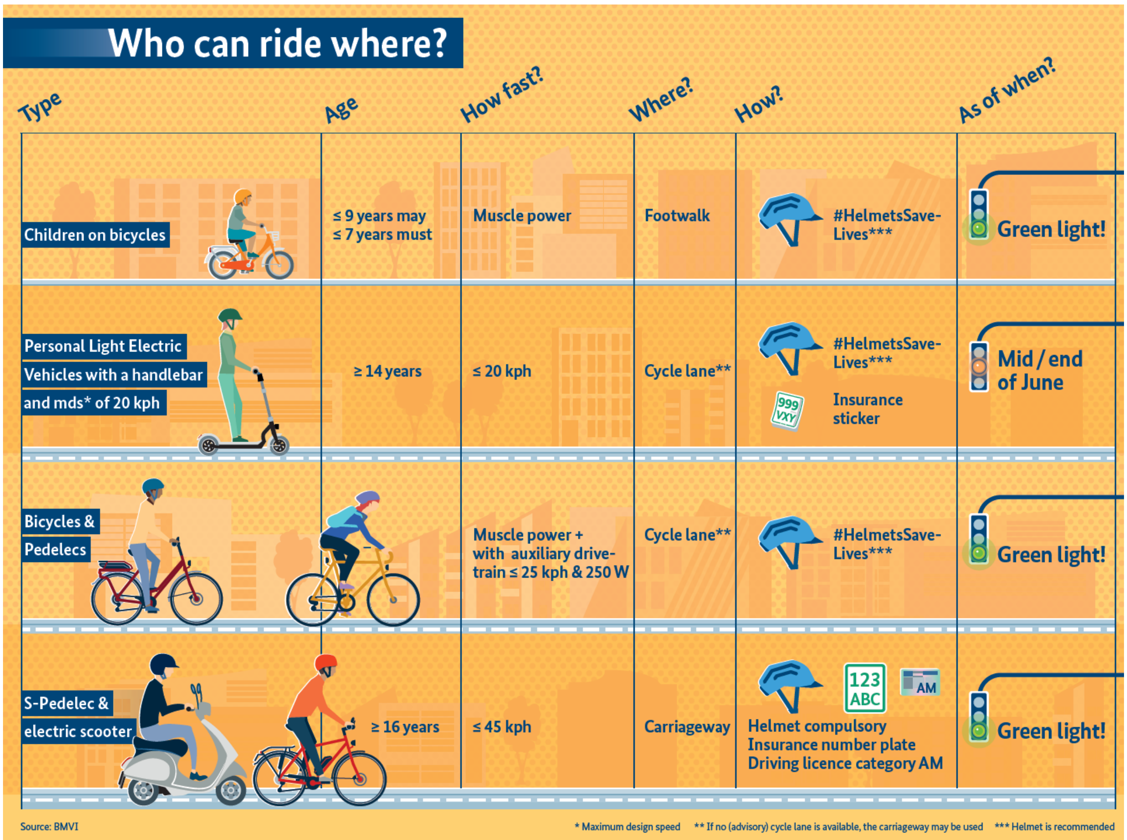


Fig. 2.1 Basic German regulation of micromobility [9].

2.2 Micromobility official safety statistics

The official accidents statistics are generally provided by national, regional or local mobility administrations in format of annual tables and summary reports. Due to the recent introduction of e-micromobility these vehicles are often classed in “Other Vehicles” categories, complicating the interpretation of statistical data. Fortunately, from 2019 an explicit e-kickscooter class has been introduced in most statistics. However, the short history of data makes it difficult to make comparisons between different locations, recognize trends and extracting conclusions.

The official figures usually report severe accidents with injuries and/or damages. A significant number of minor accidents are not communicated to police and become under-reported.

Another problem with most safety statistics is the lack of information on the causes of accidents. This information is crucial to improve regulations, such as use of helmets or vehicle certification and inspection, deploy and maintain the city infrastructure and the proposal of new safety measures. The accident statistics of several cities participating in the project have been considered in this study. Table 2.3 shows the number of reported accidents in 2018 and 2019 [10] in Barcelona. The statistics show a large increase of e-micromobiles' incidents. Accidents from 2018 to 2019 have multiplied by a factor of 380%. It is interesting to note that Barcelona authorities have not issued sharing licenses to interested companies, prohibiting parking e-kickscooters in public space. Consequently, most vehicles are privately owned with a continuous and progressive growth of the circulating fleet from 2018. The numbers of vehicles and rides in 2018 and 2019 are not known which does not allow to estimate the evolution of accident probabilities

Vehicles implicated	2018	2019
Cars	7,710	7,426
Motorcycles	6,091	6,063
Vans	1,248	1,228
Moped	890	951
Taxi	988	637
Bicycle	786	796
Truck	447	417
e-micromobiles	**129**	**490**
Non-powered kickscooters	N/A	49
Others	803	919
TOTAL	19,039	18,975

Table 2.3 Number of accidents reported to Barcelona police in 2018 and 2019 with the different types of vehicles implicated.

According to the Central Bureau of Statistics of Israel [11], in 2019 there were 569 road accidents with casualties, involving electric scooters and reported to the police. 118 accidents were Expanded R.A. type (with at least one serious injured person) and the rest "General with Slight Casualties" type. This is in comparison to 220 accidents in 2018, of which 61 were Expanded R.A. type. In 2019, 598 people were injured in these accidents, in comparison to the 237 casualties in 2018. Of all the casualties in 2019, 2 were killed, 41 were seriously injured and 555 were slightly injured (see Table 2.4).

Severity of Injury	2018	2019
Casualties reported to the Police (2)	237	598
Killed	1	2
Seriously injured	21	41
Slightly injured	215	555
Casualties not reported to the Police (3)	49	209
Seriously injured	16	90
Slightly injured	33	118
Unknown	0	1

(1) All of the casualties (including pedestrians) in all the vehicles that were involved in a road accident with electric scooters.
(2) Expanded R.A. and "General with Slight Casualties"
(3) Severity of injury according to MAIS index.

Table 2.4 Injuries in Road Accidents in which e-scooters were involved, by severity of injury and year

In the Munich case the police reported a total of 103 traffic accidents involving e-scooters along approximately 6 months period from 15th of June up to 31st of December 2019 [13]. In the case of e-kickscooters there is no previous record of accidents to assess the safety evolution, nor estimation of the number of rides or distances covered. In 31 (30%) accidents it was found that e-scooter drivers were under the influence of alcohol. This high incidence contrasts with the percentage of bicycle accidents influenced by alcohol consumption which for the same period was 3.4%.

Accident severity	Number
Accidents with material damages	36
Accidents with injuries	67
Isolated accidents (falls)	50
Slightly injured	60
Seriously injured	8
Alcohol related accidents	31
Total number of accidents	103

Table 2.5 Traffic accidents reported to Munich police involving e-scooters from 15.06.2019 to 31.12.2019

Table 2.5 shows the incidence of accidents of different severity, there were no fatalities in the reported period involving e-scooters, although 8 persons were seriously injured. It is remarkable the strong impact of alcohol consumption in the 30% of the total of accidents. Also, the number of isolated falls is very high, as it can be seen in Table 2.6, accounting for almost one half of the accidents. As a reference the percentage of isolated falls with bicycles in the same period was 15.8% which indicates a poorer stability of the vehicle, lack of training, alcohol abuse or a combination of these factors.

In 88 (85%) of the 103 traffic accidents involving e-scooters, the e-scooter drivers were found to be the primary cause of the accidents. This is consistent with the main causes reported of accidents involving e-kickscooters shown in Table 2.7

Collided vehicle	Number (%)
Isolated fall	50 (48.5 %)
With cars	38 (36.9%)
With pedestrians	9 (8.7%)
With cyclists	6 (5.8%)

Table 2.6 Munich e-kickscooter collision table showing the percentages of other type of vehicles or pedestrians involved

Accident Cause	Number
Driver error	44
Influence of alcohol	31
Incorrect road use (sidewalk, pedestrian zone)	14

Table 2.7 Most common causes of e-kickscooter accidents in Munich

The preliminary accident figures from the Danish Road Directorate for 2019 [14] show that the police has registered 57 accidents with motorized scooters, of which 24 resulted in personal injury. For comparison, the police has registered 2042 accidents with bicycles, of which 740 had personal injuries.

A calculation of the accident frequency per travelled distance shows that for bicycles and motorized scooters there are respectively 0.01 and 0.07 accidents per 10,000 km. These results indicate that there is about seven times higher risk of accidents using e-scooters compared to bicycles.

The diversity of accident data formats makes difficult to compare the statistical information between cities. Accident numbers have increased notably from 2018 to 2019 which is to be expected due to fast growth of e-kickscooter fleets. There are significant differences among the considered cities, since Munich and Copenhagen e-kickscooters are mostly shared, whilst in Barcelona the vast majority of e-scooters are privately own. Tel Aviv has a mixed fleet where both shared and privately owned micromobiles coexist. A more standardised format to report micromobility accidents and an estimation of vehicles fleets and number of rides and average distances travelled will make easier to compare among cities and extract more relevant information.

2.3 Safety reports from sharing companies

E-kickscooter sharing companies have the most accurate micromobility data, thanks to widespread deployment of fleets in many locations at continental or global scale. With GPS tracking of their vehicles and records of different types, operators are able to study in detail urban mobility patterns, trends and also safety. According to Bird data [15], e-scooters and bicycles have similar risks and vulnerabilities. Bird riders reported 37.2 injuries per million rides which is compared to an estimated rate for cyclists of 58.9 Emergency Department (ED) visits per million miles. These figures cannot be directly compared since sharing companies reports include minor injuries that do not require visiting EDs. On the other hand, US injury rates for bicycles are significantly higher than in Europe, with an estimated factor of 4.68 times injuries / million miles with respect to Germany [16]. Therefore, in Europe the safety risk of riding e-scooters per million miles may be higher than for bicycles.

The International Transport Forum (ITF) has elaborated an e-scooter safety study [2], which presents a one-year of reported e-scooter crashes' evolution. This trend, obtained by combining data from Bird and Tier e-kickscooter sharing companies is very positive with a remarkable reduction of crashes. After one year the number of reported crashes reduced in a factor of 6, from 140 crashes per million rides in September 2018, to 23 crashes per million rides on August 2019. This drastic reduction can be explained by several factors: improvements in vehicles and urban infrastructure, better regulations and information campaigns, as well as higher users' experience and safety awareness.

2.4 E-scooter accident injuries' analysis

Published studies on e-scooter-related injuries and accidents were examined to summarize accident circumstances, injury characteristics and factors associated with accident occurrences. The studies were retrieved through a detailed consideration of sources collected in the Moby Knowledge Data Base and additional searches in *Scopus* and *Science Direct*. In total, 17 peer-reviewed papers were summarized [17]-[33]. Further insights on e-scooter-related accidents and associated factors were learnt from a recent international report [2].

The studies were conducted in the USA, Australia, New Zealand, Denmark and Finland. Most studies analysed hospital data (ED visits; trauma registries), two studies examined media reports on e-scooter involving accidents [2], [32]. The studies reported consistently **an increase** in the number of related injuries following the introduction of e-scooter-sharing systems. Such increase stems from the increased exposure and can also be related to the period of initial adaptation to the new means [2]. The majority of reported injuries were minor and fatalities were rare but severe injuries did occur. The share of injuries that needed a hospitalization ranged from 5% to 30% in general samples of ED visits but was substantially higher in selected samples with head or facial trauma [29], [33], [28]. The latter actually showed a **potential severity** of e-scooter-related injuries which should be a function of impact speed, e-scooter configuration and lack of rider's protection. Similarly, media reports mostly highlighted serious and fatal injuries in e-scooter accidents, strengthening the need in separate and appropriate riding infrastructure in the city, strict regulations and enforcement of rider behaviours (such as helmet wearing, non-intoxication, safe speeds, respect of walking facilities).

Medical studies reported consistently that **head, face and extremity** injuries of e-scooter riders, with fractures/dislocations were common, indicating a need in helmets and other protective equipment for e-scooter users.

The extent of non-rider injuries – primarily pedestrians, was **low**, in the range of 1%-8% among all e-scooter-related injuries, except for a Danish study [21], which examined the total EMS records in the city and found 14% of pedestrian injury. The extent of motor vehicle involvement was low, up to 10%, in the general samples of e-scooter-related injuries (ED visits) but was substantially higher, 60% and over, in the samples with more serious injuries (hospitalized, killed). Similarly, the order of leading accident mechanisms was different dependent on the sample type: among general injuries (mostly minor), **falls** presented 80% and over, followed by collisions with moving or stationary objects; among severe injuries and fatalities, **hit by a vehicle** was the main cause followed by falls and striking an object (or another vulnerable road user). Many studies reported on low helmet use by e-scooter riders; the extent of alcohol (or drug) impairment among e-scooter users varied widely, from 4% to 91% (depending on country and sample type).

Based on injuries analysis and insights from the [2] report, the factors contributing to e-scooter accidents and injury can be summarized as follows:

- Motor-vehicle involvement in e-scooter accidents increases e-rider injury severity that is not surprising due to the differences in mass and protection between these road users. Among media reports, high shares of severe accidents were observed on arterial streets and intersections [32], i.e. at sites with higher vehicle traffic. Clearly, separate road infrastructure is needed for safe e-scooter riding.

- Pedestrian injuries are not frequent in e-scooter accidents but can be underreported. Pedestrians hit by e-scooters or tripped over parked scooters are commonly reported phenomena which indicate a need to separate e-riding facilities from sidewalks and footpaths.

- Helmet use is rare among e-scooter riders but should be increased to prevent severe head and facial injuries.

- Falls are frequent among e-scooter injuries which can be related to inappropriate road conditions and presence of obstacles in the vicinity of riding paths. This suggests that road surface should be improved by design and through maintenance.

- Additional reasons to falls may be in high riding speeds and insufficient experience of e-riders, the factors that should be treated by appropriate training and enforcement.

- Vehicle failures were not reported by e-scooter accident studies. However, due to high frequency of falls, e-scooter stability is considered as a design priority. The stability of e-scooters can be influenced by a number of design factors such as wheel size, tyre design, frame geometry, weight distribution and the presence of a seat and handlebar [2]. For example, greater wheel size can assist in negotiating poor road conditions. Obstacle detection systems and stability control solutions can enhance e-rider safety.

- Medical studies suggest that e-scooter design – a stiff handlebar, a possibility of high speeds and lack of rider's connection to the device, leads to high-speed falls over the handlebar or on the road pavement, with consequent head, face or extremity fractures and other injuries. The higher severity of motorized scooter injuries (compared to non-motorized scooters) supports this assumption [25]. Thus, a further improvement of e-scooter design is needed to diminish the risk of such scenarios.

2.5 Safety aspects of MOBY user survey

In Task 2002 of MOBY project, a detailed survey was prepared and managed by Budapest University of Technology and Economics. In total, 790 survey responses were filled in, from the following participant cities (with indication of the percentage of participation): Stockholm (29.4%), Copenhagen (19.6%), Munich (17.8%), Tel Aviv (17.0%), and Barcelona (16.2%).

In the context of this analysis the safety related survey results have been assessed. One of the aspects surveyed was the awareness and knowledge of specific laws or regulations on micromobility, which in fact in several countries and cities are in the process of development. Taking the cases of Munich and Barcelona that have published official regulations, 32% of the participants in these cities answered that they had no information on micromobility regulations. Since safety depends on the observation of regulations, it is clear that better awareness and knowledge of regulations should be reinforced, for example, by periodic information campaigns.

Another aspect asked was what were the users' main concerns on micromobility. It is interesting to note that the highest concern is **conflicts with pedestrians (55% of respondents)**, which is probably related by the second aspect of concern: **illegal parking (54%)**. It is also remarkable that 48% of users considers present micromobility **unsafe**.

The survey asked also about where the users would ride an e-micromobile. The first option is **Protected bike lanes (61%)**, second is **Painted bike lanes (47%)** and the third is **Separate lanes (38%). Sidewalks (6%)** was the less preferred option, which indicates that sidewalk riding may be a consequence of the lack of bike lanes combined with unsafe perception of riding on **streets** close to heavier vehicles.

The survey included a question on the aspects that should receive higher priorities in order to improve safety. The results, presented in Fig. 2.2 show that according to survey participants the higher priorities should be (in decreasing order): **Avoiding riding on sidewalks**, **Avoiding riding too fast or not paying attention** and **Avoiding e-micromobiles and bikes not properly parked or laying down**.

Fig. 2.2 Survey percentage of answers to the question “what are the most relevant aspects to improve the safety of micromobility?”

2.6 Accident causes analysis

From publications, reports and news compiled in the MOBY data base an exhaustive taxonomy of e-kickscooters accident causes has been carried out and presented in Table 2.8.

Primary cause	Code	E-scooter Incident/Accident Causes	Safety Impact
Vehicle	V1	Stem detachment/breakdown	*
	V2	Brakes failure or insufficient braking capability	
	V3	Bad acceleration control	*
	V4	Wheel too small/rigid to cope with pavement imperfections/transitions	*
	V5	Lack of vehicle visibility: to weak lights and/or lack of optical reflectors	**
	V6	Battery fire or explosion	
	V7	Other vehicle failures	
Driver	D1	Lack of experience (first rides)	**
	D2	Inappropriate driver age	***
	D3	Inappropriate speed	***
	D4	Driving on sidewalk or other pedestrian reserved areas	***
	D5	Driving on unsuitable lane: fast or dense car traffic	**
	D6	2 (or more) passengers on vehicle	*
	D7	Driving distracted or using mobile phone / headphones	**
	D8	Losing control or falling down from vehicle	***
	D9	Vehicle not properly parked or laying down	
	D10	Driving under influence of drugs or alcohol	**
	D11	Insufficient separation from other e-scooters or bikes (shared lane)	
	D12	Traffic signs or crossing priority not respected	******
	D13	Other driver related cause	
Road	R1	Bump, Hole or Obstacle on pavement	**
	R2	Confusing Signalling	
	R3	Frozen or Slippery pavement	
	R4	Insufficient lane separation from other vehicles or pedestrians	**
	R5	Other road related cause	
Other actors	O1	Pedestrian invasion of e-scooter lane	*
	O2	Other vehicle invasion of e-scooter lane	
	O3	Other vehicle not respecting traffic signs or crossing priority	***
	O4	e-scooter not seen and run over by faster/larger vehicle (car, bus, ...)	**
	O5	Other actor cause	

Table 2.8 E-scooter causes of accidents grouped in Vehicle, Driver, Road and Other actors classes, including the estimated safety impact from police survey results (Section 2.7).

Causes have been grouped into 4 main types according to primary accident cause: **Vehicle**, **Driver**, **Road** and **Other actors**.

2.7 The Police survey

Based on the identified accident causes, a survey asking about accident frequency estimation for each cause and severity of typical injuries was addressed to Traffic Police departments of Israel, Munich and Barcelona.

Munich, Barcelona and Israel provided statistical information. In addition, 22 experts on traffic accidents investigation filled a questionnaire to determine the most frequent causes of e-micromobility accidents and its severity.

After data processing, first the percentages of accidents caused by the four basic causes types estimated by accident investigators were determined showing that slightly **over one half of e-kickscooter accidents are caused by vehicle Driver (56%)**. **Vehicle (15%), Other actors (15%) and Road (14%)** have similar secondary incidences.

Zooming into accident cause detail in each class, the main Driver cause of accidents is **Traffic signs and priorities not being respected (18%)**, with a large difference from lower incidence causes such as **Losing control and falling down from vehicle (11%)**, **Inappropriate driver age (11%)** and **Driving on sidewalks and other pedestrian areas (10%)**. The rest of causes have slightly lower weights with the exception of **Insufficient separation from other e-scooters and bikes (3%)** which has a lower impact on accident number.

The analysis of detailed vehicle causes show the most problematic aspects are: **vehicle visibility in dark conditions (27%)** and **wheel size and characteristics to cope with pavement imperfections and transitions (27%)**. In lower priority, the survey identifies the **stem detachment or breakdown (17%)** and **bad acceleration control (15%)**.

Regarding Road causes, the survey shows that **insufficient lane separation from other vehicles or pedestrians (51%)** is estimated to cause around one half of the accidents related to road design and condition. In second position **pavement imperfections such as holes, bumps or obstacles (29%)** is estimated to cause almost one third of the road related accidents.

In the case of Other actors, the results show two causes with similar over 30% weight: **Other vehicles not respecting traffic signs or crossing priority (36%)** and **e-kickscooters overrun by faster/larger vehicles (33%). Invasion of e-scooter lanes by pedestrians (20%)** is also a relevant cause of accidents.

The safety impact of each identified cause category on micromobility safety has been estimated according to the product Accident Frequency x Injures Severity. In this survey, Severity has been obtained as an average of the Maximum Abbreviated Injury Scale (MAIS) [12], assigned to the typical injuries associated to each accident cause. **The Abbreviated Injury Scale is 0 : No injury, 1: Minor Injury, 2: Moderate Injury, 3: Serious Injury, 4: Severe Injury, 5: Critical Injury, 6: Unrecoverable/Death**. The Maximum Abbreviated Injury Scale, often used to express the severity of traffic accidents, refers to the worst injury suffered by the accidented person.

The resulting impact index normalized to a maximum value of 6 has been indicated with a number of stars in the right column of Table 2.8. The highest safety impact, well above the rest, corresponds to **e-kickscooters drivers not respecting traffic signals and priorities**. In second position of Safety Impact we found several causes: **Driving with inappropriate age or speed, Driving on sidewalks, Losing vehicle control and Falling and Other vehicles not respecting traffic signs and priorities**. In third position the survey identified **Lack of vehicle visibility, Lack of driver experience, Driving on unsuitable lane (fast or dense car traffic), Driving distracted or using mobile/headphones or Driving under the influence of alcohol, Pavement imperfections, Insufficient lane separation from other vehicles or pedestrians and Vehicle not seen and run over by larger vehicles**. These impact levels are important to prioritize safety improvement efforts addressing risks and hazards with higher costs due to higher probability and injuries' severity.

The survey included a question on the urban areas showing a higher accident frequency. **Crossings between micromobility lanes and conventional street car lanes (35%)** was identified as the most frequent location of accidents. In second position with similar safety incidence the survey identifies **Sidewalks and Crossings between micromobility lanes and pedestrians (23%) and Pedestrian reserved areas (23%)** appear to be also problematic. In lower positions appear **Pedestrian zones (15%)** and **Conventional vehicles lanes (4%)**.

Finally, the traffic investigation experts were asked to prioritise on different options proposed for micromobility safety improvement. The results are consistent with the aforementioned causes and estimated safety impacts bringing additional information. The first identified priority is the **obligation of wearing a helmet (12%)**, which is coherent with the high frequency of head/face injuries analysed in Section 2.4. The second priority is **Providing additional segregated lanes for e-micromobility (bicycles, e-scooters, etc.) (10%)** which is related to priority on **improving separation and protection of these lanes (7%)**. In fact, several high safety impact causes, such as, **Riding on sidewalks** or **Driving on fast/dense traffic ro**ads, are in most cases a consequence of the lack of segregated/protected micromobility lanes.

Other high priority improvements are addressed to increase both **Vehicle and Driver visibility in dark conditions (9%)**, by using more **intense lights, larger optical reflectors** and **using reflective clothing by drivers (9%)**. Complementary aspects with moderate priority are: **additional driver body protection measures (8%), beginner drivers training (7%), vehicle insurance and identification plates (7%) and better/larger vehicle wheels with improved tolerance to surface imperfections/transitions (6%)**. Additional 8 proposed improvements referring to vehicle, lanes and regulations were considered less relevant.

As additional safety improvements, which were not included in the questionnaire, the traffic accident experts suggested: **Enforcement of e-rider behaviours since frequently they do not follow traffic rules** and **requiring passing traffic rules test for drivers without driving license**.

2.8 The MOBY Workshop in European City Dialogue Safety Poll

On November 12th 2020, UnternhmerTUM and Roland Berger firms organised the European City Dialogue Day on Micromobility in Mediatech Hub Conference Facilities in Potsdam (Germany). A general micromobility presentation was followed by three workshops, one of them dedicated to present MOBY Project outcomes on Safety, Intermodality, Accessibility, Environmental issues and Sustainability. Due to COVID-19 restrictions, the conference participation was mostly on-line. The Micromobility plenary session attracted a large attendance of professionals with 70 participants. The MOBY workshop achieved the maximum capacity of 25 participants, which was limited to facilitate interaction and topic discussion. Several safety aspects, which are often under discussion, were presented and the audience was invited to vote among different options which are reproduced below. The discussed and voted topics involved **Helmet and reflective clothing usage, Lanes infrastructure, Insurance, Training and Regulations knowledge and harmonisation**.

There is a strong consensus on the benefits of using helmets and other protection measures like reflective clothing. However, there are arguments in favour or against making such use **compulsory**, considering that it may limit the transition to micromobility from cars or motorcycles. The option of information campaign is an alternative. Anyway, the most effective option to enhance urban safety may be culture depending and also influenced by the balance between users of sharing services with respect to users owning a vehicle. In the workshop most attendants voted for the **Information Campaign** (60%) option, the other 3 options: **Compulsory helmets**, **Compulsory helmets and reflective clothing** and **Other** received the remaining 40% of votes with equal share.

Several options of urban infrastructure were presented with examples, including segregated lanes with different degrees of protection, reducing the maximum speed of cars, buses, etc., to allow to share road lanes with bicycles and e-scooters, and creating additional lanes with superstructures and micromobility highways. Most of attendants voted for the option of deploy **More and improved bicycle lanes (73%)**. **Building micromobility highways (20%)** was considered with substantial lower priority and the less preferred option was **Sharing the road with heavier traffic with reduced speed to 30 km/h maximum (7%)**.

E-scooters are electrically powered vehicles and the need of having an insurance to cover personal and other vehicles' and pedestrian injuries in case of accident is gaining acceptation, in spite that in most regulations it is not required yet. Different insurance options were discussed and voted. The most preferred option was to include the micromobility insurance as an **extension supplement of existing insurance policies** such as house or conventional vehicle **(53%)**, **specific insurance obtained 27%** votes and **20% voted that insurance should not be required**.

Safety statistics shows that training of new users will reduce micromobility accidents. For this reason, several training options were discussed. A majority of attendants favoured the provision of **training facilities by sharing companies (40%).** However, this does not help users that own their vehicles. Including e-scooter **training at school age** will make sense, if the mobility share of e-kickscooters increases in the coming years, **33%** of the participants opined that was the best option. The option of a **Public offer of training facilities** received **13%** of votes.

The final discussion addressed the evolution of present regulations which are not known by a large percentage of users. In this context the existing regulatory diversity at country and city levels does not help a more widespread regulatory knowledge. After discussing different options **47%** of participants voted for stablishing a **Common European micromobility regulation**, **40%** voted for a **Common European regulatory framework allowing for certain flexibility in the implementation** depending on every city/country specific needs. The rest of participants **(13%)** preferred a **Location-specific regulation**.

2.9 Accident hazards mitigation using Intelligent Transportation Systems (ITS)

Over the last decade, the automotive market has witnessed remarkable developments in the vehicle safety domain. Vehicle safety systems have evolved from passive and active safety systems to Advanced Driver Assistance Systems (ADAS), which either alert the driver or intervene in order to avoid imminent collisions. These safety systems are, nowadays, evolving in two further directions. The first one is how they can be applied to smaller and more vulnerable vehicles as bikes or scooters, both mechanical- and electrical-powered, adding accelerometer sensors and micro-cameras to accurately perceive the surrounding environment and position systems as GPS (Global Positioning System) or Galileo to locate itself in the road. The second new evolution trend is introducing direct communications between vehicles

(Vehicle to Vehicle - V2V) and between vehicles and computers deployed in the fixed infrastructure that execute software to improve safety (Vehicle to Infrastructure - V2I), in general they will be able to perform Vehicle to Everything (V2X) (Fig. 2.3). These V2X communications solutions also called Cooperative Intelligent Transport Systems (C-ITS) will complement vehicle's perception sensors and play a significant role in detecting and communicating information about potential hazards to pedestrians and vulnerable road users, thereby mitigating the danger of imminent collisions.

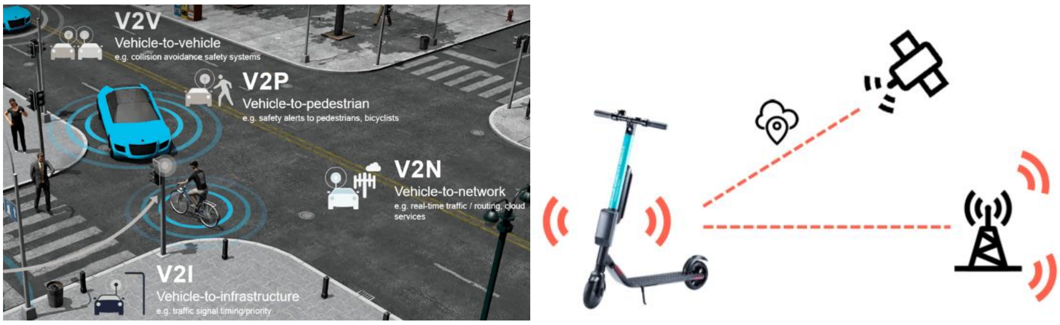


Fig. 2.3 Types of V2X communications. Sources: Qualcom, U-blox.

The intention of the C-ITS community is, using the physical infrastructure plus these messages, to develop new safety and management services whose complexity will evolve according to the network capabilities. The information that devices interchange varies from very basic messages containing the position and speed of the vehicle, to much more complex messages that can contain vehicle's trajectories and coordinated actions between them. With these messages, it is possible to develop numerous safety and traffic management applications and services as detection of collision trajectories, notification of road events (roadworks, obstacles on the road, surface condition, etc.), advising the optimal speed to reach traffic lights when they are in green.

To achieve communication interoperability among implementations of different manufacturers, standardization has an important role. The European Telecommunications Standards Institute (ETSI) Technical Committee (TC) on the ITS and its counterpart in the United States Society of Automotive Engineers (SAE) have developed standards for C-ITS applications, focusing on protocols supporting applications on the vehicle side. Moreover, they also have performed a thoughtful analysis on which are the causes of e-micromobility accidents and how they could be avoided or mitigated by means of C-ITS services using V2V and/or V2I communications. The approach comprises two phases, the first one is to make the system aware of the hazard using V2X messages and the second is to apply actions to avoid or mitigate the accident. Focussing on e-scooters, the actions that can be applied are also two. The most basic is to warn the driver using sounds directly emitted from the e-scooter. It is possible to use different sounds for different kind of situations or hazards. The second kind of actions are related with the main controller board of the e-scooter which is in charge of managing the speed, lights and, possibly, the brake. In this way, it would be possibly, to automatically modify the maximum speed, brake, accelerate and switch lights on or off.

3 Impact assessment of urban infrastructures on e-micromobility safety

3.1 Urban space design

In an urban context, space and streets design must meet the needs of people walking, driving, cycling, allowing vehicles transit. Encouraging micromobility as an efficient and attractive mode of transportation requires the provision of safe and continuous transitable facilities. Since e-kickscooters and bicycles are single user vehicles and have similar speeds, they can be accommodated in the same micromobility lane designs [34]. Therefore, the wide experience that some countries like the Netherlands and Denmark have in designing cyclable lanes and infrastructures can be applied to the design of micromobility lane infrastructure in general. Cities that have invested in cycling lanes have seen congestion levels decline and streets become safer for all users.

While cyclists and e-scooter riders can share the road with motor vehicles on quiet streets with low speeds, navigating larger streets and intersections requires dedicated facilities. Urban design should include safe and comprehensive cycle/micromobility networks for riders of all ages and abilities. High-volume corridors should provide wider cycle facilities to carry larger volumes. The design of cycle networks should consider safety, capacity, and connectivity for all riders. Design should consider future capacity and mode share goals rather than present-day demands.

3.1.1 Micromobility / Cyclable lane options

A **shared street** is a low-speed, typically curbless roadway designed as a single surface shared among pedestrians, bicyclists, and low-speed motor vehicles, see Fig. 3.1. Typically employed on low-vehicle-volume and/or high-pedestrian-volume streets, vehicles are slowed to very low speeds through a reduced speed limit, traffic calming, signage, and use of distinctive materials, furnishings, and other visual cues in the roadway that encourage drivers to travel with increased caution.

A safer alternative for busy streets is the provision of a **separated lane**. There are several options to provide micromobility lane separation from heavier vehicles traffic. The simple low-cost way consists on an **unprotected lane** based on a painting marking of dividing line and in some cases based on a vivid colour pavement in the micromobility lane usually dark red, blue or green, to make a clear distinction from the usual grey/black asphalt surface. However, this lane offers no physical protection against heavier vehicles invasion. Better options consist in adding some kind of barrier blocking more effectively against lane invasion, resulting in a **protected lane,** several options of barrier include plastic posts, curbs, bollards, planters, parked cars or elevated paths [35]. A representative example is shown in Fig. 3.2.

An alternative known as **Cycle Boulevard** are quiet streets that accommodate high cycle flows and are accompanied by very low motorized traffic.

Fig. 3.1 Shared road with 30 km/h limitation. Barcelona City Council. Sants Hostafrancs

Fig. 3.2 Protected bicycle lane in Koningsweg ’s-Hertogenbosch. From BicycleDutch

Protecting the micromobility lane from conventional motorized traffic has an important side-effect benefitting safety. It has been stated that the number of micromobility riders using sidewalks decreases drastically as a function of protection against heavier vehicles. According to a report from Portland, Oregon (US) [36], the percentages of e-kickscooter invasion of sidewalks was 39% in the case of absence of bike lanes, 21% in the case of unprotected bike lane, 8% in the case of protected bike lane and 0% in the case of bicycle boulevard. Being the micromobility traffic on sidewalks one of the dominant factors on both factual and perceived safety degradation, the benefit of using protected lane designs is double, since it reduces accidents involving larger vehicles and accidents involving pedestrians.

3.1.2 Crossing designs

As seen in Section 2, crossings and intersections are accidents black spots. For this reason, it is advisable to adopt designs that provide some degree of protection and physical separation between micromobiles, larger vehicles and pedestrians. The protected intersection [35] continues the physical separation of cycle facilities, positioning cyclists prominently ahead of right-turn conflicts and creating safe, simple cyclist movements through intersections. Conflict with motor vehicles are prevented by curb barriers and corner refuge islands. The speed of cyclists is reduced and they are better seen by drivers of larger turning vehicles. Pedestrians are also benefited from this design with more waiting space and protection. A recognised example is the Dutch Protected Crossing [37] shown in Fig. 3.3.

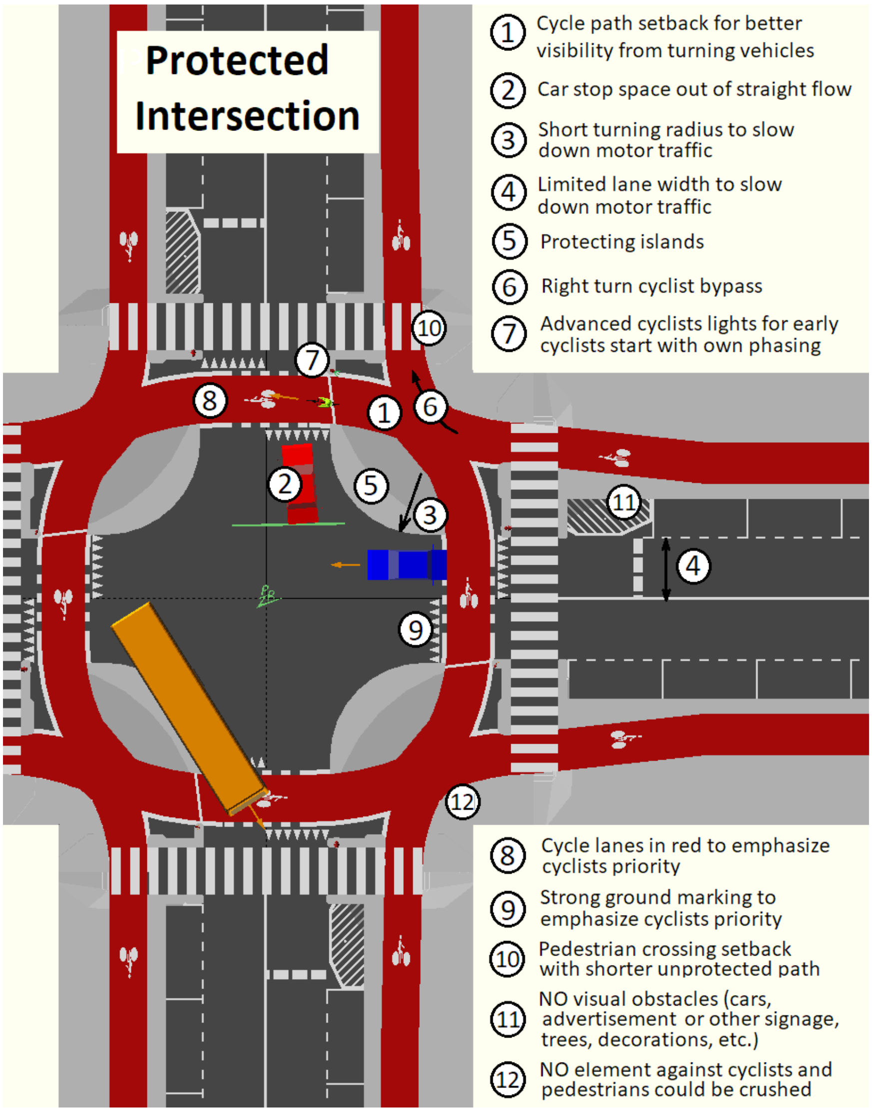


Fig. 3.3 The Dutch protected intersection, from P.Rouzeau, "Protected Crossing" [37]

3.1.3 Superblocks model

The Superblock is a new model of mobility that restructures the typical urban road network. With its implementation, Superblocks provide solutions to the main problems of urban mobility and improves both the availability and quality of the public space for pedestrian traffic. In order to achieve these goals for mobility, two fundamental changes must be made: modification to the basic road network and the establishment of differentiated routes for each mode of transport.

In Barcelona, Superblocks are made up of a grid of basic roads forming a polygon (Fig. 3.4), some 400 by 400 meters, with both interior and exterior components. The interior (intervía) is closed to motorized vehicles and above ground parking, and gives preference to pedestrian traffic in the public space. Though the inner streets are generally reserved for pedestrians, they can be used by residential traffic, services, emergency vehicles, and loading/unloading vehicles under special circumstances. The perimeter, or exterior, of Superblocks is where motorized traffic circulates, and makes up the basic roads.

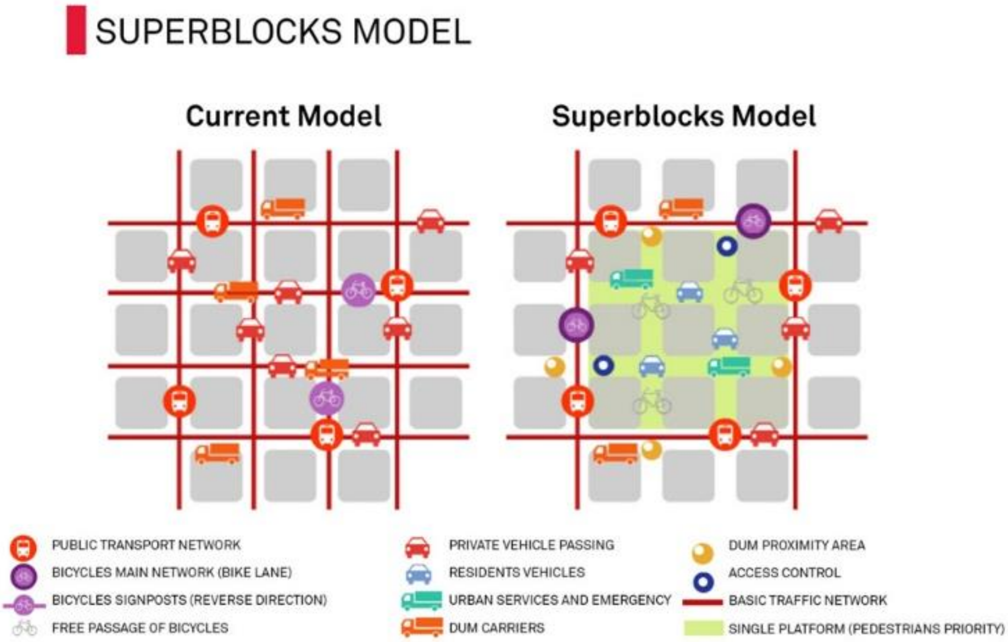


Fig. 3.4 The Barcelona Superblock model

The Superblock is a new option to the use of public space, uniting urban planning with micromobility and limiting the presence of private vehicles in order to return the public space to the citizen. In the structure of the Superblock, each grid section has universal accessibility, there is increased safety due to a 10 km/hr speed limit.

3.1.4 Bicycle/Micromobility new structural designs

Conventional designs for micromobility lanes are based on redistributing streets surface. This results in decreasing either conventional vehicles o pedestrian areas or both. A new emerging option to provide micromobility lanes is to use 3D space based on original structural designs. In terms of safety these options are ideal since they provide complete separation from heavy vehicles and sidewalks. Fig. 3.5 shows a representative example from Copenhagen where cycling is a preferred mobility choice.

3.1.5 Micromobility Charging stations

Recharging of shared e-kickscooters was initially carried out by transporting the vehicles to charging facilities, which created urban traffic and pollution overheads. To reduce cost and improve sustainability and environmental impact, charging operations are evolving towards battery swap. A better option would be installing charging stations, avoiding in this case transporting vehicles or batteries to charging facilities. This does not mean necessarily move from present “dockless” services to a fully docked concept, since a charge provides energy for tens of typical 1-kilometer rides. This concept is presently in pilot studies stage. Bird e-scooter sharing operator, has installed charging stations in Tel Aviv [38]. The stations operate in parallel to conventional vehicle transport to charging points, often provided by collaborator citizens. In the future, if micromobility growth continues, a standard charging station concept could be proposed, regulated and operated by cities or energy companies compatible for all sharing and private users.

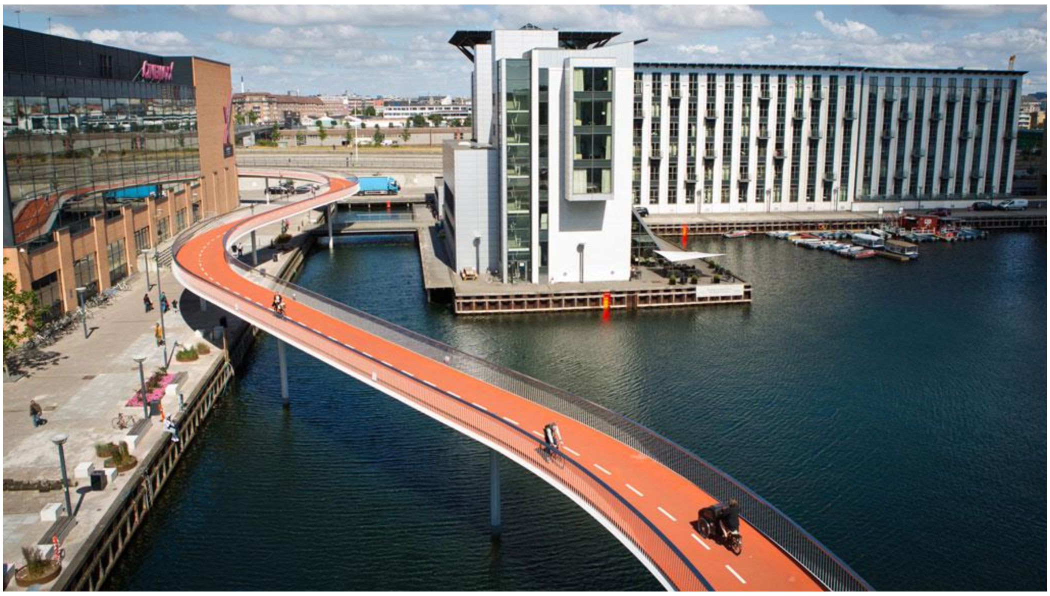


Fig. 3.5 The bicycle snake in Copenhagen.
https://www.visitcopenhagen.com/copenhagen/planning/bicycle-snake-gdk1087414

3.2 ITS based on Communications urban infrastructure

The deployment of C-ITS needs three basic components. The On-Board Unit (OBU) which is the communication element integrated in cars, micro-vehicles and, in a future, pedestrian's smart-phones will also be able to work as OBU. These devices are able to directly communicate between them, but if two vehicles are not under coverage or the message is intended for some server in the infrastructure, it is necessary to deploy Road Side Units (RSU) which act as base stations to receive and transmit V2I messages between vehicles and servers. RSUs have to be deployed on urban infrastructure and linked to the communication infrastructure to the Traffic Management Centre which, in fact, is the third element. Considering that each RSU can cover a radius approximately 300m in urban environments, it represents a significant cost to cover all the city.

Moreover, in order to be able to exploit these systems, there are still some problems or gaps that need further improvement and can represent a need of investment in the urban infrastructure:

- <u>High precision location infrastructure:</u> Positioning is one of the key enablers for Micromobility. There are different technologies involved in obtaining the vehicle's position. They can be used either independently or doing a fusion of them to improve robustness and accuracy i) GNSS (Global navigation Satellite Systems) provides position with an accuracy of meters (usually less than 3 meters), however, this accuracy varies significantly depending on many factors such as satellite visibility, reception multipath and signal propagation conditions which degrade the performance; ii) Inertial Navigation Systems (INS) are devices composed of accelerometers and gyroscopes whose output is used to calculate the movement and speed; and iii) Ultra-Wide Band

(UWB) ranging systems, as the ones based on IEEE 802.15.4a standard, that can provide up to decimetre level (< 1 m) positioning. This UWB system, which provides the highest accuracy, requires the deployment of small devices in the city that act as reference points and represent its main drawback. On the other hand, GNSS precision can also be improved using techniques as Precise Point Positioning Real Time Kinematics (PPP-RTK) which require that the receivers get additional information from stationary base stations with a known position.

- Public Key Infrastructure (PKI): The transmission of V2X messages need to be completely secure because they contain many sensitive information, so attacks in parameters like position or speed can lead in potential car crashes. This security is obtained using digital signatures and certificates which authenticate and protect the integrity of the message's content. The main challenge is that this PKI architecture, that contains the security servers which manage and coordinate the identities and certificates of the vehicles, needs to be deployed and operated at national or even European level. Therefore, until this infrastructure is ready it will be difficult to commercially exploit ITS services.

- Multi-access Edge Computing (MEC): A MEC is a computer that is "close" to its final users, which in our case are vehicles, where the information is generated and consumed. They are usually deployed in safe cabinets in the streets or buildings, and can perform multiple operations on behalf of the final vehicles as to detect potential collisions between one e-scooter and other road users or even pedestrians detected with recognition systems based on cameras. MECs can provide the intelligence in the infrastructure. They can be the bridge between different radio technologies (IEEE 802.11p and LTE-V2X), broadcast V2X messages, or provide real time information captured by analysing the scene with image processing and artificial intelligence

- Maps: Maps are critical elements across all mobility use cases. Without them, most applications, and specially collision detection, will not function properly. Moreover, there exist high demands in terms of accuracy, attributes, functional safety, freshness and continuous updates. All these requirements are turning map making into increasingly complex, high-tech, and expensive processes. The main challenge in e-micromobility safety is how to make them available in every situation. The traditional method is to have the map previously downloaded into the vehicle, but this presents the problem of memory occupation and map updating. Nowadays, there are several map providers that offer the maps-as-a-service approach where the vehicle dynamically requests the regions of the map that it really needs and also offer additional real time data in High Definition.

4 Review and selection of technologies for safety enhancement

In this Section suitable technologies with high TRL that can be used to design safety enhancement measures will be reviewed. In the Safety Analysis (Section 2) we have seen that accident causes can be related to rider, vehicle, road or other actors. In addition, the severity of injuries may strongly depend on the user protection measures. Considering the priorities identified, the following aspects will be considered: User protection and visibility, Vehicle robustness and stability, Vehicle control, Safety enhancement with ITS, sidewalk detection, traffic surveillance sensors and software applications.

4.1 User protection and visibility equipment

As commented in Sections 2.4 and 2.7 of Safety Analysis, a generalized helmet use would considerably decrease the severity of many accident injuries. Conventional helmet designs already in use for bicycles can be used or specific models for e-kickscooters which offer in general better protection. In addition, several mature technologies exist to upgrade helmet functionality.

One of the problems of e-kickscooters is the lack of visibility at night. This can be improved by increasing vehicle lights and optical reflectors luminosity. However, the low profile of e-scooters results into very low height of lights with visibility problems from elevated driver positions in large vehicles such as busses, vans and trucks. Since the rider's helmet is the highest part, the helmet is easier to see from tall vehicles. For this reason, several helmets in the market include position red lights in the backside based on efficient LED technology. Adding accelerometers, the helmet electronics can detect a braking manoeuvre increasing light luminosity or driving additional red lights as it is done in conventional vehicles. In addition to braking signalling, using a Bluetooth link with a small switch that can be installed in the handlebar, the driver can also indicate a right or left turn without the need to rise a hand.

In addition to helmet, night visibility is notably increased by using rider jackets including reflective pigments and/or reflective bands or a bright reflective vest over conventional clothing.

4.2 Vehicle integrity

In October 2020 the European Committee for Standardization approved the European Norm EN17128:2020 [39], which applies to personal light electric vehicles with or without self-balancing system totally or partially electrically powered from self-contained power sources having battery voltages up to 100 VDC, with or without an integrated battery charger with up to a 240 VAC input. The norm includes requirements and test methods applicable to electrical components and connections, moisture and vibration resistance, speed limitation, electromagnetic compatibility and batteries. The norm includes also a set of structural integrity tests complementing the German ordinance which stablished braking, light requirements and stability tests. The structural robustness (integrity) tests include a static load test on the centre of e-kickscooter platform and a handle bar and steering column tests including bending, vertical load and torque tests, as indicated in Fig. 4.1. Additional integrity tests include Handlebar grips and plugs and Frontal impact resistance.

Fig. 4.1 Main e-kickscooter structural integrity tests of EN17128:2020

4.3 Vehicle stability

Vehicle stability has been first evaluated in the German eKFV Ordinance [4] dynamic tests. In the tests, the roadway elements shall be driven at the design maximum speed and at a speed of 8 ± 4 km/h. The vehicle must complete the respective roadway element for each test run over and remain manageable at any time for the rider. The desired direction of travel must be maintained, whereby a maximum deviation between the nominal and the actual trajectory of 20° is permissible. The considered surface alterations to be tested with respect an ideal flat surface are (Fig. 4.2): Depression with exit ramp, Up and Down ramp, Unilateral drop and Kerbstone. In the figures Fahrtrichtung is the direction of travel during the test and Auffahrstufe is the ramp.

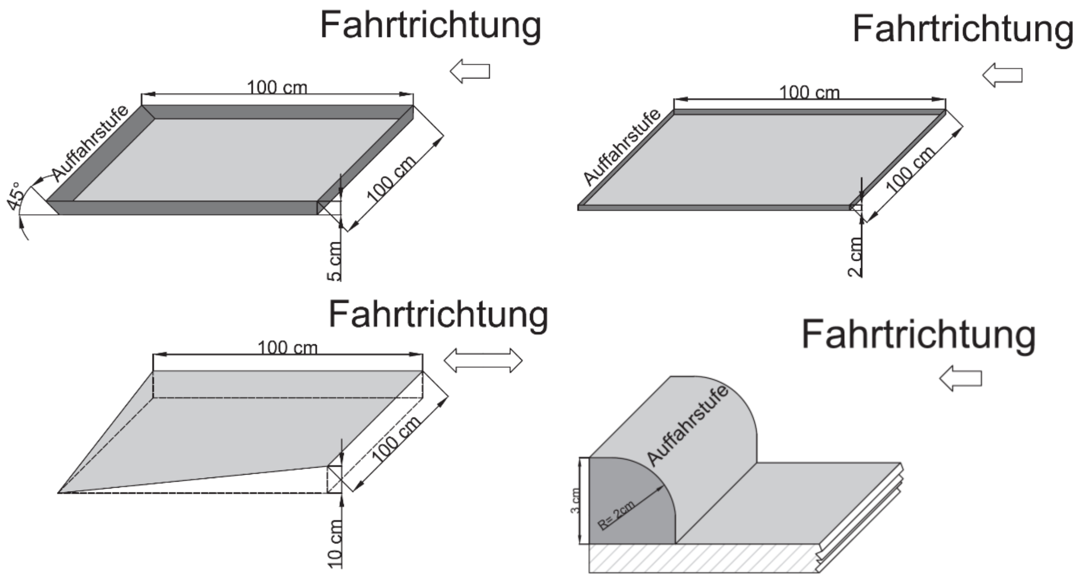


Fig. 4.2 Depression, Up and Down ramps, Unilateral and Kerbstone stability tests [4].

4.4 Vehicle control

The reduction of failures in micro-mobility vehicles are one the bottlenecks for their massive development. Power controllers available in the market do not offer a set of algorithms capable of determining the state of health of any component, even the battery, one of the most sensitive parts of an electric vehicles is poorly monitored and not protected in any case, and sometimes, they can catch fire.

Motor inverters in electric vehicle applications require high-performance vector control operations that use variable voltage, current, and operation frequency as demanded by the necessary services for the electric vehicle to start, accelerate/decelerate, and stop. These inverters also need to support functions such as high-capacity response, high-speed communication, anomaly detection, torque security, failure diagnosis, and functional safety by using, generally, Controller Area Network (CAN) protocols.

From the point of view of the development of new hardware components, the last breakthroughs in the power electronics field, will let the inclusion of new semiconductors based on wide-bandgap materials such as Gallium Nitride (GaN) and Silicon Carbide (SiC), letting to higher reliability, efficiency and power density compared with the traditional Silicon (Si) semiconductors. Also, the introduction of newer capacitor technologies, like ferroelectric components, as well as the development of Insulated Metal Substrate (IMS) in the design of newer PCBs, will provide superior thermal performance compared with current systems for getting higher power density devices.

The safety of drivers and pedestrians can be improved by developing new smart drives that aim to provide driving assistance to prevent any accident and when it is not possible to reduce its severity. So, the interaction with the rest of the system will increase by adding more intelligence and sensors to the main controller. It will be based on having more knowledge about the state of the vehicle and its surroundings, by evolving these converters to a new more intelligent power manager. Authorities at all levels should require safer motor vehicle designs that include both active and passive safety solutions. Relevant active safety features include intelligent speed assistance (available on all new car in Europe from 2022) and autonomous emergency braking systems (AEBS). There is little information about micro-vehicle trips and crashes, so it is important to collect this data to develop efficient policies.

All the information that can get the powertrain may come from different sides: interior, exterior, or cloud as is indicated in Fig. 4.3. The supervision of the powertrain elements will come from sensors located inside the battery pack, the power inverter, or the electric motor. Mechanical or electric failures can be detected and this information will be shared with the user or the fleet company to assist the quick replacement of the damaged component. Generally, the Battery Management System (BMS) will be responsible for the management of the battery pack but the interaction with the smart drive will be constant to enlarge the lifespan of the battery and the diminution of hazards. The BMS will have the capability to by-pass some cells if they are damaged for improved reliability, and also to analyse the State of Charge (SoC), the State of Health (SoH) and the Safe Operation Area (SOA). It will limit the capability of smart drive to inject or extract energy that can put in risk the battery pack.

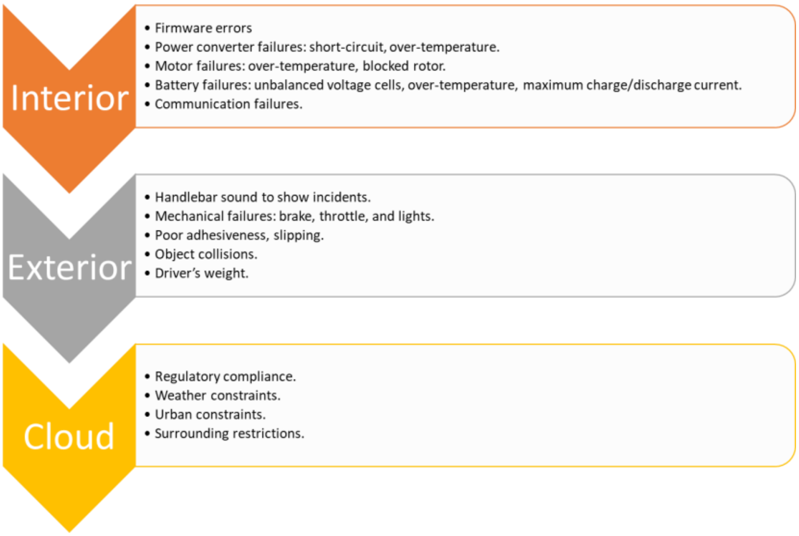


Fig. 4.3 New features in e-micromobility vehicle to improve its reliability and safety.

Fig. 4.4 shows some functionalities that can be introduced in the definition of new and future smart drives for micromobility vehicles. Some aspects related to the external safety has been introduced in Fig. 4.3. In the case of fleet companies, where the maintenance of its vehicles is a considerable cost, the development of intelligent algorithms to predict some failures or the degradation of some components will reduce the time spent and the cost of the broken vehicles' replacement. This feature is essential in the future vehicles where their intelligence will be enough to analyse the operation of each component. The information will be shared between the vehicle and the cloud and intelligent algorithms developed in the cloud which will know the technology, and the current state, and it will predict the future state according to the accumulated received data. So, the development of newer software tools based on available data on the electric vehicle will increase the reliability and durability of these vehicle. Measuring variables in key components will result in a set of warnings and errors to determine the state-of-health of the electric vehicle to program an appropriate maintenance and repair service. In addition, rules and regulations, weather data, rate of traffic congestion, and smart city integration such as traffic light and integration in the GIS that includes parking limitations, and speed limit regulations can be applied intelligently over the power converter controller.

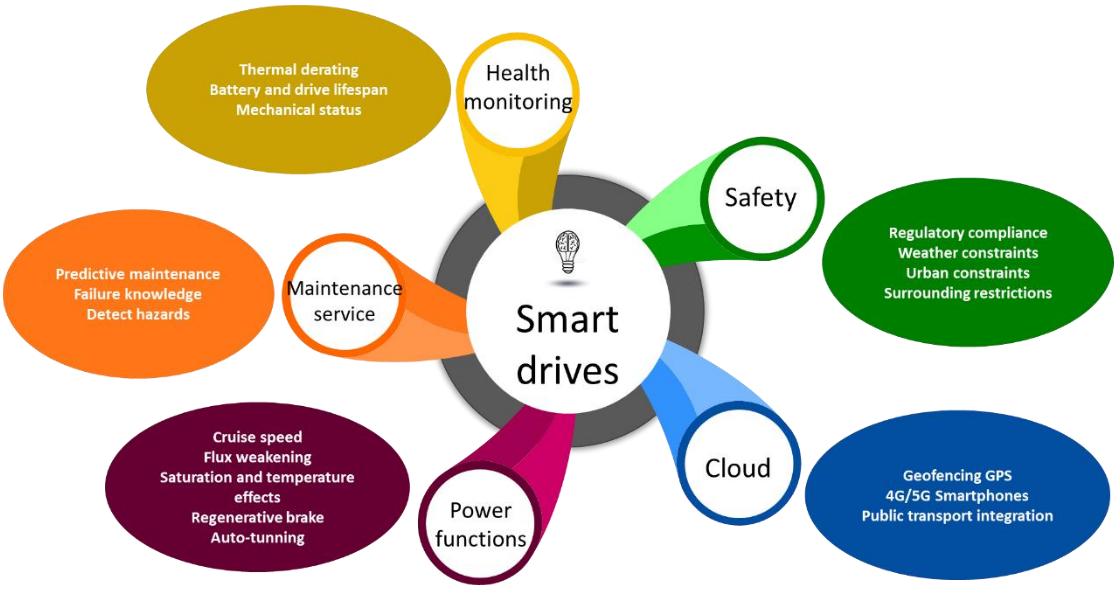


Fig. 4.4 New concept of future smart drives for e-micromobility.

4.5 Micromobility safety enhancement based on ITS

Current vehicular communication technologies are basically composed of 3 subsystems, i) the communication protocols architecture, ii) the radio technologies used to transmit the information, which includes the management of the radio spectrum, and iii) the systems to precisely position the vehicle.

The V2X communications protocol architecture is used in any ITS device (On-Board OBU and Road Side RSU Units) and it provides a compatible communication channel between all the nodes. Nowadays, there are different protocol architectures but two of them lead the industry, the European called ITS-G5 and defined by the ETSI, and the American, named WAVE (Wireless Access in Vehicular Environments) and defined by the IEEE and the SAE (Society of Automotive Engineers). In spite of using the same model and performing similar functionalities, both protocol architectures have technical divergencies and they are not interoperable. In the practice, every region (US, Europe, Japan) will use its own architecture.

These architectures, although work with different protocols, use the same layers. On the top level, there is the Applications layer which performs the services that the user will consume (alarms, assisted driving, etc.). Just below, the Facilities layer defines common data structures and messages to guarantee the interoperability of ITS services. One step lower, we find the Networking and Transport layer which represent layers 3 and 4 of the OSI (Open System Interconnection) model. Here, the ITS-G5 architecture defines the GeoNetworking and BTP (Basic Transport Protocol) protocols, which consider geographical coordinates for addressing and forwarding messages. Finally, the bottom layer is named Access Technologies and is comprised by the radio technologies that are used to transmit the messages.

As for late 2020, there are two big trends in radio access technologies, the IEEE 802.11p and the LTE-V2X. Historically, IEEE 802.11p is older, more mature, with many years of research and pilots behind. In fact, it is derived from the IEEE 802.11a, but using 10 MHz and supressing the need to set up a Basic Service Set (BSS) and is called Outside the Context of a BSS (OCB). Its commercial adoption has been slow, with problems due to poor scalability, requiring the deployment of RSU and struggling when the number of devices goes high. In the meantime, LTE-V2X development has taken advantage of the LTE technology and infrastructure to avoid costly deployments, performing slightly better in transmission parameters. Under this situation, IEEE has started the new Task Group 802.11bd in January 2019, and 3GPP is improving the original LTE-V2X definition in Release 14 with the NR-V2X (New Radio Vehicle to Everything) being introduced in Release 16.

V2X communications are transmitted in the so-called ITS G5 band in the 5,9 GHz frequency band, that has been simultaneously adopted by the ETSI in Europe and by the Federal Communications Commission (FCC) in United States. There are multiple articles that analyse coverage distances, but all of them are for particular scenarios or with different propagation models or made with prototypes with different antennas and transmission characteristics. Nevertheless, averaging their findings, we could say that, for a transmission power of 23 dBm and antennas of 3 dB of gain, the IEEE 802.11p coverage distance, for its default transmission speed (6 Mbps), is approximately 200 m, and that the LTE-V2X (PC5 interface), using its mandatory mode (QPSK and coding rate 0,48), has an approximate coverage range of 350 m.

Detection of presence of the Vulnerable Road Users (VRU) is a key issue in ITS positioning systems. As VRUs are smaller than vehicles and the trajectory is less predictable, the relative accuracy of VRUs' positions need to be better than for non-VRU vehicles. The techniques used to improve localization for VRU, keeping them with low cost, are a real challenge. There exist a wide range of technologies (GNSS, inertial sensors, odometer, cameras, terrestrial radio ranging, map matching, etc.) none of which provides the optimal solution for the wide range of scenarios emerging in C-ITS applications. In general, the appropriate approach is to provide a multi-sensor hybrid solution, which combines them, to use the best of each technology to obtain a single blended solution for position, velocity and, in some cases, altitude estimation. The techniques based on Ultra-Wide Band (UWB) may be especially useful for VRUs positioning systems. Since they allow to measure distances with an accuracy of several centimetres, it might be a good solution for achieving the required accuracy. Nevertheless, UWB ranging requires to investigate further aspects such as improving the range and the scalability.

4.6 Side-walk sensors

As shown in Section 2, the integration of sidewalk detectors on vehicles would increase micromobility safety allowing regulation enforcement by informing sharing operators about unwanted driving patterns of users and even reducing maximum vehicle speed to tolerable limits. Sidewalk detection can exploit geolocation techniques and physical differences of sidewalk pavement such as surface structure and colour or a combination of them.

- Surface structure: the asphalt or cycling roads are rough with a statistically homogeneous random topography with transitory discontinuities in case of repairs, holes, cracks or bumps. On the other hand, sidewalk tiles have different shapes typically rectangular or hexagonal, some of them containing design patterns.

- Colour: every pavement has a unique surface colour. Typical asphalt surfaces are dark grey, lighter gray in concrete cases, both with a certain degree of granularity due to the embedded gravel. To increase awareness of cycle/micromobility lanes, many countries and cities use vivid colour surface pigments including dark red, green or blue. In the case of sidewalks, colour depend on the type of tiles but will be in most of cases different from cyclable lanes or asphalt. For this reason, surface colour is a physical discriminant that can be exploited for sidewalk detection.

- Location: Since micromobility regulations and policies are changing frequently, the tile types and colours of sidewalks and micromobility lanes can dynamically change depending on the street or neighbourhood.

In this case, satellite navigation (GNSS) which can be complemented with inertial measurement units, and Ultra-Wide Band techniques for improved accuracy.

Preliminary experimental assessment has been carried out based on a prototype, combining low-cost optical and accelerometer sensors providing colour, structure and vibration information. Using automatic adaptive detection techniques implemented on a low-cost microcontroller reliable sidewalk detection results have been achieved on different types of sidewalk and road pavements in Barcelona metropolitan

4.7 Traffic surveillance with optical sensors

Specialized cameras and 3D lidar sensors offer unprecedented capabilities to monitor traffic and detect potentially dangerous situations for micromobility. This review has been arranged as a general overview of the potential uses that Optical sensors can provide for the self-protection of micro mobility vehicles, and for the protection of other users of the public space. We have divided such review into on-board sensors, which may be integrated within the current vehicles, in special high-end ones, and the infrastructure sensors which may be implemented.

Onboard sensors: The main requirement for inclusion of Optical sensors on board of micro mobility vehicle is obviously the need of compact, cheap and lightweight sensors This, of course, mainly points towards different types of 2D cameras where longer industrialization paths and intensive miniaturization processes have already been undergone. In particular, there is a strong market pull related to micro cameras being introduced in automotive units (e.g. parking cameras, rear-view mirror cameras, etc.) which are directly applicable to micro mobility systems. Although less mature, 3D compact sensors have been recently introduced in the market following the automotive trend. Flash-lidar sensors, where a flood of light is projected on the scene and is recovered in an array of highly sensitive detectors, in particular, start to be commercially available. Their small size and cost enable an easy on-board integration on vehicles. Further, the rush towards long-distance lidars and its miniaturization may also contribute to increase the availability of 3D sensors for on board vehicle sensing.

Infrastructure sensors: Infrastructure sensors, however, do not present the restrictions imposed by the small size and weight of the vehicles, and have several uses, and are well known both in the 2D and 3D versions. The most relevant application for vehicles should be pedestrian identification and tracking for prevention of accidents, are detection of micromobility units at inadequate speeds. All types of sensors may be used for pedestrian detection and tracking. As when speaking of miniaturization, 2D sensors are in advantage due to their longer development, although 3D sensors are extremely promising as long as the introduction of geometry (and speed) in the scene enables more precise classification due to the additional information available. There are already several well-known strategies to identify and track pedestrians using 2D cameras, being YOLO the most popular, although promising result shave also been obtained using 3D point clouds, where the complete information of geometry may be used (Fig. 4.5).

Finally, one very interesting approach has been recently introduced by some companies in the shape of multimodal imaging, that is, the use of detection and tracking procedures based on information of 2D and 3D cameras which are previously calibrated and fused so each point in the point clouds contains the 2D and the 3D information simultaneously.

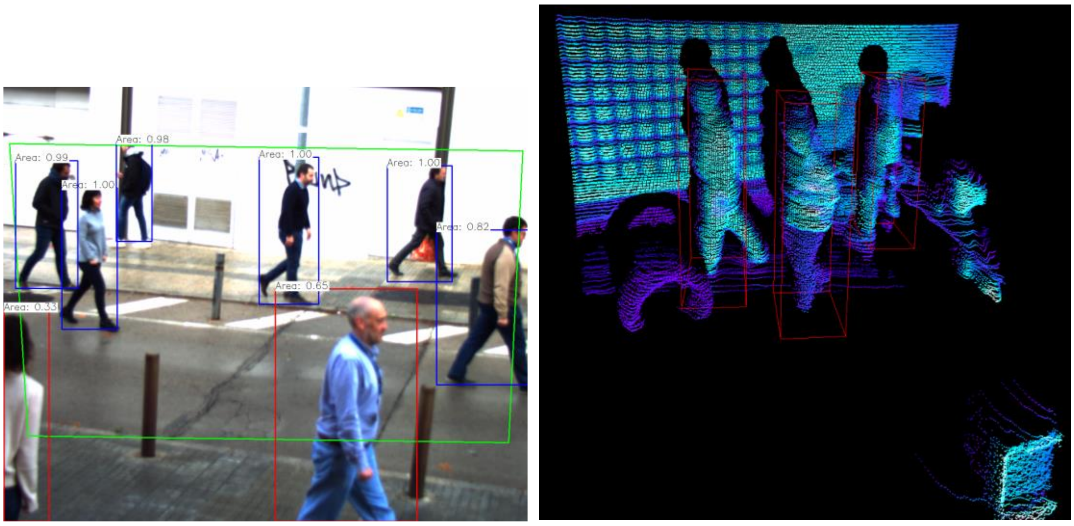


Fig. 4.5: Pedestrian identification and tracking using 2D images (left) and 3D point clouds (right)

4.8 Radar Sensors

EU Regulation 2019/2144 of the European Parliament and of the Council of 27 November 2019 will come into force in July 2022 [40]. It defines users of powered two-wheelers, such as electric scooters within the category of "vulnerable road users", and provides in its article 7 that passenger and light van vehicles shall be equipped with **advanced emergency braking systems** (AEBS) providing for detection of obstacles and moving vehicles in a first phase and the extension of detection capability to include pedestrians and cyclists in a second phase. There are different sensor technologies for AEBS and Radar based ones are preferred for its all-weather performance, in comparison to LIDAR sensors that cannot operate under fog or heavy rain conditions. ETSI has set different standards concerning frequency allocation, system definition and testing procedures for automotive radar equipment that shall operate in the 77 to 81 GHz band [41]. In order to assess present automotive radar capabilities for micromobility safety applications a set of measurements have been carried out to: obtain the Radar Cross Section (RCS) of an electrical-scooter with different view angles, determine the contribution of the scooter driver to the RCS, evaluate the effect of simple RCS augmentation scheme. The Radar Cross Section of an object is the key radar visibility parameter to assess the radar detection capability. The measurements were conducted by placing the scooter at approximately 11 meters from the Radar.

The measurements have been done in three different conditions: 1. The electric scooter free-standing, 2. The electric scooter with a driver, 3. The electric scooter with a driver and with a 6 cm side trihedral reflector attached on top of the rear wheel of the scooter. The nominal RCS of the trihedral is 5.5 dBsm. The results are shown in the form of a table in Fig. 4.6. Several conclusions can be drawn from the measurements: 1. When observed from the front or the back the RCS of the scooter with driver essentially coincides with the RCS of a pedestrian, 2. Seen from the side the observed RCS is essentially that of the free-standing scooter and the driver has little effect, 3. From the side the RCS of the scooter with driver is about 10 dB larger than seen from the back, 4. The integration of a small trihedral reflector increases the RCS of the scooter with driver seen from the back by 5 dB. A comprehensive explanation of these results would require some additional measurements and analysis, but it can be hypothesized that the body of the driver blocks most of the scooter structure as seen from the back.

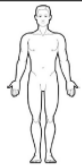
RANGE: 11.3 meters				
Target	Electric scooter	Pedestrian	Electric scooter + Driver	Electric scooter with trihedral + Driver
Front side	 RCS = - 4.6 dBsm	 RCS = 2.6 dBsm	RCS = 3.3 dBsm	RCS = 4.7 dBsm
Rear side	 RCS = - 6.5 dBsm	 RCS = 1.2 dBsm	RCS = 1.5 dBsm	RCS = 6.6 dBsm
Left side	 RCS = 15.9 dBsm	 RCS = - 3.3 dBsm	RCS = 14.9 dBsm	RCS = 15.2 dBsm
Right side	 RCS = 15.7 dBsm	 RCS = - 3.3 dBsm	RCS = 15.8 dBsm	RCS = 15.0 dBsm

Fig. 4.6 Results of RCS measurements.

The use of small size Radar reflectors in the same way as they are also employed at optical frequencies can help in increasing the detectability of electric scooters by automotive Radars. As of year 2022 new passenger vehicles and light vans will be mandatory equipped with AEBS, that will be probably based among others in Radar sensors operating in the 77 GHz band. The RCS of an electrical scooter seen from the back with a driver is of the same order of magnitude as the one of a pedestrian. The micromobiles RCS and consequently the detectability by a Radar can be substantially increased with the use of simple reflectors.

4.9 Software applications for safety and traffic management

Managing traffic dynamically entails a large set of challenges, as it consists on informing the drivers about the current state of roads in real time. For that, we need to use a technology that is capable of calculating the impact of a myriad of situations (e.g. accidents, climatological effects, traffic density, etc.), as well as a set of decisions taken by the authorities (e.g. road closures, maximum speed, road directions, restrictions on the mobility, etc.), over each of the drivers and propose safe alternatives. Notice that to achieve all that, this kind of technology, not only need high levels of CPU power to calculate complex models, but also to be connected with many sources of information (e.g. weather stations, city council and other administrations control centres, emergency control centres, etc…).

Notice that the technological requirements of a platform capable of dealing with real time data, as well as processed data, to assist the travellers in their daily routing is challenging in many ways. First, it requires a methodology capable of receiving real data from multiples sources, e.g. vehicles sensors, weather forecasts, open data, etc. Second, it needs to exploit these data in real time to assist travellers, e.g. road closures need to be informed in order to avoid them. Third, data needs to be processed to extract models capable of predicting/foreseeing events to help travellers, e.g. rush hours, roads likely to be affected due to an external event, etc. Fourth, neither the reception nor the analysis of data can become a bottleneck that affects the user experience and the usability of the applications. Fifth, specific algorithms to assist navigation while including safety measures through the exploitation of collected data need to be implemented and provide real time information to the final-end users.

There are many applications that are designed to assist users in their daily routine. Many of them are owned by public administrations (e.g. TMB App, AMB Mobilitat) or private corporations (e.g. SwashApps for Israel, Switzerland, Stuttgart, Netherlands, Paris and Estonia) focused on public transport. Others, such as Google Maps or Waze, initially designed for private transport include now public transport and other options like Taxis, Uber or Cabify. However, none of these applications is ready to support the myriad of aforementioned challenges. Some of them are capable of dealing with real time traffic or even the closure of roads.

As an example of appropriate platform development, CIGO! [42] is an ongoing project which is being designed to be capable of dealing with these challenges and many others by means of collaborative, open and accessible data. CIGO! is an event-based platform that allows calculating complex models as requested or needed, which are exploited by mobile devices.

Fig. 4.7 shows CIGO! Architecture, which consists of three main interrelated components. Each of these components is in charge of implementing different aspects of the project:

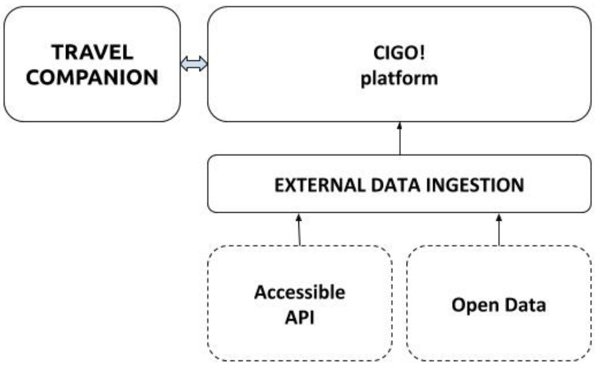


Fig. 4.7 Platform CIGO! Architecture

CIGO! Algorithms are in charge of implementing algorithms that are useful for the Travel Companion. Note that the number of models to be implemented is only limited by the data sources. Data source can be collaborative, i.e. collected by other users, or obtained through public APIs or open data. Thus, the amount of models to be created and exploited by the Travel Companions to recommend alternative routes is almost unlimited. Here, we list a few as examples:

- **Traffic rules:** Traffic speed is variable in different zones of the city and also, in some scenarios depending the time of the day, which may derive in an easy confusion for the user. As, static and dynamic, traffic rules can be easily included in the platform and they can be shown permanently, or also just alert when speeding, to the user allowing him/her to avoid fines and reduce the risk of having an accident.
- **Weather conditions – Road**: Predict road safety based on the analysis of accidents under particular weather conditions.
- **Robbery/Criminality:** Identify areas in which the criminality rate for micro mobility users is higher than others.
- **Pavement state:** Based on the experience of other users, which can collect the state of the pavement (e.g. bumps, cracks, ramps, etc.) calculate the probabilities of an accident at a given speed. It could also, show the maximum speed in which this probability is reduced to the minimum, even if this is a lower speed than the one permitted by the traffic rules in the area.
- **Personalized routes:** A travel companion cannot only exploit the characteristics/state of the pavement, weather or traffic but also the specific characteristics of the users, which can be learned over time. It allows the travel companion to suggest the better route to a particular user based on his/her needs. For example, while the travel companion could suggest the fastest route for a particular user, it could also, based on gathered information, recommend the safest route to another.

The Travel Companion is the application that aims to act as a real travel companion providing recommendations that are helpful to improve the trips. Thus, it is the interface between the driver and the whole CIGO! ecosystem. It provides recommendations that are based on the models calculated within CIGO! Platform.

4.10 Parking control

Enforcing parking in authorized zones is required to minimize side-walk blockage and hazards created by laying down micromobiles. Different techniques can be used to control micromobiles parked properly parked or stationed in unwanted areas or laying down.

A possible option proposed by UnternehmerTUM and Upride start-up company (https://upride.io/) is based on Bluetooth technology which is already present in e-kickscooters. By integrating 1-3 Bluetooth Low Energy (BLE) beacons to parking spots it is possible to control if the vehicles are correctly parked. Bluetooth beacons are cheap and energy efficient. Moreover, the new version Bluetooth 5.1 allows submetric positioning which is ideal for precise parking control of e-kickscooters. Users that park correctly the vehicles can be rewarded by sharing companies, for example with extra riding minutes, as an incentive to follow regulations. An experimental parking zone in Munich evaluating this concept can be seen in Fig. 4.8.

Fig. 4.8 UnternehmerTUM and Upride experimental parking zone in Odeonsplatz (Munich)

5 Conclusions and proposed safety enhancement measures

All transport modes have associated accident risks, which are periodically assessed with the aim to reduce frequency and severity. The recent growth of micromobility has been accompanied by an increase of safety incidents and accidents, highlighting the need of rigorous safety analysis in order to identify the accident causes and influencing factors. A better comprehension of micromobility safety is a prerequisite to propose effective safety improvement measures. Micromobility safety analysis is a difficult task due to the diversity of information sources, often biased, and the lack of a standard accident reporting procedure. In addition, accidents are rare events which are consequence of many different causes and strongly influenced by diverse contextual situations. In the safety analysis a large amount of published information of all kind has been reviewed. Moreover, we have used existing surveys and proposed complementary ones addressed to both micromobility users and traffic accident investigation experts. Although the views and priorities are not always coincident the most important safety causes and related problems have been identified which are in line with recently published studies.

The availability and deployment of appropriate urban infrastructures have a strong impact on safety, notably the urban space and lane/crossings design and the level of protection from heavier vehicles and offered to pedestrians. Expertise and concepts from countries with widespread bicycle use such as the Netherlands and Denmark are being adapted to micromobility needs. Intelligent Transportation Systems Signalling and Telecommunication infrastructures and Charging stations are also part of the urban infrastructure that will improve future micromobility safety and efficiency.

Additionally, considering the main safety gaps in micromobility, a review of existing technologies has been carried out with emphasis on high TRL options. A special focus has been placed on emerging ITS techniques, that extending new communications standards is introducing very relevant changes in all transport modes. Relevant safety and efficiency improvements are expected from technical innovations, micromobility has the opportunity to benefit from them in early development stages, since it is being promoted by high-tech innovative firms.

From the safety analysis which highlighted the main accident causes and considering what present and near-future technologies can offer, the following safety enhancement measures that have been identified along this study are summarized below:

- Improve micromobility user's protection with generalised use of helmets, preferably with integrated position lights and braking and turn indication functions. Promote the use of reflective clothing and additional body protection devices for hands and limbs.
- Improve the knowledge of traffic rules, specific micromobility regulations and signalling with appropriate infographics and periodic information campaigns.
- Promote training in protected areas of new users of sharing services and also vehicle owners.
- Extend the urban networks of cyclable/micromobility lanes offering appropriate capacity and protection with respect to heavier vehicles and pedestrians.
- Complete the development of a European safety standard for micromobility which has been initiated by the PLEV (eKFV) Ordinance in Germany and continued with the recent publication of EN17128:2020 norm.
- Improve vehicle structural robustness, stability, braking capacity, speed and acceleration control, including appropriate sensors, navigation and communications subsystems to enforce safe riding and preventing accidents.
- Use the existing communication technologies already present in e-micromobiles, users' smartphones and city infrastructure to improve safety by enforcing traffic rules and regulations and helping users taking the safest itineraries and reporting safety problems to city authorities.
- Deploy and complement urban ITS infrastructures by including appropriate signalling and telecommunication subsystems providing precise positioning and V2X communications, allowing regulations enforcement, collision prevention and traffic dynamic management.

As a final conclusion point we strongly believe that there is a need to stablish an international systematic observation of micromobility safety, with homogeneous protocols of accident reporting and traffic measurement parameters. This will allow to rigorously compare among different urban planning and mobility approaches, observe trends, study the impacts of new safety measures and regulations and identify and promote cases of success.

6 References

[1] T.H.Møller, J.Simlett, E.Mugnier, "Micromobility: Moving cities into a sustainable future", EY Report, pp. 1-34, March 2020. Available in https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/automotive-and-transportation/automotive-transportation-pdfs/ey-micromobility-moving-cities-into-a-sustainable-future.pdf. Accessed on 27/8/2020.

[2] International Transport Forum. "Safe Micromobility". International Transport Forum, Corporate Partnership Board Report, pp. 1-96, February 2020. Available in https://www.itf-oecd.org/safe-micromobility. Accessed on 27th August 2020.

[3] Barcelona City Council, "Regulating personal mobility vehicles and cycles with more than two wheels in Barcelona", pp. 1-11. 2018. Available in https://ajuntament.barcelona.cat/bicicleta/en/noticia/new-regulation-for-personal-mobility-vehicles-and-bikes-with-more-than-two-wheels. Accessed on 1/03/2020

[4] EC Notification, "Ordinance on the use of personal light electric vehicles (PLEV) on public roads and amending other road traffic regulations", Notif. No. 2019/84/D, pp. 1-46, 26th February 2019. Available in https://ec.europa.eu/growth/tools-databases/tris/en/search/?trisaction=search.detail&year=2019&num=84&source=post_page---------------------------, accessed in 20th July 2020.

[5] City of Copenhagen, "Copenhagen cycling guidelines 2019" also applicable to e-scooters, pp. 1-2, available in https://international.kk.dk/sites/international.kk.dk/files/uploaded-files/copenhagen_cycling_guidelines_2019.pdf accessed on 23 June 2020.

[6] The Yeshiva World (2019) Israel: Helmet & License Is Now Required For Electric Bike Riders. Retrieved from: https://www.theyeshivaworld.com/news/israel-news/1654985/electric-bike-riders-in-israel-require-a-license-beginning-january-1-2019.html. Accessed on 20th June 2020.

[7] Dept. of Transport-UK, "E-scooter trials_ guidance for local areas and rental operators", pp. 1-25, e-scooter regulation, 22 September 2020. Available in: https://www.gov.uk/government/publications/e-scooter-trials-guidance-for-local-areas-and-rental-operators/e-scooter-trials-guidance-for-local-areas-and-rental-operators. Accessed on 10th November 2020.

[8] M. Modijefsky, "Electric scooters banned from being parked on Copenhagen streets". Aricle published in Eltis, Urban Mobility Observatory, pp.1-2, 30th October 2020. Available in https://www.eltis.org/in-brief/news/electric-scooters-banned-being-parked-copenhagen-streets. Accessed on 12th November 2020.

[9] German Federal Ministry of Transport and Digital Infraestructure BMVI, "Who can ride where?", May 2019, available in https://www.bmvi.de/SharedDocs/EN/Documents/K/perosnal-light-electric-vehicles.pdf?__blob=publicationFile, accessed in 13/10/2020.

[10] Barcelona City Council, "Anàlisi de la sinistralitat a la ciutat de Barcelona de l'any 2019", pp- 1-13, January 2020, available in https://ajuntament.barcelona.cat/premsa/2020/01/28/analisi-de-la-sinistralitat-a-la-ciutat-de-barcelona-de-lany-2019/. Accessed in 10/8/2020.

[11] Israel Central Bureau of Statistics, "Road accidents with casualties 2019. General Summaries", pp.1-257, Publ. No. 1805, August 2020. Available in https://old.cbs.gov.il/publications20/1805/pdf/e_print.pdf. Accessed on 10/09/2020.

[12] Elaine Petrucelli, John D. States, Lee N. Hames, "The abbreviated injury scale: Evolution, usage and future adaptability", Accident Analysis & Prevention, Volume 13, Issue 1, March 1981, pp.29-35, https://doi.org/10.1016/0001-4575(81)90040-3.

[13] Polizeipräsidium München, "Verkehrsbericht 2019", pp.1-86, April 2020. Available in https://www.polizei.bayern.de/content/1/5/6/5/verkehrsbericht_2019_internet.pdf. Accessed on 20.07.2020.

[14] Faerselsstyrelsen, "EVALUERING Af forsøgsordningerne for små motoriserede køretøjer", pp.1-47, February 2020. Available in https://viatrafik.dk/wp-content/uploads/2020/07/Evalueringsrapport-om-sm%C3%A5-motoriserede-k%C3%B8ret%C3%B8jer.pdf. Accessed in 25.07/2020.

[15] Bird, "A look at e-scooters safety", pp- 1-19, Bird Report, April 2019, Available in https://www.bird.co/wp-content/uploads/2019/12/Bird-Safety-Report-April-2019.pdf, Accessed on 22/07/2020
[16] Buehler and Pucher, "Trends in Walking and Cycling Safety: Recent Evidence From High-Income Countries, With a Focus on the United States and Germany", AJPH Research, Vol 107, No. 2., pp.281-287. February 2017. doi: 10.2105/AJPH.2016.303546. Available in https://ajph.aphapublications.org/doi/pdfplus/10.2105/AJPH.2016.303546.
[17] Aizpuru, M., Farley, K. X., Rojas, J. C., Crawford, R. S., Moore Jr, T. J., & Wagner, E. R. (2019). Motorized scooter injuries in the era of scooter-shares: A review of the national electronic surveillance system. *The American Journal of Emergency Medicine, 37(6),* 1133-1138.
[18] Badeau, A., Carman, C., Newman, M., Steenblik, J., Carlson, M., Madsen T. (2019). Emergency department visits for electric scooter-related injuries after introduction of an urban rental program. *American Journal of Emergency Medicine*, 37, 1531–1533.
[19] Beck, S., Barker, L., Chan, A., & Stanbridge, S. (2019). Emergency department impact following the introduction of an electric scooter sharing service. *Emergency Medicine Australasia*. doi: 10.1111/1742-6723.13419
[20] Bekhit, M. N. Z., Le Fevre, J., & Bergin, C. J. (2020). Regional healthcare costs and burden of injury associated with electric scooters. *Injury, 51(2),* 271-277.
[21] Blomberg, S. N. F., Rosenkrantz, O. C. M., Lippert, F., & Christensen, H. C. (2019). Injury from electric scooters in Copenhagen: a retrospective cohort study. *BMJ open, 9(12).*
[22] Bresler, A.Y., Hanba, C., Svider, P., Carron, M.A., Hsueh, W.D., Paskhover, B. (2019). Craniofacial injuries related to motorized scooter use: A rising epidemic. *American Journal of Otolaryngology*, 40(5), 662-666.
[23] Dhillon, N.K., Juillard, C., Barmparas, G., … Ley E.J. (2020). Electric Scooter Injury in Southern California Trauma Centers. *Journal of the American College of Surgeons,* 231(1), 133-138.
[24] Kobayashi, L.M., Williams, E., Brown, C.V. et al. (2019). The e-merging e-pidemic of e-scooters. *Trauma Surgery & Acute Care Open.*, 4, e000337.
[25] Lee, K.C., Naik, K., Wu, B.W., Karlis, V., Chuang, S.-K., Eisig, S.B. (2020). Are Motorized Scooters Associated With More Severe Craniomaxillofacial Injuries? *Journal of Oral and Maxillofacial Surgery* 1-7, 2020. https://doi.org/10.1016/j.joms.2020.04.035
[26] Mitchell, G., Tsao, H., Randell, T., Marks, J., & Mackay, P. (2019). Impact of electric scooters to a tertiary emergency department: 8-week review after implementation of a scooter share scheme. *Emergency Medicine Australasia, 31(6),* 930-934.
[27] Nellamattathil, M., Amber, I. (2020). An evaluation of scooter injury and injury patterns following widespread adoption of E-scooters in a major metropolitan area. *Clinical Imaging*, 60, 200–203.
[28] Oksanen, E., Turunen, A. and Thoren, H. (2020). Assessment of Craniomaxillofacial Injuries After Electric Scooter Accidents in Turku, Finland, in 2019. *Journal of Oral and Maxillofacial Surgery* 1.e1-1.e6. https://doi.org/10.1016/j.joms.2020.05.038
[29] Schlaff, C. D., Sack, K. D., Elliott, R. J., & Rosner, M. K. (2019). Early Experience with Electric Scooter Injuries Requiring Neurosurgical Evaluation in District of Columbia: A Case Series. *World Neurosurgery, 132,* 202-207.
[30] Trivedi, T. K., Liu, C., Antonio, A. L. M., Wheaton, N., Kreger, V., Yap, A., ... & Elmore, J. G. (2019a). Injuries associated with standing electric scooter use. *JAMA Network Open*, *2*(1), e187381-e187381.
[31] Trivedi, B., Kesterke, M.J., Bhattacharjee, R. et al. (2019b). Craniofacial injuries seen with the introduction of bicycle-share electric scooters in an urban setting. *Journal of Oral and Maxillofacial Surgery*, *77*, 2292-2297.
[32] Yang, H., Ma, Q., Wang, Z., Cai, Q., Xie, K., Yang, D. (2020). Safety of micro-mobility: Analysis of E-Scooter crashes by mining news reports. *Accident Analysis and Prevention*, 143, 105608.
[33] Yarmohammadi, A. Baxter, S. L., Ediriwickrema, L. S., Williams, E. C., Kobayashi, L. M., Liu, C. Y., Korn, B. S., Kikkawa, D. O. (2020). Characterization of Facial Trauma Associated with Standing Electric Scooter Injuries. *Ophthalmology*, 127(7), 988-990. https://doi.org/10.1016/J.OPHTHA.2020.02.007
[34] NACTO, "Guidelines for regulating shared micromobility", pp. 1-56, September 2019. Available in: https://nacto.org/wp-content/uploads/2019/09/NACTO_Shared_Micromobility_Guidelines_Web.pdf. Accessed on 10/07/2020.

[35] NACTO, "Global Urban Street Design", National Association of City Transportation Officials, pp. 1-426, October 2016. Island Press.
[36] PBOT, "2018 E-Scooter Findings Report", Portland Bureau of Transportation, pp. 1-36, January 2019. Available in: https://www.portlandoregon.gov/transportation/article/709719. Accessed on 12/07/2018.
[37] P.Rouzeau, "Protected Crossing", Application to design protected cross-roads 'dutch style'. Available in: https://github.com/PRouzeau/Protected-crossing. Accessed on 20/10/2020.
[38] M.Raz, "Bird chooses Israel to trial scooter recharging points", Globes, 6th Novemeber 2019, Available in: https://en.globes.co.il/en/article-bird-chooses-israel-to-trial-scooter-recharging-points-1001306089. Accessed on 3/11/2020.
[39] CEN European Committee for Standardization, EN17128:2020, "Light motorized vehicles for the transportation of persons and goods and related facilities and not subject to type-approval for on-road use - Personal light electric vehicles (PLEV) - Requirements and test methods", October 2020.
[40] REGULATION (EU) 2019/2144 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 November 2019.
[41] ETSI EN 302 264 V2.1.1 (2017-05) Short Range Devices; Transport and Traffic Telematics (TTT); Short Range Radar equipment operating in the 77 GHz to 81 GHz band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU
[42] CIGO! Platform web. http://www.smart-cigo.com/smart-cigo. Accessed on 10th November 2020.