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Exploring road safety in the era of micro-mobility: evidence from Rome

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Abstract

Urbanisation is taking place all over the world, and the number of vehicles on the road is increasing year by year. The worldwide trend highlights the importance of shifting from a private car to public transport and active mobility (e.g., walking, wheeling). Thus, micro-mobility is attracting many users who substitute short round trips and journeys for access/egress to transit services (e.g., home-work-home; home-school-home; tourist movements around historical monuments). Although micro-mobility has many advantages, there are also some disadvantages that need to be pointed out, as well as the road accidents involving such users. For this reason, the paper proposes a study of road accidents involved micro-mobility devices. It presents empirical evidence from Rome (Italy). The main factors are identified, and the patterns and users' behaviours that could guide the identification of the appropriate countermeasures to adopt are explored. The results of this study may be of interest for local authorities in integrating micro-mobility into urban mobility planning and in promoting new sustainable transport alternatives.

Keywords: micro-mobility, driving beehaviour, road safety, road accident.

1. Introduction

In the 1980s, the World Commission on Environment and Development (WCED, 1987) underlined the need to promote sustainable development. In 2015, the United Nations adopted the Sustainable Development Goals as a universal call to action to end poverty, protect the planet, and ensure that all people enjoy peace and prosperity by 2030 (United Nations, 2015; UNECE, 2020). Seventeen Sustainable Development Goals (SDGs; UN, 2015) and 169 targets have been identified and shared between all the countries and the stakeholders involved.

Through these goals and objectives, a "*world free from poverty, hunger, disease and where all life can thrive... A world with equitable and universal access to quality education at all levels, health care and robust protection, where physical, mental and social well-being is ensured*". Furthermore, the future of the Earth will be urban. In fact,

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according to Filippova et al. (2020), the world is becoming more and more urban. By 2050, the world's population is expected to grow by more than 9 billion people, 67% of whom will live in urban areas. On the other hand, the demand for urban mobility could explode from 25.8 trillion passenger-km in 2010 to 67.1 trillion passenger-km in 2050. In this context, the participants at the Tokyo U20 Summit in 2019 jointly stated that that "*building sustainable and resilient cities it is essential to safeguard the quality of life, livelihood and health of our citizens*" (Tokyo Mayors Summit, 2019). Obviously, due to the high impacts, mobility and transport must change and actively contribute to this process.

According to the SDG 11, which points out urban contexts, and in order to address the above mentioned issues in city planning, the European Commission (EC) promoted the concept of sustainable urban mobility, and published guidelines for the development and implementation of the sustainable urban mobility plans (SUMP, 2019; UN, 2015). In the past, several European projects have addressed this issue. Since its launch in 2002, CIVITAS has carried out research and innovation activities in the field of sustainable urban mobility and has enabled local authorities to develop, test, and roll out measures through a series of local projects. URBACT (Urbact, 2023), which ran from 2002 to 2006, built upon EU pilot projects that began in the late 1980s to develop integrated approaches to urban regeneration. Later, URBACT II focused on sustainable urban development across a wide range of policy areas, and it included capacity-building initiatives for the first time. URBACT III (2014-2020) involved more than 670 European cities. It focused on sharing good practises through transfer networks and the implementation of integrated action plans (Pellicelli et al., 2022).

Therefore, the negative impacts produced by urban vehicles have attracted much attention. In particular, attention has been paid to modifying the use of private transport. Promoting a shift from private cars to micro-mobility can represent a valuable measure to improve the sustainability and liveability of cities. Micro-mobility can help to replace trips by individual private cars and improve the coverage and accessibility of transit services, thereby subsequently reducing traffic impacts (e.g., pollutant emissions and congestion). In this way, the paper can contribute to define the strategies for increasing the use of micro-mobility devices (i.e., bicycles, e-bikes, electric scooters, electric skateboards, shared bicycles, and electric pedal-assisted bicycles; Sandt, 2019). These are preferably considered for movement at distances of up to 5 km (Campbell et al., 2016; McKenzie, 2019). According to several urban surveys, many commuting trips within urban/ areas are short round trips and for the access/egress to transit services (e.g., home-work-home; home-school-home; tourist movements around historical monuments; Fan and Harper, 2022). In Rome, for example, micro-mobility is an important innovation. As access to some zones of the city centre is prohibited for cars and heavy-freight vehicles, city users (travellers, residents, etc.) are increasingly using micro-mobility to cover short distances (Nigro et al., 2022). It encourages people towards more active mobility behaviour, which also contributes to well-being goals (Abduljabbar et al., 2021; Comi et al., 2022b; Nigro et al., 2022). This is due to its environmental friendliness (less pollution), efficiency (fuel costs are not relevant), manoeuvrability (it is possible on all types of urban roads), and so on.

The proliferation of these devices has had both positive and negative consequences. In fact, the rules for micro-mobility are not so clear and defined. Micro-mobility can be unsafe for a number of reasons. For example, it should be noted that there are no restrictions on users; anyone can take micro-mobility devices, etc. Thus, lacking sufficient skills, users can be a threat to themselves or others. Traffic regulations do not pay enough attention to this mode. For example, to introduce rules for the use of micro-mobility devices, Bai and Jiao (2022) described parking violations. In addition, the inexperience of users in riding micro-mobility devices and in non-reserved lanes causes several road accidents involving their users. When a micro-mobility user is involved in a road accident, the consequences can be very dangerous.

In this context, the paper proposes an investigation of road accidents involving micro-mobility devices and presents the evidence from Rome. The proposed road accident analysis aims to investigate the main factors that characterise an accident, in order to understand patterns and/or behaviours and, consequently, to guide the identification of the appropriate countermeasures to be adopted to avoid such accidents. The results of this study may be of interest to local authorities in integrating micro-mobility into urban mobility planning and in promoting new sustainable transport alternatives.

The paper is organised as follows. Section 2 presents the data used and the proposed research methodology of the investigation. Section 3 summarises and discusses the results of the investigation, while Section 4 draws conclusions and discusses the further development of this study.

2. Data and Methodology

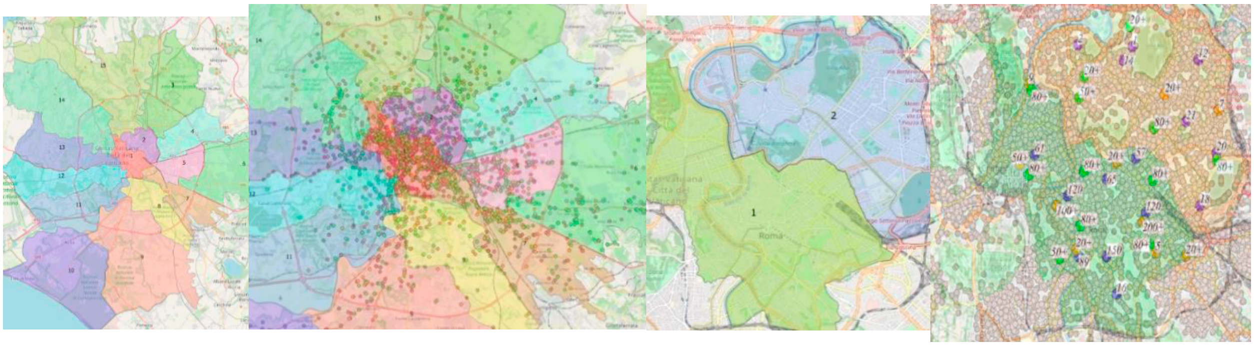
Statistical indicators identify Italy as one of the most active European countries in terms of urbanisation from 2018 to 2050 (UN, 2019). Rome is a large city with a high number of city users (i.e., residents, employees, tourists) with different spatial distribution. Rome has 15 municipalities with different characteristics and land uses (Comi et al., 2019). Furthermore, the concentration of users is in the city centre. On the other hand, this area has a list of conditions that push to point out the area in terms of road safety. For example, there are narrow streets with limited access for vehicles (heavy goods vehicles, cars, etc.) and a high number of pedestrians and cyclists. In addition, the authorities make environmental decisions on restrictions for vehicles (environment-constraints for access, time windows, etc.; Cipriani et al., 2019; Comi et al., 2008). Due to the trip characteristics (e.g., round and short trips), a large portion of passengers are moving to become micro-mobility users (Nigro et al., 2022). In fact, micro-mobility offers users a friendly way to move within the restricted area (e.g., flexible route, high permeability, etc.). However, the interference with other road users (e.g., buses, private cars) caused an increase in road accidents with relevant consequences for micro-mobility users, as detailed below. Hence, the need to study this segment of mobility (Carrese et al., 2021b). The presented analysis uses a large dataset consisting of 301,848 road accidents that occurred in Rome (Italy) between 2012 and June 2022. The study area covers 1285 km^2 and has a resident population of almost three million inhabitants (Figure 1a and Table 1).

The recorded accidents are those that required police intervention (reports from "Roma Open Data"). The information available for each accident is: the type, the number of people involved, the time and date, the location, the severity (unharmed, confidential prognosis, died, other) and the type and the number of involved vehicles. Other information relies with the road characteristics, weather, lighting and traffic conditions. In particular, about 375 road accidents (involving micro-mobility devices) occur annually and the number of road accidents involving micro-mobility devices increased by 2.6 % last year. First, the fleet composition is analysed identifying the main classes of users involved, e.g., vulnerable users (pedestrians and cyclists, as well as micro-mobility users), four-wheeled vehicles (e.g., cars), two-wheeled vehicles, public service vehicles and heavy vehicles. The fleet composition of the accidents in relation to the municipality in which they occurred, the month of the year, the time of the day, etc. are pointed out. Further analyses are ongoing to use data mining techniques to analyse the identified road accidents, to identify the most significant causes and the most recurrent patterns of road accidents by means of a descriptive analysis. Descriptive analysis could then be used to uncover groups or clusters of data objects based on similarities between these objects that arise as a result of interactions between independent variables.

The dataset therefore consists of information from around 10 years. First, the annual trend is examined, which shows a linear trend (Figure 2). With regard to the number of road accidents involved micro-mobility devices, it could be expected that the number of accidents could approximately double the number in 2021. Moreover, although the total number of road accidents in the city decreases from 2019 (also due to the restrictions implemented during the COVID-19 pandemic), the number of accidents involving micro-mobility devices raises. Such an increase becomes more significant when scaled with the total number of moving vehicles. According to Carrese et al. (2021), the flow of vehicles decreases by about 70%. It makes it relevant to point out the characteristics of micro-mobility road accidents.

3. Results and discussion

Continuing to explore the characteristics of road accidents in Rome (Table 2) over 10 years of investigation, it emerges that the "side collision" has a high level every year and the "run-off roadway" has a low level. As shown in Comi et al. (2021), March and November are still the months with the highest level of accidents, while August is the month with the lowest number. It is also worth noting, the increase in the share of "sudden braking" (from 2.3% to 2.7%), "vehicle stopped/parked" (from 8.9% to 14.3%) and "pedestrian hit" (from 6.6% to 6.9%). Nevertheless, there is a downward trend for "head-on collision" (from 12.5% to 11.5%) and "other" (from 2.8% to 1.6%).



a) study area b) location of accidents that involved micro-mobility devices c) study area zooms I and II municipalities d) location of micro-mobility stations and number of devices available

Figure 1 - Road network data

Table 1 – Number of people involved in accidents (with micro-mobility devices)

District	Population	2014	2015	2016	2017	2018	2019	2020	2021	2022	2022*	Total
I	185,435	68	63	65	89	52	79	77	151	132	264	908
II	168,354	42	34	32	39	18	44	37	66	49	98	410
III	205,019	11	19	10	17	14	9	14	18	22	44	156
IV	176,981	11	14	14	14	13	16	17	19	24	48	166
V	247,302	20	21	25	30	22	31	48	61	54	108	366
VI	257,534	21	21	17	15	20	25	22	26	20	40	207
VII	308,076	30	36	23	28	33	33	49	65	51	102	399
VIII	131,180	11	14	6	10	12	21	20	23	26	52	169
IX	182,026	23	16	17	16	11	15	19	13	18	36	166
X	231,723	68	63	34	38	33	31	35	36	22	44	382
XI	155,586	8	6	13	7	5	7	12	21	17	34	113
XII	141,104	9	9	14	10	8	12	10	26	16	32	130
XIII	134,147	12	5	14	15	7	14	10	31	18	36	144
XIV	191,776	6	8	7	15	5	8	16	27	21	42	134
XV	159,984	12	14	17	13	7	19	27	23	15	30	162
Total	**2,877,215**	**352**	**343**	**308**	**356**	**260**	**364**	**413**	**606**	**505**	**1010**	**4517**

2022 – the predicted number based on data January-July 2022*

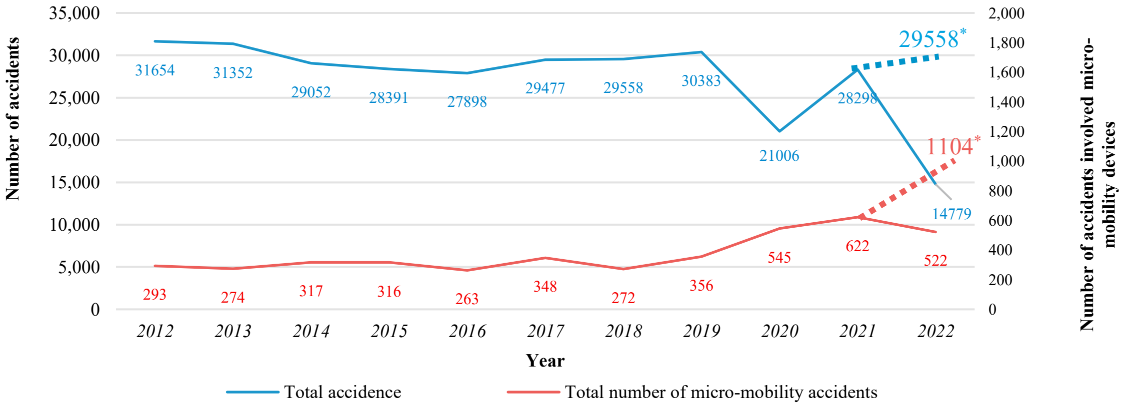


Figure 2 - The number of total accidents and accidents involved micro-mobility devices (**forecasted trend*)

Table 2 presents the cardinality of accident types by year. In all years, the main type of accident is a “side collision” (37.5%). The “with obstacle”, “real-end” and “head-on” types of collision also have a high percentage among each other. “Run-off roadway” (0.9%) is the least frequent type.

Table 2 - Types of road accidents

Type of accident	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022*	Average
Collision with obstacle	10.3%	13.6%	16.0%	16.7%	16.9%	13.3%	17.4%	13.8%	12.2%	10.8%	8.5%	**14.0%**
Rear-end collision	15.6%	15.1%	15.0%	14.7%	15.2%	15.8%	14.8%	15.1%	14.8%	15.8%	15.9%	**15.2%**
Side collision	40.2%	38.4%	36.8%	36.4%	36.8%	38.4%	36.4%	37.3%	36.5%	37.3%	37.8%	**37.5%**
Head-on collision	12.5%	12.1%	12.0%	12.1%	11.3%	11.9%	10.9%	11.1%	11.6%	11.4%	11.5%	**11.7%**
Pedestrian hit	6.6%	6.5%	6.7%	6.7%	6.4%	6.6%	6.4%	6.6%	6.6%	6.0%	6.9%	**6.6%**
Sudden braking	2.3%	2.0%	2.3%	2.3%	2.2%	2.2%	2.2%	2.0%	2.0%	2.4%	2.7%	**2.2%**
Vehicle stopped/parked	8.9%	8.6%	8.7%	8.5%	9.1%	9.4%	9.7%	11.9%	13.7%	13.9%	14.3%	**10.2%**
Run-off roadway	0.8%	0.8%	1.0%	1.1%	0.8%	0.9%	0.8%	0.9%	1.0%	0.8%	0.8%	**0.9%**
Other	2.8%	2.9%	1.4%	1.4%	1.2%	1.4%	1.3%	1.2%	1.5%	1.6%	1.6%	**1.7%**
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Subsequently, the attention has been paid to the involvement of micro-mobility devices. Table 3 presents the types of road accidents in relation to the types of devices involved, i.e., bike, e-bike, and others (i.e., hoverboard, monowheel, segway and e-scooter). The "collision with obstacle" and "side collision" is about half of the total number of accidents. The collision with "vehicle stopped/parked" is also significant. The "pedestrian hit" and "run-off roadway" represent approximately 1% of total accidents (Table 3).

Table 3 – Micro-mobility devices involved in different accidents

	Micro-mobility devices			
Type of accident	**bike**	**e-bike**	**other devices**	**Average**
Collision with obstacle	26.5%	25.0%	25.0%	26.2%
Rear-end collision	8.8%	0.0%	1.1%	7.6%
Side collision	27.8%	25.0%	18.8%	26.4%
Head on collision	5.6%	0.0%	6.3%	5.6%
Pedestrian hit	0.2%	0.0%	0.0%	0.2%
Sudden braking	7.8%	16.7%	6.3%	7.7%
Vehicle stopped/parked	15.1%	8.3%	18.2%	15.5%
Run-off roadway	1.0%	0.0%	1.1%	1.0%
Other	7.3%	25.0%	23.3%	9.8%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**

The location of accidents, which involved micro-mobility devices (Figure 1b) depends on the municipality. Municipality I and II are the inner areas (Figure 1c). There is a high level of city users. This is where the highest number of accidents occur. In addition, attention should be paid to municipalities V and VII that have the highest number of residents (Table 1). The Figure 1d presents the location of the stations of micro-mobility devices.

It is well known that Rome is a very touristic city. Each municipality has different characteristics in terms of city users. For example, the inner area (Municipality I and II) is the smaller one but with the highest proportion of tourists. On the other hand, the surroundings are the more populated areas (e.g., Municipality V and VII). However, the number of accidents involving micro-mobility devices does not follow such a pattern. In the inner area, where occasional and inexperienced drivers could be present, the number of accidents increases. It emerges that: Municipality I has the highest number of road accidents involving micro-mobility (22%), also due to the high share of this mode option. Municipalities II, V and VII have a similar number of road accidents, but they refer to inner area (II) and surrounding areas (V and VII); moreover, the population is quite different 10%, 9% and 10% respectively; if the number of road accidents is scaled in relation to the population, the level reached by Municipality VIII becomes relevant, i.e., the fourth most dangerous municipality in the city (4%).

The Figure 3 reports the *percentage* of road accidents involving micro-mobility devices. Two trends can be revealed: before and after 2019. In particular, from 2012 to 2019 the trend is quite flat and around 1%, while after 2019, it increases exponentially reaching the 3.5% in 2022. It demonstrates that Rome needs to implement useful measures and that much more effort should be put into it.

The subsequent reported analysis refers to the *location* of accidents involving micro-mobility devices. More than 66% occur on straight roads also due to the characteristic paving of Roman roads (Table 4), and as argued by Comi et al. (2022a), measures addressed to improve safety in these locations can have safety benefits and thus contribute to improving urban sustainability. Analysing types of micro-mobility device (Table 4), it emerges that "bike" is involved in the highest number of accidents registered in the analysed period, although. However, it should be noted that. This is because the dataset consists of information about bikes from 2012 to June 2022. Although the "e-bike" and "other" emerged just in 2020, there are many accidents in a "straight" location. Rome has a lot of bridges and urban tunnels. Nevertheless, users of micro-mobility devices choose an alternative road to the urban tunnel. In addition, the "not regulated intersections" are an undesirable location for the movement of the devices.

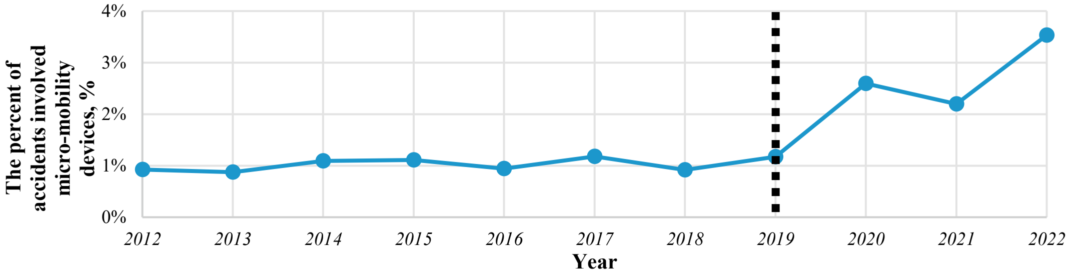


Figure 3 – The percent of accidents involved micro-mobility devices from 2012 to June 2022

Table 4 - Number of accidents involved micro-mobility devices by location

Device	*straight*	*curve*	*urban tunnel*	*not regulated intersection*	*intersection with traffic lights*	*intersection with round bound*	other	Total
Bike*	638	55	5	179	57	30	37	**1001**
e-bike**	8	1	0	1	0	0	2	**12**
Other**	114	9	0	17	16	4	16	**176**
Total	**760**	**65**	**5**	**197**	**73**	**34**	**55**	**1189**

*2012- June 2022
** 2020-June 2022

The number of persons injured and the number of deaths are given in Table 5. The result of accidents in many cases is one person with injuries. These are high speed accidents and collisions with road equipment. Nevertheless, "nothing" means that the micro-mobility devices crashed or it was an accident with a car and the driver did not have injuries (Table 5).

Table 5 - Number of people injured, dead, and nothing in micro-mobility accidents

Device	*Injuries*				*Deaths*	*Nothing*	Total	Period
	1 person	2 persons	3 persons	4 persons				
bike	705	34	5	2	4	263	**1013**	2012-Jun 2022
e-bike	5				1	5	**11**	2020-Jun 2022
other	125	3			1	36	**165**	2020-Jun 2022
Total	**835**	**37**	**5**	**2**	**6**	**304**	**1189**	

The analysis performed on the weather condition shows that the main percentage has "normal" weather without additional characteristics (80.23%). However, when it is cloudy the accidents were in 13.36% of the accidents involved micro-mobility devices. The lower impact of rain is 2.91%, as the use of such a device is rather limited in bad weather conditions. In addition, the proportion of road accidents is quite high given the limited number of micro-mobility users. Fog, wind, and hail were also investigated, at 1%.

The particular attention was paid to municipalities I and II. As already mentioned, this area represents the inner area of the city area with a high level of accidents and city users. In addition, municipalities V, VII, and VIII have a dangerous level of accidents. Figure 3 shows the monotonic values from 2012 to 2019. Based on this, the interest is in 2021 and 2022 full years. The tendency per month for 2020-2021 (Fig. 4a) shows a higher number of accidents involved micro-mobility devices from May to July. August has a low frequency. Then, September and October show a sharp increase. Nevertheless, winter has a low number of accidents, because the weather is not comfortable for use. The Fig. 4b investigated a different trend between municipalities. The Ist has a monotonous trend, except for June with the highest level. The Municipality II has April and September as dangerous months. The Municipality V has a high level of accidents involving micro-mobility devices from May to September, excluding August. The Municipality VII has a curve that rises and falls. The Municipality VIII has an upward trend from January to December.

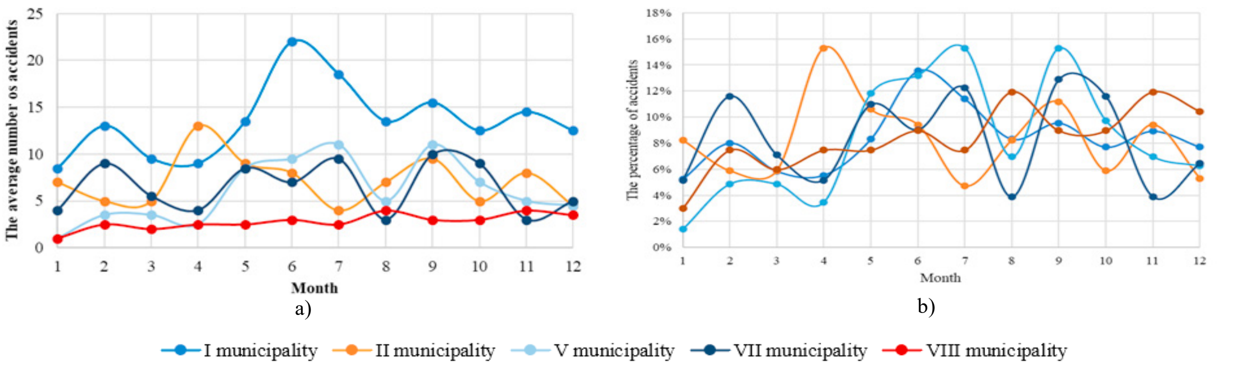


Figure 4 - The average number of accidents involved micro-mobility devices (a) and percentage of it (b) per months by investigated municipalities

The results allow investigating the number of accidents by day of the week (Fig.5a). Sunday is a less popular day. Nevertheless, Wednesday in 2020 and Thursday in 2021 are the most “dangerous” days for the micro-mobility devices. Figure 5a also shows that the number of accidents involved micro-mobility devices multiplies about twice from 2020 to 2021. The peak and off-peak periods are defined according to Fig. 5b. The peak hours are 13.00 in the middle of the day and 17.00-20.00, i.e., the most popular pastime in the evening. The period from 21.00 in the evening to 7.00 in the morning is analysed like an off-peak period. Nevertheless, the period from 8.00 to 13.00 has a growing characteristic. The period from 13.00 to 17.00 has a high level of accident rate. After 20.00, it decreases.

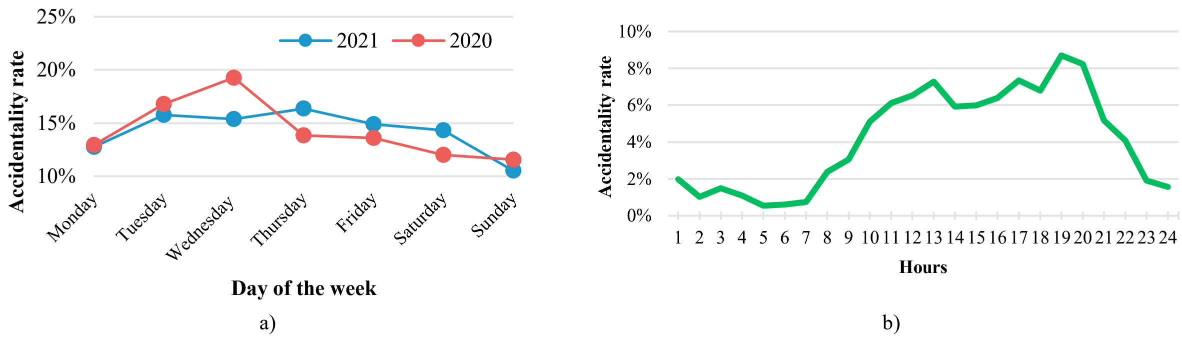


Figure 4 – The distribution of accidents by day and year (a) and by hours (b)

4. Conclusions

Urbanisation is on the rise and is forcing a large number of urban movements that have a strong negative impact on the sustainability and liveability of cities. Researchers, planners, and authorities pay a lot of attention to the optimisation and development of the transport network. On the other hand, the European Commission’s goal for a sustainable and liveable city has pushed for more environmentally friendly solutions. Shifting from the private car to an alternative mode of transport is a great challenge. The best choice is to move towards active mode, such as walking and micro-mobility devices. It allows city users to pay attention to health (walking as a sport) and zero-emission devices (e-bike, scooter, etc.). Then, nowadays, the micro-mobility mode is gaining popularity. Users prefer to be flexible and have access to all places, etc.

A good case of implementing micro-mobility devices is Rome (Italy). This city has a large number of users due to a large flow of city users, including tourists. Rome has some restrictions on access to the city centre and this area is large. Therefore, the demand is high and there are a lot of stations and applications that offer the ability to take a device from a convenient location. Unfortunately, there is also a negative side. The micro-mobility devices are not safe, secure, unregulated, etc. They have been on the increase since the 2020s and are the cause of many accidents. Nevertheless, the tendency of accidents involving micro-mobility devices is increasing from year to year.

Of the 15 municipalities, the most dangerous area is the inner area, where some restrictions on vehicles are also in place. The trend was analysed by month, day and hour. Each municipality has a different tendency from month to month. The results address towards measures for traffic user separation and to make decisions and rules according to the profile of each municipality. The evening peak hour has to be considered as a priority, as many factors influence driving style, visibility, etc.

Traditionally, such new mobility segment characteristics are neglected in road accident management strategies, which generally do not take into account the micro-mobility devices. Besides, as the road accidents studied are also closely related to the built environment, a comparison was made between the road accident patterns in different municipalities and it was confirmed that they are highly spatially dependent. In addition, the relationship with traffic patterns should also be investigated using traffic count data in sections within each municipality.

Further developments of this study are ongoing. They mainly concern additional investigations on new districts and traffic counters, and the use of data mining techniques to identify clusters of accidents involving micro-mobility. Finally, the development of performing models for the spatial location of road accidents as a function of the infrastructural and functional characteristics of geographical areas through the conjoint use of time series and spatial regression methods should be explored.

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