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Developing micromobility in urban areas: network planning criteria for e-scooters and electric micromobility devices

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Abstract

The rapid spread of micromobility, characterized by the use of e-scooters and other electric micromobility devices, has brought both urban and transport planners to deal with the presence of a huge number of new vehicles with different size and technology with respect to those traditionally circulating in urban areas. In particular, the massive use of e-scooters is leading technicians and administrations to think about how to re-design urban spaces to accommodate the new form of mobility. Many European countries are starting to set rules for the novel users, some of them by equating e-scooters with bicycles. However, it is necessary to focus on some peculiar aspects of this mode of transport, namely safety, access to the main points of interests and integration with public transport. Based on this premise, this work identifies and proposes a set of criteria for the planning and design of a network of infrastructures for micromobility devices. The criteria are applied to evaluate the case study of Palermo (Italy). Suggestions for planning interventions are provided based on the analysis of different data sources and case studies, which can constitute a guidance for administrators, urban and transport planners.

Keywords: e-scooter; active modes; urban safety

1. Introduction

Micromobility devices include mainly electric powered personal mobility vehicles, such as hoverboards, segways, electric scooters and monowheel.

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In particular, electric scooters (i.e. e-scooters) are non-self-balancing vehicles, powered by an electric motor, consisting of a footboard, handlebar with column, brakes, wheels, battery, motor, control unit and lights. They are generally used to perform short-distance trips in a brief time. For this reason, they are a good candidate to become an alternative to private car, especially for the first/last mile connections. The success of this innovative transport mode cannot ignore the urban spaces in which the end user will be able to ride it. Due to the technical characteristics and performance of the vehicle, a proper network and infrastructure planning can play a key role in spreading its use. Indeed, the lack of planning and design of dedicated infrastructures can be the cause of possible traffic accidents, especially when their users are crossing connection areas in which safe conditions cannot be ensured, due to the interaction with motorized traffic.

This paper identifies and proposes a set of criteria that must be taken into consideration for the planning and design of a network of infrastructures in which e-scooters could circulate. The identification of the criteria is partly based on the principles for planning the cycle network developed by European Union, i.e.: Coherence and Accessibility, Linearity, Safety, Attractiveness, Intermodality and Comfort.

The final aim of this paper is to give suggestions for planning interventions aimed at satisfying these criteria, drawing inspiration from case studies in which e-scooters and electric micromobility devices have already established. The resulting set of criteria can provide a guidance for administrators, urban and transport planners to ensure safer and sustainable mobility conditions in the usage of this new form of mobility, as shown in the application to the case study of Palermo.

2. Research framework

In Europe about 30% of trips made by car are less for distances than 3 kilometres and 50% less than 5 kilometres. In this range of distances, it would be advisable to encourage the spread of more ecological forms of mobility, i.e. walking and cycling, the so-called "active mobility" (EC, 2016). Active mobility must be considered an integral part of an overall planning process, coordinating the needs of pedestrian and bicycle users with those private motorized traffic and public transport (EC, 2007). Through EU co-funding, both at national level or by stakeholder within Europe, several documents have been made available to support the process of implementing cycling infrastructure and associated measures (EC, 2021), e.g. the Guidelines for developing and implementing Sustainable Urban Mobility Plans (SUMPs) (ELTIS, 2021). In this legislative scenario, e-scooters stays in the middle: on the one hand, these vehicles are certainly more ecological than private cars; on the other hand, being electric vehicles, they do not have the same advantages as active modes (i.e. improving users' health); moreover, they generate several safety issues. This brings to frame the role of e-scooters in sustainable mobility plans as vehicles to perform first-last mile trips in connection with more sustainable modes (overall transit).

Since 2018, many countries in Europe have begun to regulate the use of e-scooters within their legislative frameworks; but their innovative aspect and the different levels of decision-making (from national to local level), led to the implementation of different regulatory approaches. In most European countries, e-scooter traffic is allowed on the road, in bicycle infrastructures and on sidewalks; in other cases, their circulation on sidewalks and pedestrian areas is prohibited. The parking of vehicles is one of the major problems affecting urban spaces, also due to the fact that this mode is frequently associated with sharing schemes. The USA has experimented strategies to tackle this issue; an interesting best practice is the one in Santa Monica (California, USA) where staging areas for shared e-scooters have been created "utilizing a curb bulb out space created at a mid-block crosswalk" (Shared Micromobility Playbook, 2020). Furthermore, circulation on sidewalks is strongly discouraged to avoid potential conflicts between vehicles and pedestrians, due to the difference in speed (Fig. 1a). In Europe, Paris was among the first European cities to provide dedicated spaces for shared micromobility, creating around 2,500 exclusive parking hubs "Zone partagée de remisage" (ZPR), reserved exclusively for e-scooters (Fig. 1b). The objective is to reduce the possibility of vehicles hindering sidewalks and pedestrian areas and possible interference with pedestrians. In addition to preferred parking spots, on-street corrals for e-scooters were created.

Nevertheless, it is not enough only to rethink and adapt transport systems and redesign the road infrastructures, but it is also essential to investigate the users' attitude towards this new mode, focusing on the transport demand (Reck et al., 2021), but also on safety issues. A recent review highlighted that health and safety constitute the most studied research areas in relation to e-powered micromobility (O' Hern and Estgfaeller, 2020). Other studies investigated user preferences in relation to these innovative forms of mobility; Boglietti et al. (2021) performed a survey on e-powered micro personal mobility vehicles, by analysing the motivations, the parking behaviour and the modal shift generated using these transport means. Zhang et al. (2021) developed a choice model to analyse e-scooter route choices preferences on university campus. The use of big data has also been investigated as a support a support for micromobility planning both in terms of mobility patterns and characteristics of the service (Feng et al., 2020). To the best of the authors' knowledge, no studies have investigated the quality design principles for e-scooters' infrastructure and network: in this paper the authors' aim is to fill this literature gap by providing specific criteria and principles for this new form of mobility but relying on already consolidated assumptions linked to active modes.

Fig. 1: Parking areas for share e-scooter in (a) Santa Monica (Source: www.santamonicanext.org/2018/09/regulating-the-scooters/); (b) Paris (Source: Le Figarò, 2020)

3. Data and Methods

3.1. Territorial framework: Italy

E-scooters have recently started to appear in Italian cities. In contrast to the international definition of micromobility, the Italian one does not include bicycles. At the beginning, micromobility has been introduced via pilots in some cities thanks to a national decree in 2019 (the so-called "Decreto Toninelli") allowing these vehicles to circulate only on some infrastructures (i.e. 30 km/h zones, cycling paths and pedestrian areas). Later on, a new National decree established that e-scooters would have been considered like bicycles, thus since 2020 they are currently allowed to circulate in the street network like bicycles. Shared e-scooters services are currently present in many Italian cities, among which Milan, Naples, Rome, Palermo and Turin. A big boost to this new type of urban mobility has also been given by the National incentives to buy electric vehicles ("Buono mobilità"†), mainly bicycles and e-scooters, to contrast the lower capacity of public transport and the likely increase of private car use due to social distancing rules induced by the COVID-19 pandemic. By the same token, many cities started building new cycling infrastructures to foster this type of sustainable mobility. However, the differences between bicycles and e-scooters are usually not considered while planning and designing new infrastructures. In this respect, these two vehicles are very different and imply different criteria to guarantee a safe mobility.

3.2. Criteria Selection

Given the current similarity to bicycles established by the Italian government, the definition of the design criteria of a network for micromobility cannot disregard the ones generally considered in the case of cycle network design. A starting point can be constituted by the "Basic quality design principles for cycle infrastructure and

† https://www.mit.gov.it/comunicazione/news/sostenibilita-fino-500-euro-per-buono-mobilita (in Italian; accessed on 17 May 2021)

networks" established by the European Union (EU, 2020). These requirements can be used to assess the quality of the existing network and infrastructure, but they also aim to be considered as goals to be achieved by the cities, to promote the modal shift from motorized transport modes to active mobility. However, while the benefits associated with the use of bicycles are universally recognized in terms of environmental sustainability and effects on physical well-being, e-scooters have been criticized by public opinion since they are considered unsafe and unhealthy (they require minimal physical effort) and for their frequent use on potentially pedestrian distances. A further negative impact often attributed to this method in the case of e-scooter sharing is the one linked to the parking of vehicles in unauthorized areas, often on the sidewalk, obstructing pedestrian mobility. Network planning should help in discouraging these unproper behaviours.

Based on these premises, the following network planning principles are proposed below, adapted from the EU basic principles for cycling to the innovative forms of micromobility:

Coherence and accessibility of routes, allowing users to easily move from their origin to their destination. These principles are similar both in the case of bicycles and e-scooters and underline the importance of adequate knowledge of the demand for travel and of the main Origin-Destination patterns. In particular, in the case of e-scooter sharing, it is essential to regulate the presence of dedicated parking spaces that avoid the improper occupation of other infrastructures.

Linearity, with the creation of direct routes allowing to guarantee adequate travel times and distances.

Safety and Security. E-scooters and other micromobility vehicles are considered less safe than bicycles, both in terms of stability and of interaction with other road users. In a study conducted in Washington D.C. (Chang and Miranda-Moreno, 2020), from the comparison between e-scooters, bicycles and pedestrians, it emerges that bicycles reach an average speed of 20 km/h, e-scooters 15 km/h and pedestrians 6 km/h, both on sidewalks and roads, and traffic conflicts are similar. In general, users of micromobility vehicles often feel vulnerable when they are sharing the space with motorized vehicles due to differences in speed, the size of the vehicles, lack of infrastructure maintenance and traffic volume. There may also be a lack of understanding by drivers of motor vehicles of the needs of micromobility users, also due to the novelty represented by this type of vehicle. Moreover, micromobility users adopt distracted driving behaviours, which are among the main causes of accidents with this new transport mode. Therefore, among the principles of quality design, it is necessary to aim at increasing actual and perceived safety and adequately train users on the correct behaviours to adopt, by including this new form of mobility in road safety education paths, specifying its peculiarities with respect to cycling. From the point of view of security, private e-scooters seems to have the advantage of reducing the problem of theft typical of bicycles, as they are more "compact" and transportable.

Attractiveness and Intermodality. In line with what happens for bicycles, users are encouraged to use this type of mobility if the infrastructure and the route are aesthetically attractive and pleasant, and equipped with dedicated services. In particular, private and shared bicycles have a high potential to bridge the last mile gap of public transport, as demonstrated by recent studies (Capodici et al., 2021). In the case of e-scooters, it is essential to guarantee intermodality with other transport modes, with a dual purpose: (i) in the case of public transport systems, the e-scooter allows to increase the number of users who are able to access quickly and with less physical effort at stations located at greater distances than pedestrian ones; (ii) in the case of private transport, the use of these vehicles can be encouraged to travel the last mile of the journey from the parking lot to the central areas. In case (i) it is essential that suitable and safe parking spaces are provided at the main transport hubs; moreover, it is advisable to define suitable spaces to store the vehicles in public transport where it is allowed to bring them on board. In case (ii) it is necessary that the parking lots are suitably linked to the main network of dedicated routes through a direct and safe connection.

Comfort. Finally, it is essential to ensure good driving comfort. Some considerations in this regard can be equated to those valid in the case of cycles, for example avoiding discontinuities (steps or illegal stops along the route) and providing refuge from adverse weather conditions. Due to the small size of vehicles, e-scooter drivers experience more vibrations than traditional cyclists (Cano-Moreno et al., 2019). Failure to maintain the infrastructure is one of the main causes of accidents for this type of vehicle and this leads drivers to often pay more attention to the characteristics of the pavement than to other road users, generating traffic conflicts.

Principles, criteria and possible suggestions for the design of the dedicated network are summarized in Table 1.

Table 1. Principles, criteria and design recommendation for micromobility networks.

PRINCIPLES	CRITERIA	DESIGN RECOMMENDATIONS
COHERENCE and ACCESSIBILITY	- Continuity of the route - Freedom of choice of routes - Route connectivity - Appropriate parking spaces	- Limit interruptions and minimize changes in the road section; - Signalling and clear indications along the route; - Consider the opportunity of at least two path alternatives; - Ensure the presence of parking spaces and regulated by signage; - Route design to ensure accessibility to the main POIs.
LINEARITY	- Adequate operating speeds - Ratio between direct distance and distance actually travelled (Detour factor)	- Geometric design to allow a constant operating speed consistent with the road level considered; - Minimize overall travel time by considering detours, number of stops at intersections, traffic lights and slopes: - Prioritize non-motorized traffic over motorized one.
SAFETY and SECURITY	- Reduce the risk of accidents - Reduce the risk of conflicts - Reduce the risk of theft	- Identify any links between accidents and road design; - Segregate e-scooter traffic from high-speed vehicular one; - Reduce speeds and volumes of vehicular traffic in mixed use areas; - Ensure good visibility, especially at intersections; - Include the new mode in road safety education paths; - Presence of secure parking facilities close to the main POIs.
ATTRACTIVITY and INTERMODALITY	- Attractiveness of the context - Connection options with different transport modes	- Ensure good lighting and visibility; - Create connection paths with the park-n-ride facilities; - Provide at public transport nodes a safe parking area; - Define suitable spaces for resting vehicles in public transport (if allowed to bring vehicles on board).
COMFORT	- Reduced slopes - Reduced number of stops - Protection from adverse weather conditions - Low vibrations	- Reduce the elements of discontinuity (e.g. steps) - Reduce illegal parking of other vehicles on the route - Ensure the presence of trees to create areas of shade and shelter - Ensure constant maintenance of the pavement

In the following section we will apply the concept of Table 1 to assess the quality of the infrastructure in the case study of Palermo and will provide some potential intervention measures.

4. Case study

Palermo is a city of approximately 650,000 inhabitants located in Sicily, Italy. It suffers many transport problems as the majority of cities in Southern Italy, especially related to the predominant use of private vehicles, causing high levels of traffic congestion. During the last years, the city of Palermo has been undergoing many changes in its transport systems, including the building of a tram network, and has plans to develop future sustainable scenarios as envisioned by the Sustainable Urban Mobility Plan of 2019. A Limited Traffic Zone (LTZ) has been established in the city centre to improve its liveability by limiting the presence of private vehicles. In addition, several bike lanes have been built to foster cycling mobility and shared mobility options have been raising (e.g. bike and car sharing). In this evolving context, also e-scooters can have a role and recently started to appear, both as private vehicles and as part of a shared mobility service. At present, five e-scooter sharing companies operate in Palermo: Link, Dott, Wind, Helbitz and Bird. The rules imposed by the city administration for the service foresee that vehicles can travel at a maximum speed of 25 km/h, users aged 14 to 18 must wear a helmet and vehicles cannot be parked in parks and public gardens, but only on stalls dedicated to bikes and mopeds[‡]. However, there are several cases of rule violations and some accidents also occurred, raising the problem of a correct planning and management of such new services and vehicles. Based on this premise, in the following the case of e-scooter mobility in Palermo will be analysed according to the criteria defined in section 3.2.

[‡] https://sicilianews24.it/monopattino-sharing-piu-di-1000-mezzi-a-palermo-regole-e-tariffe-650112.html (in Italian; accessed on 19th May 2021)

In this paper we conducted a first analysis for the city of Palermo, based on the information provided by the companies and open GIS. All the five companies have defined a circulation area for scooters. Fig.2a shows the areas of 3 of the 5 companies (as for the other two companies, they foresee similar areas for which at present it has not been possible to find a clear mapping), corresponding to the urban area of Palermo and with the seaside neighbourhood of Mondello, in the north. Fig.2b shows the streets network included in the area; we exported the network from the OpenStreetMap database, and we filtered the network intended for e-scooters by excluding the service roads (e.g. inside parks and hospitals) and the routes excluded from e-scooters traffic (e.g. stairs, highways). A total of 3874 arcs forms part of this network. The lack of coverage in the peripheral areas is the issue that at first glance emerges from Fig.2. This is quite common for this type of service, for several reasons: (i) most of the daytime population is located downtown; (ii) operators want to avoid peripheral roads which generally have higher maximum speeds than urban ones; (iii) a very large service area generates a difficult relocation of the e-scooters according to the general demand peaks.

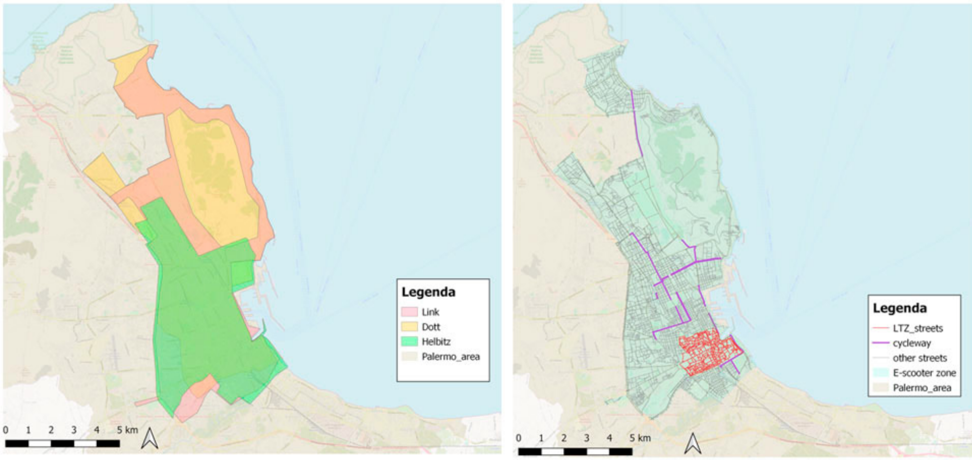

Fig. 2. (a) Operation areas for three of the six e-scooter services in Palermo and infrastructure involved (b)

The service area includes the segregated cycle paths in the Palermo area and the LTZ in the historic centre, allowing, in these facilities, a safer and more comfortable riding of the vehicle. More in detail, Fig.3 shows the coverage of main facilities (health, educational, social facilities and public administration) and of public transport stops. While a low number of points of interest remain uncovered, a large amount of public transport stops is not served by e-scooters.

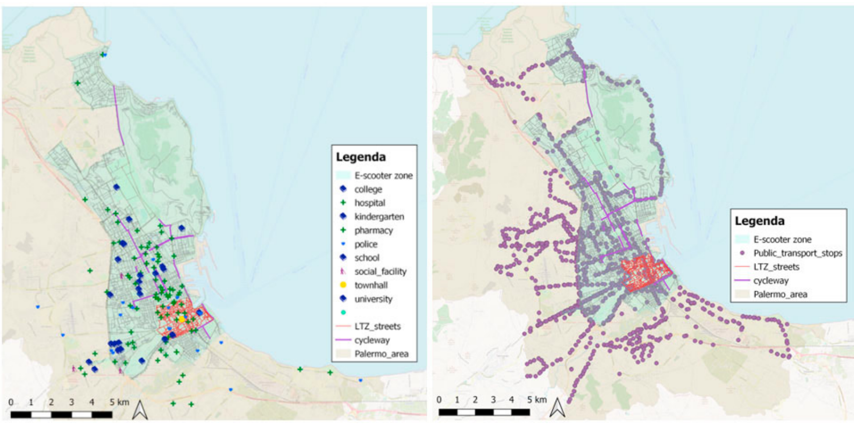

Fig. 3. Points of interest (a) and public transport (b) coverage of the e-scooter network

Finally, the service is totally free-floating, i.e. no dedicated parking areas are provided by operators; the rules of the municipal administration allow parking only in correspondence with dedicated stalls for bikes and mopeds. Only the Bird company provides predefined parking areas, in order to allow the correct use of the vehicle and avoid clutter on the street[§]. This generates difficulties in finding free stalls and does not guarantee safety neither it avoids the risk of theft in the case of a private e-scooter. In addition, the urban public transport company prohibits on board transport of the e-scooters; these two facts make the modal exchange between e-scooters and public transport less easy, while it should be encouraged. Table 2 summarizes the fulfilment of the criteria presented in previous section for the e-scooter network in Palermo.

Table 2. Checklist of criteria satisfaction for Palermo.

CRITERIA	**Yes/No (Y/N)**	**COMMENTS**
Continuity of the route	Y, inside the area	E-scooters allowed to travel on all roads inside the dedicated area → continuous routes and ease of choice of routes
Freedom of choice of routes	Y, inside the area	
Route connectivity	No	Services only in the central area of Palermo/parking is not allowed in some areas →coverage is not guaranteed.
Appropriate parking spaces	No	Fully free floating → the companies do not provide parking spaces. Parking only in correspondence with dedicated stalls for bikes and mopeds.
Adequate operating speeds	Y, inside the area	continuity of the network → adequate speeds and low detours
Detour factor	Y, inside the area	
Reduce the risk of accidents	No	E-scooter traffic coexist with vehicular one, even in areas with speeds higher than 30 km/h
Reduce the risk of conflicts	No	
Reduce the risk of theft	No	Fully free floating → the companies do not provide parking spaces. Parking only in correspondence with dedicated stalls for bikes and mopeds
Attractiveness of the context	No	LTZ included in the network, and, for some operators, also the new redeveloped area of the port. Parks excluded from the network
Connection options with different transport modes	No	Peripheral public transport stops excluded from the network. No transport mode interchange areas. It is forbidden to carry e-scooters on board.
Reduced slopes	No	E-scooters allowed to travel on all roads inside the dedicated area → no attention paid to slopes
Reduced number of stops	/	Needs in-depth survey
Protection from adverse weather conditions	No	No proper facilities are provided
Low vibrations	/	Needs in-depth survey

5. Discussion and Conclusions

The rapid spread of e-scooters in urban areas has brought new challenges for city administration and planners, both in terms of safety in the interaction with motorized vehicles and complementarity with active transport modes. While the spread of e-scooters internationally has been around for some time, European states are recently adapting their regulations for these innovative modes of transport: in particular, Italy has equated the circulation of e-scooters with that of bicycles.

In this context, a framework of criteria for the design of a network for the circulation of scooters, also shared with other modes of transport, has been proposed in this study, taking inspiration from the European guidelines for the design of the cycle network. The definition of criteria included some fist indicators and drafted design recommendations, suitable for the Italian case, but scalable to other contexts. The framework was tested on the case study of Palermo, demonstrating that some criteria are already met within the restricted operation area of the e-scooter sharing services, which have been recently introduced in the city. However, the low coverage of the service does not allow to guarantee adequate accessibility from the more peripheral areas, thus eliminating the fundamental function of integration with public transport for the first-last mile.

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https://www.vaielettrico.it/bird-sbarca-a-palermo-con-400-monopattini-leettrici/ (in Italian; accessed on 19th May 2021)

This paper presents a first set of criteria and applied it to a single case study. Future research endeavours might enlarge the analysis performed by including more cities and performing an in-depth multicriteria evaluation, both to validate and modify the set of criteria according to the context of implementation and to weigh them from a multistakeholder perspective. Besides, a detailed spatial analysis could be helpful to support the planning and design of suitable and safe networks for micromobility, as usually performed in the case of active modes (Ignaccolo et al., 2020).

This is one of the most critical issues for administration and e-scooter usage and, in general, for all micromobility modes: shared micromobility is currently seen by administrations as a recreational mode, and its social value as commuting mode is not properly assessed when contracting such services to private companies. However, public administrations cannot ignore the potential of this new mode of transport and should include it in future planning scenarios.

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