Modelling of Micromobility (M3) - Prestudy on Knowledge Needs and Usage Patterns

Research project funded by Trafikverket (TRV 2019/87471)

Final report
January 19, 2021

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Foreword

This report documents the results of the research project ”Modelling of micromobility (M3) - Prestudy on knowledge needs and usage patterns” which was operated by KTH Division of Transport Planning from December 2019 to December 2020. The project was funded by Trafikverket (Swedish National Transport Administration) through the Centre for Traffic Research (CTR) and the Planera research portfolio. Per F Eriksson handled the project at Trafikverket.

The project was led by Erik Jenelius. Hugo Badia Rodriguez conducted the state-of-art review and supervised the stakeholder interviews. Mariana Montelo conducted and summarized the interviews, and Eric Lansner performed the empirical travel pattern data analysis.

We would like to thank Björn Idrén at Voi Technology for sharing the e-scooter trip data used in the empirical analysis, and all stakeholders who participated in the interviews.

The report begins with short summaries in English and Swedish, followed by an introductory section. The remainder is divided into three parts: Part A contains the state-of-the-art review of micromobility and e-scooters, Part B describes the empirical travel pattern analysis, and Part C presents the interviews conducted with Stockholm transport authorities.

Stockholm January 2021
Erik Jenelius and Hugo Badia Rodriguez

Summary

In the last years, a new generation of shared micromobility services has rapidly proliferated in urban areas. The distinctive characteristics of these services in comparison to previous ones are dockless security systems, electric power assistance and a new device different from bicycles, the e-scooter. These technological advances reduce implementation costs and expand potential demand for these services, factors that made their promotion by private companies easy, reinforced by the lack of regulations on e-scooters.

This type of service consists in a floating fleet of e-scooters distributed over a service area where companies conduct several tasks of collection and distribution for device relocation and battery charging. Through the company's app, users find, unlock and lock the scooters and pay for the service. The spread of these services has opened several questions about their impacts on four main areas: mobility, environment, infrastructure and urban space, and safety. The experience from several cities shows several insights about those issues:

Travel behavior

- The average user is a 30-35 years old man who makes an average trip of one mile and ten minutes long, running at speed below 10 km/h. According to this average trip, scooters provide an intermediate solution between walking and cycling.
- Temporal distribution shows only one main peak during the afternoon, having more users during weekends, similar behavior as casual bike sharing systems, but different from the global mobility. Spatial distribution shows a similar behavior as the rest of the modes with high concentration in city centers and other attracting zones with high densities and mixed uses.
- The main trip purpose is related to free time for social or recreational activities, ranging between 30% and 75% of the total rides. The second most common purpose is related to the job and the third is shopping and errands. Based on the description of the trip purpose, current evaluations do not observe a generalized role as a feeder solution for public transport.
- Until now, this mobility service is not enough consolidated as an everyday transport solution since most of riders use the service with a monthly frequency or even less.
- These results are coherent: leisure trips are occasional and more frequent during the afternoon/evening and weekends.
- The main displaced mode is walking, around 40% of cases. In American cities, car trips also reaches similar substitution degree. However, in European cities, public transport is the second mode more affected by the arrival of scooters.
- However, taking into account the proportion of scooter trips in the global mobility, its impact is limited.

Environmental impact

- Although scooters are introduced as a sustainable transport solution from an environmental perspective, several studies emphasize the current limitations that these services present today: short lifetimes, low daily usage rates and kilometers traveled by auxiliary vehicles for collection and distribution tasks among others. The first two are associated to a high impact for materials and manufacturing; the last one is connected to the day-to-day operation.
- The estimations of their impacts show worse results than the rest of transport modes, only surpassed by cars. For that reason, the current mode substitution does not improve the sustainability of the transport system since the proportion of eco-friendly alliance (walking, public transport and cycling) is greater than the car displacement, for European cities more than for American ones.
- To become a mode that improves the sustainability of the transport system, shared e-scooter services should achieve certain goals: lifetimes of 12-24 months, more than 10 kilometers traveled per scooter and day, fuel-efficient auxiliary vehicles, renewable energy sources, strategies to reduce the distance traveled due to operating tasks, and focused on the substitution of car trips.

Infrastructure and urban space

- Uncontrolled spread of scooters in cities has increased the pressure on transport infrastructure and urban space, creating conflicts with other vehicles and activities. The main frictions are the obstructions due to inappropriate parked scooters and unsafe riding on sidewalks.
- However, the most common infrastructure where users ride is bike lanes, otherwise traffic lanes are the main alternative, being sidewalks the last option. Although riders would like to increase the use of segregated lanes for micromobility showing a lack of this type of infrastructure, or at least calming traffic streets.
- In the same line, most of scooter are properly parked on sidewalks (corrals or furniture areas without obstructing other flows). However, the improperly parking takes long times up to some hours, an extra factor that explains the negative perception about these new mobility services. This seems a visual or aesthetic impact more than a real obstruction issue.

Safety

- Medical reports evidence a growth in the number of accidents where e-scooters are involved; although most of these incidents cause minor injuries, there are a certain percentage that require hospitalization and operations, even fatalities have been reported.
- The most common accident only involves the same scooter (falls, infrastructure in bad conditions, collision with objects, vehicle malfunction). However, crashes with motorized vehicles are the accidents with severe consequences.
- Accident rate estimated in different cities ranges from 20 to 70 accidents per 100,000 trips.
- Riders using a helmet are a minority, around 10% or less, even in those cities where it is mandatory.
- Since e-scooter trips are short, the perception of risk is smaller and users accept more risky behaviors.

Measures and Policies

- From a legislative perspective, assimilation of the e-scooter as a pre-existing vehicle either bicycle or motorized vehicle.
- Cities order the uncontrolled and chaotic implementation of these services by means of constraints on the number of operators and fleet sizes. The former moves the competition off the road since companies should compete for operating permissions through a selection process. The latter meets the number of devices to the level of demand, introducing dynamic balancing depending on the usage rate of the e-scooters.
- Different fees are introduced in order to compensate some of the externalities generated by shared e/scooter services. Additionally, several fines for operators and users try to encourage a better management, safer riding and properly parking.
- Definition of non-riding (pedestrian streets, sidewalks), non-parking zones (parks, campus) and speed limits (10-30 km/h) in order to avoid conflicts with other transport modes and urban activities. Implementation of geofencing technology and speed controllers and lock-to technology in the devices to manage these measures.
- Campaigns of education and communication promoted by cities and companies.
- Equity policies to remove barriers that limit the accessibility to shared e-scooters: pricing discount programs, lack of smart technology for managing subscriptions, location of devices in areas of disadvantaged communities, vehicle design to avoid standing riding, etc.
- Development of Mobility platforms to integrated the whole fleet of shared e-scooters in only one app, and extension to other transport modes to promote the role of feeder solution for public transport.
- Systematic evaluation for the monitoring of the services, requiring collaboration from companies sharing their mobility data with cities.

Based on the current situation of shared e-scooter services, there are still a need of knowledge at three different levels of analysis: understanding the role of this type of mobility solutions in the global transport system, guidelines and strategies for a competitive service design and operating measures for an efficient management of the day-to-day deployment.

Svensk sammanfattning

Under de senaste åren har en ny generation av delade mikromobilitetstjänster snabbt spridit sig i stadsområden. De särskiljande egenskaperna hos dessa tjänster jämfört med tidigare är docklösa säkerhetssystem, elektrisk assistans och en ny enhet som skiljer sig från cyklar, e-scootern. Dessa tekniska framsteg minskar implementeringskostnaderna och utökar den potentiella efterfrågan på dessa tjänster, faktorer som förstärkta av bristen på regler för e-skotrar gjorde det lättare för privata företag att marknadsföra dem.

Denna typ av tjänst består av en flytande flotta av e-skotrar fördelade över ett serviceområde där företag utför insamling och distribution för enhetsförflyttning och batteriladdning. Genom företagets app hittar, låser upp och låser användare skotrarna och betalar för tjänsten. Spridningen av dessa tjänster har öppnat flera frågor om deras inverkan på fyra huvudområden: rörlighet, miljö, infrastruktur och stadsrum och säkerhet. Erfarenheterna från flera städer har gett insikter om dessa frågor:

Resebeteende

- Den genomsnittliga användaren är en 30-35 år gammal man som gör en genomsnittlig resa på en mil och tio minuter lång och kör med hastigheter under 10 km/h. Enligt denna genomsnittliga resa ger skotrar en mellanliggande lösning mellan gång och cykling.
- Den tidsmässiga fördelningen visar endast en huvudtopp under eftermiddagen, med fler användare under helgerna, vilket påminner om cykeldelningssystem men skiljer sig från den mobiliteten generellt. Rumsfördelningen visar ett liknande beteende som övriga färdmedel med hög koncentration i stadskärnor och andra attraherande zoner med hög densitet och blandad markanvändning.
- Det huvudsakliga syftet med resan är relaterat till sociala eller fritidsaktiviteter, som sträcker sig mellan 30% och 75% av de totala resemålen. Det näst vanligaste syftet är relaterat till jobbet och det tredje är shopping och ärenden. Baserat på beskrivningen av reseändamålet visar i allmänhet inte aktuella utvärderingar på en roll som matarlösning för kollektivtrafik.
- Hittills är denna mobilitetstjänst inte tillräckligt konsoliderad som en daglig transportlösning, eftersom de flesta förare använder tjänsten med en gång per månad eller ännu mer sällan.
- Dessa resultat är sammanhängande: fritidsresor är enstaka och ske oftare under eftermiddagen/kvällen och helgerna.
- Det huvudsakliga ersätta färdmedlet är att gå, cirka 40% av fallen. I amerikanska städer når bilresor också en liknande ersättningsgrad. I europeiska städer är dock kollektivtrafik det färdmedel som påverkas näst mest av skotrarnas ankomst.
- Med hänsyn till andelen scooterturer i det totala resandet är dess påverkan dock begränsad.

Miljöpåverkan

- Även om skotrar lanseras som en hållbar transportlösning ur ett miljöperspektiv, betonar flera studier de nuvarande begränsningarna som dessa tjänster har idag: kort livslängd, låg daglig användningsgrad och många körda kilometer för hjälpfordon för bland annat insamlings- och distributionsuppgifter. De två första är förknippade med stor påverkan på material och tillverkning; den sista är kopplad till den dagliga driften.
- Skattningarna av deras påverkan visar sämre resultat än resten av färdmedlen, bara överträffade av bilar. Av den anledningen förbättrar inte den nuvarande överflyttningen mellan färdmedel hållbarheten i transportsystemet eftersom andelen är större för miljövänliga färdmedel (gång, kollektivtrafik och cykling) än för bilar, för europeiska städer mer än för amerikanska.
- För att bli ett färdmedel som förbättrar transportsystemets hållbarhet bör delade e-scooter-tjänster uppnå vissa mål: livslängder på 12-24 månader, mer än 10 kilometers reslängd per scooter och dag, bränsleeffektiva hjälpfordon, förnybara energikällor , strategier för att minska sträckan på grund av driftuppgifter, och fokus på att ersätta bilresor.

Infrastruktur och stadsrum

- Okontrollerad spridning av skotrar i städer har ökat trycket på transportinfrastruktur och stadsrum och skapat konflikter med andra fordon och aktiviteter. De främsta friktionerna är hindren på grund av olämpligt parkerade skotrar och osäker körning på trottoarer.

- Den vanligaste infrastrukturen där användarna åker är dock cykelfält, annars är trafikfält det viktigaste alternativet, eftersom trottoarer är det sista alternativet. Förare skulle vilja öka användningen av segregerade körfält för mikromobilitet, eller åtminstone lugnande trafikgator, vilket visar på en brist på denna typ av infrastruktur.
- De flesta skotrar parkeras ordentligt på trottoarer (parkeringsfickor eller utrymmen utan att hindra andra flöden). Felaktig parkering tar dock lång tid, upp till några timmar, en extra faktor som förklarar den negativa uppfattningen om dessa nya mobilitetstjänster. Detta verkar vara en visuell eller estetisk inverkan mer än ett verkligt hinderproblem.

Säkerhet

- Medicinska rapporter visar att antalet olyckor där e-skotrar är inblandade växer. även om de flesta av dessa incidenter orsakar mindre skador, finns det en viss andel som kräver sjukhusvistelse och operationer, även dödsfall har rapporterats.
- Den vanligaste olyckan involverar endast skotern själv (fall, infrastruktur under dåliga förhållanden, kollision med föremål, felfunktion). Kollisioner med motorfordon är dock de olyckor som har allvarligast konsekvenser.
- Olycksfrekvensen uppskattas i olika städer från 20 till 70 olyckor per 100 000 resor.
- Resenärer som använder hjälm är en minoritet, cirka 10% eller mindre, även i de städer där det är obligatoriskt.
- Eftersom resor med e-scooter är korta är riskuppfattningen mindre och användarna accepterar mer riskabelt beteende.

Åtgärder och policyer

- Ur ett lagstiftningsperspektiv, klassning av e-scootern som en befintlig fordonstyp, antingen cykel eller motoriserat fordon.
- Städer begränsar okontrollerat och kaotiskt genomförande av dessa tjänster genom begränsningar av antalet operatörer och flottstorlekar. Det förstnämnda flyttar konkurrensen från vägen eftersom företag konkurrerar om drifttillstånd genom en urvalsprocess. Det senare anpassar antalet enheter till efterfrågan och introducerar dynamisk balansering beroende på användningsgraden för e-skotrarna.
- Olika avgifter införs för att kompensera några av de externa effekter som genereras av delade e-scootertjänster. Dessutom försöker olika böter för operatörer och användare uppmuntra till bättre hantering, säkrare ridning och korrekt parkering.
- Definition av icke-körning (gågator, trottoarer), parkeringszoner (parker, campus) och hastighetsgränser (10-30 km / h) för att undvika konflikter med andra transportsätt och stadsaktiviteter. Implementering av geofencing-teknik och hastighetsbegränsningar och lock-to-teknologi i enheterna för att hantera dessa åtgärder.
- Kampanjer för utbildning och kommunikation som främjas av städer och företag.
- Fördelningspolicy för att ta bort hinder som begränsar tillgängligheten för delade e-skotrar: prissättning av rabattprogram, brist på smart teknik för hantering av prenumerationer, placering av enheter i områden med missgynnade samhällen, fordonsdesign för att undvika stående ridning etc.
- Utveckling av mobilitetsplattformar för att integrera hela flottan av delade e-skotrar i endast en app och utvidgning till andra transportsätt för att främja rollen som matarlösning för kollektivtrafik.
- Systematisk utvärdering för övervakning av tjänsterna, som kräver samarbete från företag som delar sin mobilitetsinformation med städer.

Utifrån den nuvarande situationen för delade e-scooter-tjänster finns det fortfarande ett behov av kunskap på tre olika analysnivåer: att förstå rollen för denna typ av mobilitetslösningar i det övergripande transportsystemet, riktlinjer och strategier för en konkurrenskraftig tjänstedesign, och driftåtgärder för en effektiv hantering av den dagliga trafikeringen.

Introduction

Micromobility is a form of transport whose main characteristic is the use of light vehicles such as bicycles, skaters or scooters to complete totally or partially trips. According to this simple definition, this type of mobility has always been presented in the urban context; although its weight progressively followed a decreasing tendency (Bruèze and Veraart, 1999) since its number of trips did not grow as the same rate as other transport modes such as motorized transport, especially car. However, the magnitude of this reduction in the modal share was not the same everywhere. In some cities, micromobility has retained a relevant share of urban transport. Cities such as Copenhagen, Amsterdam or Groningen have shares around 40% (Pucher et al., 2010). Their countries, Denmark and The Netherlands, are the most cycling with a modal split of 27% and 18% respectively (Pucher and Buehler, 2008). Other countries, although with a lower use of this type of vehicles, still have a certain weight with at least 10% of share (e.g., Sweden, Finland or Germany).

Due to the vehicle characteristics, micromobility modes are an efficient and sustainable transport with regard to environmental impact (pollution and noise), energy consumption, congestion, urban space degradation and health benefits. For that reason, public authorities make efforts to encourage the use of this type of solutions in order to reduce the automobile dependence and its negative consequences for all those mentioned issues. The promotion of cycling transport was initially based on the development of policies such as the provision of segregated bike lanes (Carstensen et al., 2015) combined with traffic calming zones, bike parking, integration with public transport and education and training of bike riders and car drivers (Pucher and Buehler, 2008). These measures promoted cycling at least as a private transport, where bike owners take advantage of the pro-bike designs of urban spaces.

A complement to these policies was the implementation of bike-sharing services in order to create a large cycling population. Although there were trials previously, DeMaio (2008) explains that this type of solutions did not succeed until the beginning of this century where different types of technological improvements (electronically locking docks, telecommunication systems, smartcards, mobile phone access, credit cards, etc.) started what is defined as the third generation of bike-sharing. Those improvements minimize thefts or inappropriate use of the bikes due to more secure stations and clear track of bikes and users, and make subscriptions and payments easier.

The new opportunities motivated a progressive interest in a high number of cities that introduced bike-sharing systems from the middle of the first decade of this century. At that time, the number of cities with this kind of public transport was around 10 and grew in one decade until more than 700 systems in the world (Fishman, 2016), it means more than four millions of public bicycles (Fishman et al., 2013). The success of this type of services is reinforced by the significant growth in the number of available bicycles experienced in some cities (e.g., Paris, London, Barcelona, Lyon, and Toulouse) years after the initial implementation as Parkes et al. (2013) show.

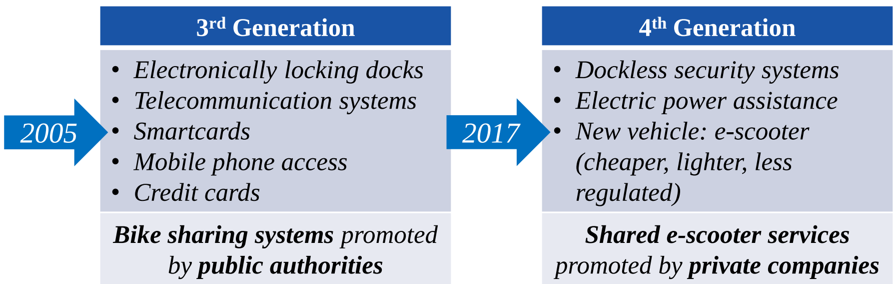


Fig. 1. 3rd and 4th generations of micromobility sharing systems.

Generally, those bike-sharing systems are a form of public transport where a bicycle fleet is available for renting for those people who previously get some kind of subscription. Bicycles are allocated in different dock stations distributed across a service area. Users can take one bike in any of those stations and ride it to the end of their trip, where they drop the bike off at any station. The most generalized cost structure of renting a bike is an initial fix price for a first period and an additional fee for the extra time consumed after that initial period. That fee increases with the temporal trip length and automatically charged to the credit card associated to the subscription.

In the last years, a fourth generation of bike-sharing systems have followed a progressive implementation. This new stage introduces two main technological improvements: dockless security system and electric power assistance for vehicles. The former makes the location of vehicles flexible, allowing a wider distribution of bicycles over the service area, that is, a higher accessibility. It is relevant since the proximity of vehicles to origins or destinations has a significant influence on the utilization of the bike-sharing systems (Fuller et al., 2011), and reduce the negative impacts of crowded stations. At the same time, no infrastructure is needed, simplifying the implementation of these services from a technical, spatial and economic perspective. The power assistance increases the speed and, at the same time, reduces physical constraints of users in some circumstances. For instance, to travel on paths with a difficult topography, this power assistance help cyclists in order to complete their trips. Senior riders, which can also have health problems, are another example where powered vehicles extend the applicability of micromobility. Lazarus et al. (2020) evidence the benefits of dockless e-bikes comparing them with pre-existing docked bikes. The new trips are longer, faster and serve areas outside of the dense urban center that have higher elevations. Additionally to these main changes, others such as solar-power, transit smartcard integration, and smartphone application for registration, payment and real-time updates (Shaheen et al., 2010) complement and make this new generation of shared micromobility systems more attractive.

However, in this new generation, a new vehicle has appeared competing with bicycles, the e-scooters. This alternative has some advantages for operators since they are smaller, occupying less space on the streets, are lighter, making its transport easier, have lower acquisition cost and require less maintenance. Although scooters have smaller batteries (i.e., less travel autonomy) and in case battery is uncharged, there is no alternative way to use them while bicycles have pedals to continue riding, combining manual and electric power. This last property of bikes gives more flexibility and becomes a healthier transport mode for users. At the same time, bigger wheels and bike design make its riding more stable and comfortable, and allows higher speeds. However, for short trips, stand up on scooters is acceptable and riding them is easier, in particular, for non-usual users.

This new generation of micromobility distinguishes from previous bike sharing systems because it is mainly promoted by the private sector rather than public administration. The companies behind the shared e-scooter services have taken advantage of the absence or less regulations for this vehicle in comparison to bicycles, leaving a gap to expand their business easily. This type of services has shown a wide and fast expansion around the world in the last four years (Møller et al., 2020) with the arrival of a high number of new firms (crunchbase, -).

In this document, we focus on those sharing mobility services provided by e-scooters. To be more precise, taking as a reference the taxonomy of powered micromobility vehicles from SAE (2018), we refer to the type of vehicle called powered standing scooter when we use the terminology of e-scooter or simply scooter. The land of this vehicle in urban environments has provided a new mobility solution as an independent transport mode or as a complement of others. However, its arrival has opened several questions about the impacts, benefits and problems that this kind of service brings about (Grössling, 2020). The goal is to make a description of this type of micromobility and its consequences for the transport system and urban environment based on the outputs of previous experiences in cities form North America and Europe.

Part A: State-of-the-Art Review

1 Overview

The first part of the report provides a review of current knowledge related to micromobility and particularly e-scooters. The first step is to describe this type of services in Section 2. In Section 3, we focus on the characteristics of scooter trips and the impact in the global transport system. Section 4 summarizes previous analysis about the environmental impact of shared e-scooters and their limitations to make more sustainable the current transport system. The conflicts produced on transport infrastructure and urban space are explained in Section 5, and the derived safety concerns are included in Section 6. How cities have manage the proliferation of these services is treated in Section 7, where we describe the main measures adopted. A global discussion of the current situation is included in Section 8.

2 Service description

According to Vuchic (2007), public transport is any kind of form of transport where the owner of the vehicle and users are not coincident, existing at least two stakeholders. In that sense, we can consider shared e-scooters as an alternative public transport system, or more precisely a paratransit form due to its flexibility degree. The business model of a shared e-scooter service works as a business-to-costumer (B2C) system. A company that owns a fleet of this type of vehicles gives the opportunity to potential clients to use those vehicles following specific operating rules and in exchange for an amount of money. In this section, we present a general picture of this service. The description includes three main characteristics: first, the operations required to supply the service, second, the way of use, and third, the fare system.

2.1 Operation

The companies that supply this type of service have a floating fleet of electric scooters distributed over a service area. This area can be the whole city or a smaller region such as a district or university campus. The system does not need any kind of docking station since the devices are equipped by a self-blocking system, which is an important factor to make the expansion of this type of service easy. During the deployment of the service, the company makes different tasks such as collection, distribution and relocation of vehicles and charging their batteries. The supplier of the service has larger auxiliary vehicles to carry the scooters for their distribution over the service area at the beginning of the service. Depending on the rules of each city, it is forbidden to leave the e-scooters during the night on the street. Therefore, the company has to collect all the scooters at night and distribute them the following morning. However, other cities allow companies to operate during the night, avoiding the collection and distribution of all the scooters every day.

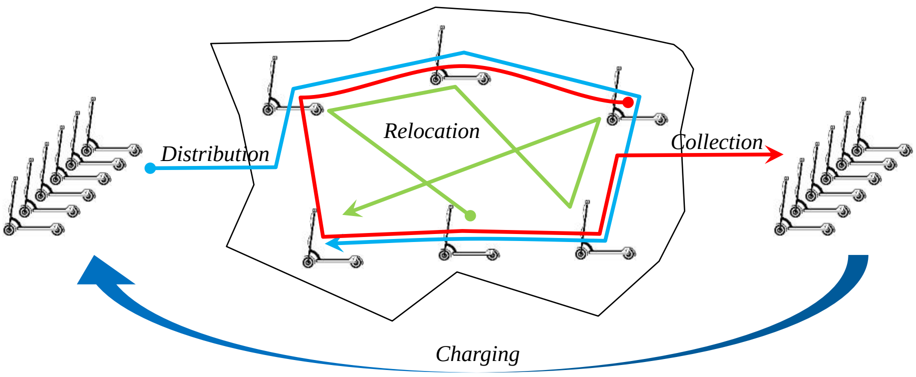


Fig. 2. Operating scheme of a shared e-scooter service.

In any case, the use of the scooters derives in a new location at the end of the trips. This new position could not be attractive for other users, causing an underemployment of the vehicles and a deteriorated level of service. To avoid this result, the company relocates the vehicles to places that are more accessible and attractive, and at the same time, guarantees a well balance of the supply over the whole area. Other factor that implies the collection of scooters is the battery charging. As any other electric vehicle, scooters have a battery that provides the propulsion force. Therefore, the company has to charge the batteries as they are discharged. In this case, the scooters are picked up when they are out of service and dropped off at a charging station. Once they are charged, the company distributes them again in the service area.

The supplier, that is, the owner of the scooters, can carry out the previous collection and distribution tasks by itself (own vans and workers, charging the vehicles at their depots) or subcontract other companies or individual people for these purposes. For instance, some companies delegate the battery charging to “community of chargers”, i.e., people who take scooters with a low battery level, preferably at the end of the day, to recharge them at private properties overnight, and return the vehicles to the service at specific locations or hubs, first thing in the next morning. In return for this support, these individuals earn money. Some companies have developed this type of programs such as Lime Juicer (Lime, -a), Bird Flyer (Bird, -), Voi Hunter (Voi, -a) or Wind Supercharger (Wind, -).

Helling (2020) describes Lime Juicer program and Campbell (2019) explains how to be a Bird charger. These two examples show how this type of solutions works. For the eligibility of a participant, the programs require some legal specifications (age, driver license, social security number), means to carry discharged e-scooters (car or van, as large as possible better), and a smartphone to work with the specific app that manages this activity. Participants assume all the cost derived from transport and charging as an independent contractor, however, the company could provide the chargers. Companies provide around three chargers at the beginning and can increase that number in case of a stablished, active collaborator. In the Lime’s case, that number of chargers could be up to ten; and although participants could purchase more chargers by themselves or use charging stations (Perch, 2020), there are limitations on how many scooters can be under the care of the same person at the same time, which is 25 scooters for Lime.

The standard compensation per charged scooter ranges from \$3 to \$5. The company, to promote the collection of scooters during periods or areas with few participants, can pay higher values with a maximum of \$12 - \$20. Additionally, the companies communicate other kind of needed tasks through the app: spatial balance without charging, searching for hard-to-find scooters and even maintenance works (Campbell, 2018). All of them give the opportunity for the participants of the program to get more money.

2.2 Use

A requirement for clients to use shared e-scooter services is a smartphone where they download the app of the correspondent company and create their own account to manage their trips, accepting the terms and conditions about how to use the service provided by the company (Lime, 2019a; Voi, -b). In this profile, the client chooses the payment method (credit card or online money transfer system) to pay automatically for the use of scooters. This app is also the communication channel to provide information with regard to different issues of the service. On the one hand, recommendations about how to ride scooters such as wearing a helmet for safety reasons, appropriated use of the scooter, where to ride and park them, aspects that often depend on the legislation of each service area. On the other hand, the app informs about the location of each scooter and their battery charge levels.

When one client wants to use the service, he checks through the app if there are available scooters and their location to evaluate which of them is the best choice for his trip. Once user gets the desired scooter, he will be able to unlock the device scanning a QR code on the same vehicle. At that moment, the system considers that user has started a trip and that scooter is unavailable on the app. Client rides to his destination where he parks the scooter and informs through the app that the trip is finished, being the scooter available again at the new location. At that moment, the system will calculate the cost of the service and charge it by the payment method indicated in the user’s account.

Fig. 3. Diagram of use for shared e-scooter services.

There are some constraints regarding the trip length. For example, Voi limits the trip duration up to three hours, when the system automatically ends the trip, and Wind interrupts the service in case users stop riding for more than ten minutes.

Due to the requirements of use, the system excludes that population without smartphones or credit cards. To guarantee the access of those citizens, local governments encourage companies to provide non-digital and credit-free solutions. Among these alternative, we find cash payments, pre-paid cards and call centers to schedule rides.

2.3 Fare system

The fare system in this kind of service follows a similar structure in the different companies and cities. Table 1 shows some examples of fares from different cities and companies. We observe that the most common fare has two components. One is fixed and charged just because the client has unlocked the scooter. The other follows a linear relation with regard to the consumed time of the device. However, there are some divergences. For example, there are companies do not debit any fixed cost at the beginning of the trip, being the final price only calculated based on the travel time. Even in a minority of cases, the fare structure is different since the cost is per time slots.

Regarding the price of the service, the most common one is \$1 or 1€ for unlocking the scooter plus \$0.15 or 0.15€ per minute of use. This has been the price during the implementation of most of the companies. However, these values have been progressively adjusted according to the context of each city. In USA cities, which were the pioneering in the introduction of shared e-scooters, these changes are observed. In Table 1, Washington DC presents the highest fares since most of suppliers increased the price from that base price of 15 cents per minute to the current values (Lazo, 2019). Similarly, Lime has grown the price per minute from \$0.15 to \$0.20 in Minneapolis (Zbikowski, 2019). Focusing on the company Bird, the time-dependent fare varies from \$0.10 to \$0.33 in the different USA cities where supplies its service (Hawkins, 2019). It means that the current price is double than the base one in Baltimore (\$0.29) or Detroit (\$0.33) now, but it is lower in smaller cities such as Bloomington, Charlottesville or Columbia where the price is \$0.10/min. In other cases such as Raleigh (North Carolina), the adjustment was in the unlocking fee, which rose up to \$2.

These prices make this mobility service expensive for a daily or frequent use, and in particular, for that portion of population with low incomes. In comparison with public transport or other micromobility services such as bike sharing systems, shared e-scooters are a private business initiative. It means that the introduction and operation of this new service does not count on the help of subsides from public administrations. Therefore, the cost is higher than shared bicycles and public transport services as shown in Table 1 for the cities included. The duration of the trip from which on the e-scooter is not competitive against public transport ranges from 2.6 min in Washington DC traveling by Bird to 12.7 min in Berlin traveling by Circ, Tier or Voi. Regarding bike sharing systems, e-scooters are more expensive for any trip length like in Paris and Berlin, while they are more competitive up to 13.3 min using Koko in Madrid. This comparison shows how fast e-scooter services become a costly transport mode, being only efficient for trips shorter than 2.2 km assuming an e-scooter speed of 10 km/h. A study from Chicago estimates that length as 1.5 km (Smith and Schwieterman, 2018). This fact has an impact on travel behavior of e-scooters as it is explained below in Section 3.1.

To overcome this situation, there are two courses of action, which have similarities to fare policies and benefits previously tested in shared bikes (NACTO, 2018). On the one hand, the same suppliers create membership programs to encourage a more frequent use for a reasonable price and increase the loyalty of clients. Period passes for a day or a month allow clients to ride unlimited trips during that period, for instance, Voi Pass (VOI, 2020a) among others (Lekach, 2019). These passes remove the unlocking fee and the first minutes of the trip are free. In case the trip is longer, users have to pay the extra time.

Table 1. Fares of shared e-scooter services per company and city in comparison to public transport and bike sharing.

City/Company	Fixed fare	Time-dependent fare	Time (min) vs. Public Transport	Time (min) vs. Bike sharing
Washington, DC ($) (Lazo, 2019); PT: Metrobus $2 (WMATA, -); BS: Capital bikeshare $2/30 min (Capitalbikeshare, -)				
Bird	1	0.39	2.6	2.6
Bolt	-	0.30	6.7	6.7
Jump	-	0.25	8.0	8.0
Lime, Lyft, Razor	1	0.24	4.2	4.2
Skip	1	0.25	4.0	4.0
Spin	-	0.29	6.9	6.9
Chicago ($) (Hernandez, 2019); PT: Bus $2.25 (CTA, -); BS: Divvy $3/30 min (Divvy, -)				
Bird, Lime, Bolt, Lyft	1	0.15	8.3	13.3
Paris (€) (Landais-Barrau, 2020); PT: All €1.90 (RATP, -); BS: Velib' €1/30 min, e-bikes €2/30 min (Velib, -)				
Bird	1	0.25	3.6	0; 4.0 for e-bikes
Lime, Bolt, Wind, Tier, Circ, Hive, Voi, Dott, Jump, Ufo, B Mobility	1	0.15	6.0	0; 6.7 for e-bikes
Madrid (€) (Costas, 2020); PT: All €1.50 (EMT, -); BS: BiciMad $2/60 min (Bicimad, -)				
Acciona	-	0.23	6.5	8.7
Ari, Bird, Buny, Circ, CityBee, Flash, Lime, Mygo, Taxify, Tier, UFO, Voi, Wind	1	0.15	3.3	6.7
Eskay	1	0.11	4.5	9.1
Jump	1	0.12	4.2	8.3
Koko	-	0.15	12.0	13.3
Stockholm (SEK) (Thatsup, 2020); PT: All SEK37 (SL, -); BS: No service				
Bird, Lime	10	3	9.0	-
Moow	20 for 10 minutes		18.5	-
Tier	10	2.25	12.0	-
Voi	10	2.5	10.8	-
Berlin (€) (Schroeder, 2019); PT: All €2.90 (BVG, -); BS: Deezer Nextbike €1/30 min, Lime bike €1/30 min (e-bike €1/unlock + €0.15/min), Jump €1/20 min, Donkey Republic €1.5/30 min (Nextbike, -; Berlin, -)				
Circ, Tier, Voi	1	0.15	12.7	0; 3.3 for Donkey bikes; the same fare as Lime e-bikes
Lime	1	0.20	9.5	0; 3.3 for Donkey bikes; 0 for Lime e-bikes

Additionally, there are loyalty programs where companies reward users with different levels of discount on the price depending on how much users travel with the company's vehicles. For instance, the Voi's program Voialty (VOI, 2020b) consists on a classification of clients by levels. Depending on the level, users get discounts up to 40% of the initial price. Users move up or down through the scale of levels based on the number of rides in a period. Bird operates in the same way with its program Frequent Flyer Program (Bird, 2020a). The discounts can reach 30% and users are available to book scooters some minutes before they start their trips for free. Other companies with a wider business field involve shared e-scooters in their loyalty programs, getting free rides or discounts too. As an example of this is Lyft Pink (Lyft, 2019).

Table 2. Types of discount plans for equity reasons for some companies and cities

City	Company	Type
Washington, DC (District Department of Transportation, -)	*Bird, Bolt, Jump, Lime, Lyft, Razor, Skip, Spin*	Free unlimited 30-minute trips
Tucson (City of Tucson, 2020)	*Bird – Access*	Monthly pass 30-minute trips for $5
	Razor – Affordability	50% of discount from regular fee
Portland (PBOT, -)	*Bird*	50 30-minute rides per month for free; No unlock fee
	Lime, Razor, Spin	50% of discount from regular fee
Arlington (DeMeester et al., 2019)	*Bird*	No unlock fee
	Lime, Skip	50% of discount from regular fee
Los Angeles (LADOT, 2020)	*Bolt*	50% of discount from regular fee
	Jump	Monthly pass for $5 that allows riding during 60 minutes per day
	Bird, Lyft, Lime, Sherpa, Spin, Wheels	Monthly pass 30-minute trips (Bird and Lyft for $5)

On the other hand, some councils have promoted equity programs in collaboration with the private companies to make the service affordable for a wider population range. The financial barriers are overcome through diverse solutions. Table 1 includes some examples, showing the differences between companies and cities. We have identified at least four of them: monthly passes for a low price, a free amount of trips per month limited to a certain trip duration, removal of unlock fee, and a percentage of discount of the regular price. To benefit from these type of programs, users have to be enrolled in an assistance program of the city/state or accomplish other kind of eligibility conditions (e.g., pensioner, unemployed, etc.).

For instance, Lime with its Access program reduces 50% the regular fee (Lime, -b). Razor – Affordability (Razor, -) and Skip – Rider Accessibility (Skip, -) also apply a percentage of discount. Bird – Low Income (Bird, 2020b) offers a monthly pass for $5 that allows users to make five 30-minute trips per day. These are the main type of solutions provided by each of these companies, finding different options in the same city depending on the supplier. However, companies adapt the affordability programs in some cities such as Washington DC where the system is the same for all the operators.

3 Travel behavior

The purpose of this section is to describe the characteristics of trips made by shared e-scooters and the impact of this new mobility service on the rest of transport modes. We base this analysis on preexisting studies from American and European cities. In particular, we work with the pilot program evaluations from the cities of Alexandria (City of Alexandria, 2019), Arlington (DeMeester et al., 2019), Austin (City of Austin, 2018)), Calgary (Sedor and Carswell, 2019), Chicago (City of Chicago, 2020), Denver (Denver, 2018), Los Angeles (LADOT, 2020), Portland (Orr et al., 2019; PBOT, 2018a and 2018b), San Francisco (SFMTA, 2019), Santa Monica (City of Sanata Monica, 2019) and Tucson (City of Tucson, 2020), and other evaluation reports from France (6t-bureau de recherche, 2019), which includes the cities of Paris, Lyon and Marseille, Brussels (SPRB – Bruxelles Mobilité, 2019) and Oslo (Fearnley et al., 2020). Along the document, when we mention these cities, we refer to those studies unless we indicate other source. Furthermore, various research papers complement the travel description presented below. These studies add information about shared e-scooter services from Austin, Indianapolis, Nashville, Portland, San Diego and Washington DC.

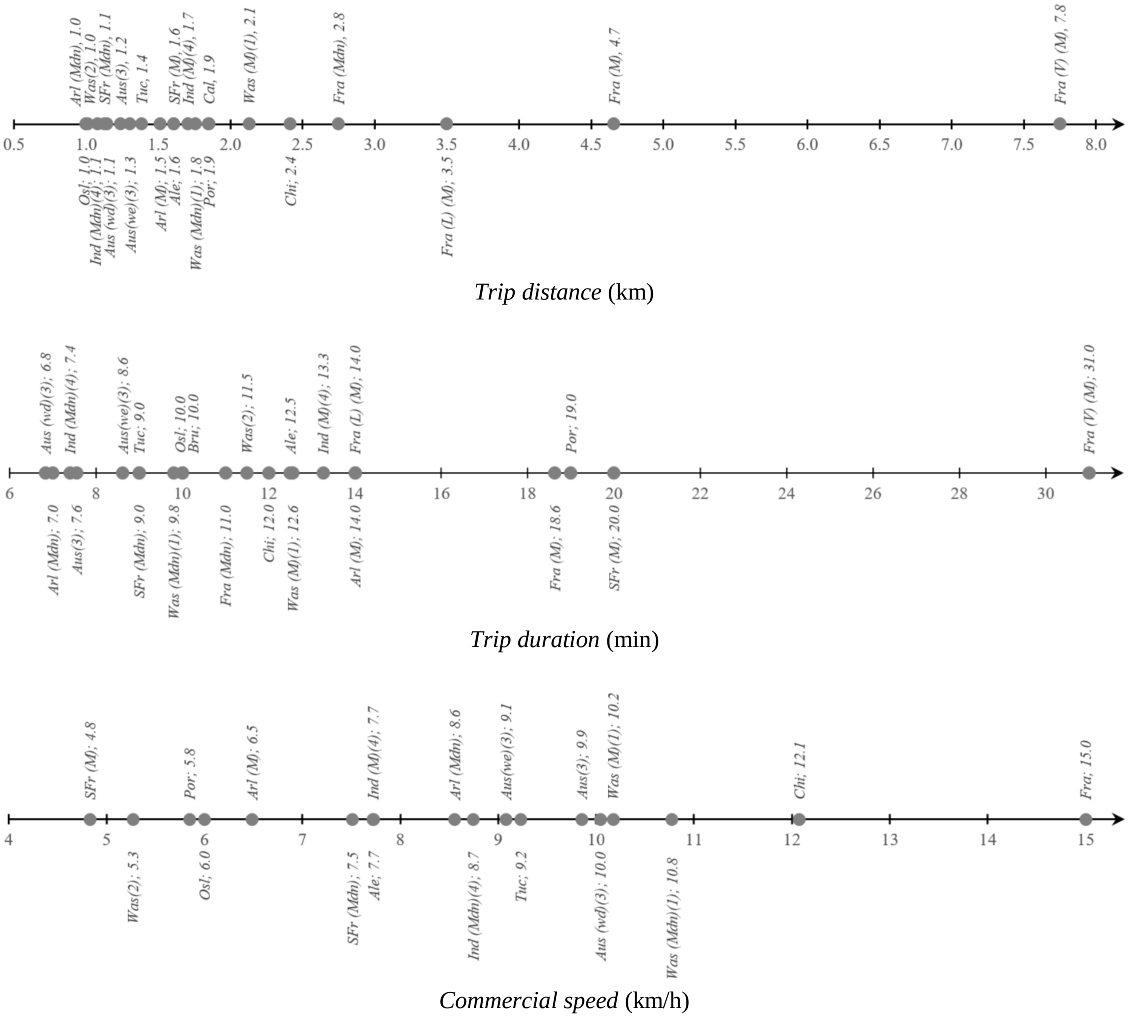
3.1 Characteristics of shared e-scooter riders and trips

The evaluation reports of shared e-scooter services include in most of cases a survey that describe the characteristics of the riders. The standard user is a man, two thirds of the total, around 30-35 years old, younger than the average population. He has a high level of education with some kind of university degree and incomes slightly above the average salary. However, this last assertion is conditioned by who participates in the survey. The characteristics of all survey respondents are similar independently if they are riders or non-riders as it is observed in the statistics from Arlington, Chicago, Tucson and Oslo. In France, the analysis of the type of user includes household composition, where more than a half of riders are singles or couples with no kids. This characteristic matches with the type of vehicle, which is an individual form of transport.

Users approximately make one-mile trip (i.e., 10-minute trip) in shared e-scooter services. Figure 4 shows the average trip length, duration and speed by shared e-scooters in the mentioned cities above. The average length ranges from 1 km in Oslo to 4.7 km in France and the trip duration varies between 7.6 min in Austin to 20 min in San Francisco. The differences between length and duration come from different commercial speeds, being the average around 9-10 km/h. This factor explains the long distance in France compared to the rest of cities where the length is mostly less than 2 km. In that case, the authors estimate the length from the duration assuming a commercial speed of 15 km/h, which is the highest one among the different cities. When we compare the duration, the values in France are closer to the others, showing that the assumed speed overestimated the traveled distances.

The studies in France, San Francisco, Washington, Indiana and Arlington distinguish the mean and the median of the trip distance. Longer means than medians show the existence of a portion of long trips, some of them take more than one hour, especially in France where the mean is two kilometers longer than the median. The authors of the study suggest that these long trips are recreational trips without no specific destination such as sightseeing purpose. The different behavior between local riders and visitors supports this assertion. The latter spend on average half an hour per trip, being double than the trip duration of the former.

The distinction between mean and median in San Francisco, Washington DC, Indianapolis and Arlington also shows different speeds for short and long trips. The speed mean is slightly slower than the speed median in Washington DC, but this divergence is greater in San Francisco, where the median trip is fifty-five percent faster than the mean trip. Long recreational trips penalize the mean. During these trips, riders do not prioritize the travel time and stop more frequently spending additional times than trips with a specific destination, where users go directly to the end of the trip. In the same line, Jiao and Bai (2020) observe differences between weekdays and weekends in Austin. The average traveled distance is 1.14 and 1.30 km or 6.83 and 8.62 minutes respectively, that is, commercial speeds of 10 and 9 km/h. Weekend trips are slightly longer than weekday trips in Denver, approximately 9%.



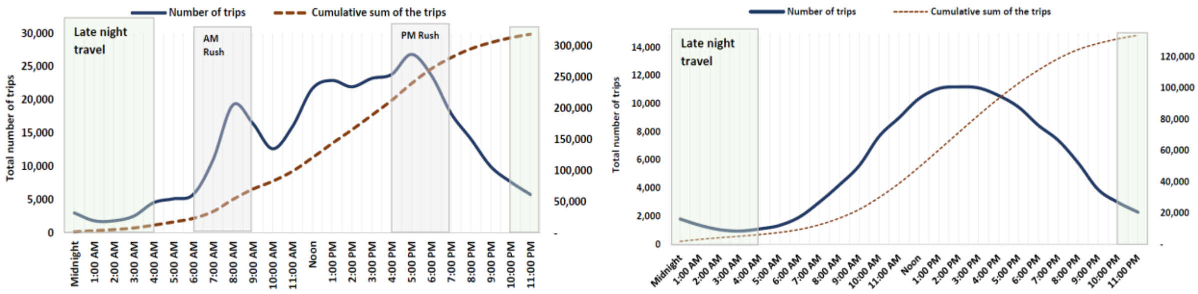
(M): mean; (Mdn): median; (L): local riders; (V): visitor riders; (wd): weekdays; (we): weekends; (1): McKenzie, 2020; (2): Younes et al., 2020; (3): Jiao and Bai (2020); (4): Mathew et al. (2019a)

Fig. 4. Length, duration and commercial speed of trips made by shared e-scooters.

3.2 Temporal distribution of shared e-scooter trips

The temporal distribution of these trips is similar across all the studied cities. The highest number of daily trips occurs during the weekends, especially on Saturdays. During the weekend, there is an extended peak period, which starts around noon and ends beyond 6 pm. In most of cases, the highest levels of demand are in the middle of that period. However, the demand distribution is different depending on the city. In Washington D.C. (McKenzie, 2019) or Nashville (Maxwell, 2019), the peak is closer to the noon. On the other extreme, the peak tends to the beginning of the evening in Brussels. In San Diego, there are two distinguished peaks, one at 12 pm and the other between 5-6 pm (Maxwell, 2019).

On the other hand, during weekdays, the temporal pattern shows a tendency to delay the main peak to the evening. Beyond this global peak, two local peaks are identified, one coincides with the general morning peak (around 8 am) and the other occurs at noon during the lunchtime. This pattern is clearly observed in Arlington or Chicago among other cities (Maxwell, 2019; Younes et al., 2020; Oslo, Alexandria and Calgary). However, the number of trips is smaller at those local peaks, in particular, during the morning. Figure 5 shows the main travel patterns during weekdays and weekends. In any case, they do not show the traditional temporal distribution with two main peaks, morning and evening, as the general mobility behavior.



(a) Weekdays (b) Weekend

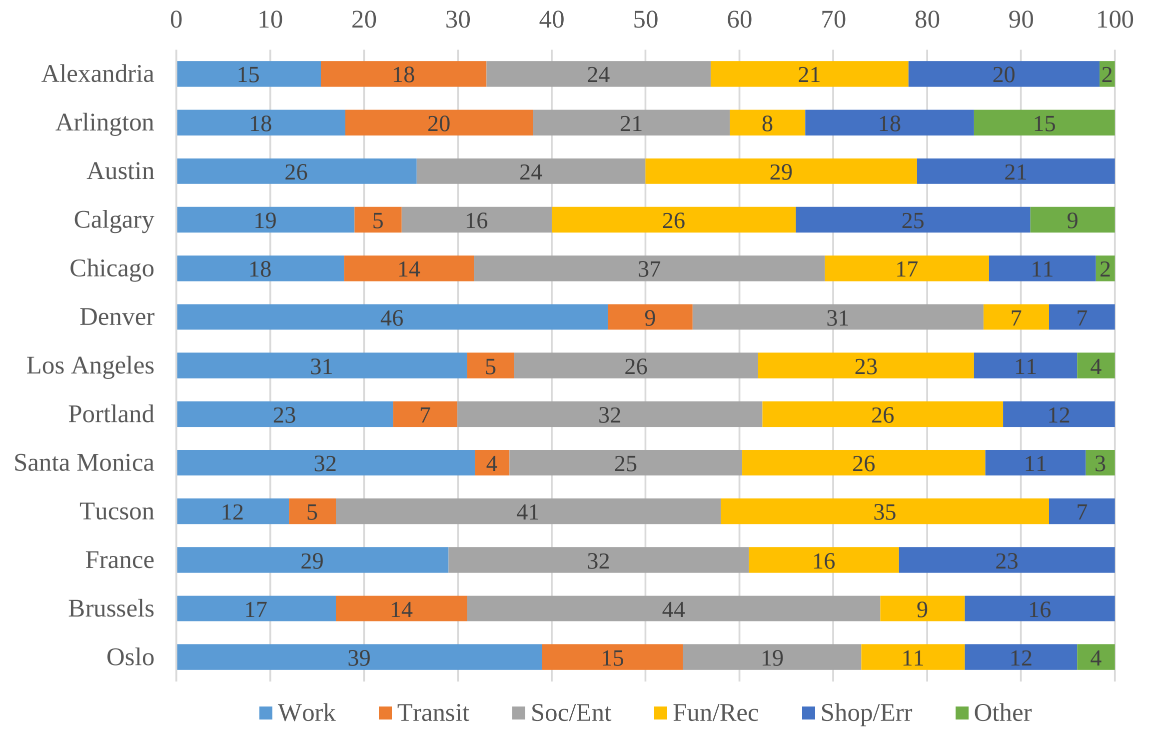
Fig. 5. Temporal distribution of trips made by shared e-scooters (Source: De Meester, 2019).

3.3 Purpose of shared e-scooter trips

Focusing on the trip purpose, we adapt the results from the different cities to make a uniform comparison among them. We distinguish seven different categories: work (commuting, other work-related trips and school), transit (connection to stops/stations), social/entertainment (restaurants, visits to family and friends, etc.), fun/recreation (exercise, tourism, etc.), shopping/errands (health appointments, etc.) and others. Figure 6 gathers the purpose distribution for those previous cities where their studies provide this information.

According to those results, the main purpose of e-scooter trips is leisure that include two of the categories in Figure 6: social/entertainment and fun/recreation. This includes the trips that support the social life of users and other activities during their free time (dining, taking a stroll, sightseeing, and other hobbies). In most of the cities, the joint share is higher than 40%, and in a half of them more than 50%. This purpose clearly predominates in Portland and Tucson with six and eight out of every ten trips respectively. However, this type of trips are around 30% in Arlington and Oslo, where other purposes play a more important role. Anyway, this percentage in any city is high enough to evidence the use of scooters for these leisure trips, a conclusion reinforced in McKenzie (2019). The author shows a higher percentage of recreational trips, which increases during the weekends at the expense of work-related trips, a factor that determines the distinct temporal travel patterns.

Other insights support the prevalence of leisure trips. In France, a high percentage (42%) of users were visitors, whose trips have a recreational nature and they find a simple transport solution for occasional mobility needs. In the same line, 36% of riders travel collectively, where around one fourth of users take one device per person and the remainder 10% two people ride in the same scooter.



* Some cities distinguish the purpose Professional displacement, which is included in purpose Work in this graph. Professional displacements represent: Arlington 5%, Chicago 4%, Denver 11%, Portland 8%, Oslo 9%.

Fig. 6. Purpose of trips made by shared e-scooters.

On the other hand, commuting trips made by shared e-scooters are less than 20% in most of the cities. However, there are some exceptions such as Denver, where this is the purpose of almost half of the trips, Oslo, where this is the main reason of use with almost 40%, Santa Monica and Los Angeles, where one out of every three trips are work-related, and Austin and France, exceeding 25%. Although in these two last cities, the studies do not distinguish transit as an independent purpose, increasing the work-related trips in case e-scooters combined with public transport complement each other to complete commuting trips.

Since shared e-scooter services are promoted as a powerful feeder solution for public transport systems, knowing if the combination of these two modes usually occurs is relevant. Based on the results shown in Figure 6, this role for scooters is not widely consolidated. Six of the eleven cities that provide information show low percentages below 10%. On the other side, the maximum weight of this type of trips occurs in Arlington, limited to 20%.

The surveys in France and Brussels complement this information directly asking about the intermodality of shared e-scooters and the results show greater evidences of this role. The combination of this mode with others occurs in 23% and 46% of shared e-scooter trips in these two cities respectively, being public transport the main complementary mode (66% and 56%) followed by walking (19% and 21%). In the same line, the San Francisco pilot program indicates that the last e-scooter trip for 34% of respondents was a feeder solution to get to or from public transport stop/station, and most of them would not take a public transport service in case an e-scooter was not available. The study concludes that e-scooters promote public transport since they feed this service four times more than the trips where they replace public transport.

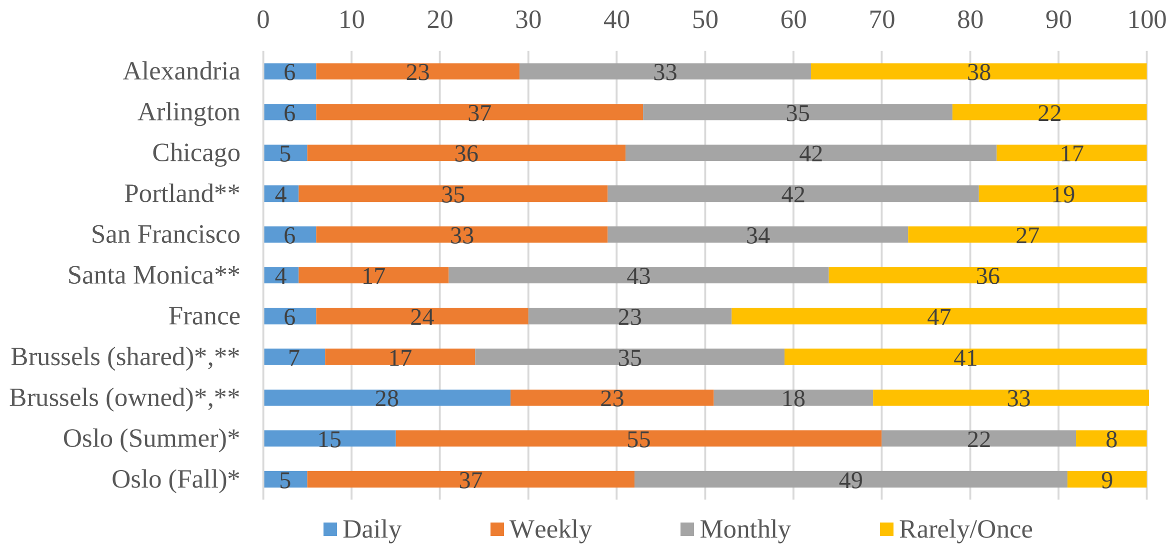
On the other hand, the survey from Denver asking for how often users take an e-scooter to complement public transport shows a low frequency: 44% never, 37% less than once per week, and only 19% weekly. In Los Angeles, data analysis on the location of origins and destinations shows that less than seven percent of them are within 100 meters around a metro station. Based on data from Austin, Zuniga-Garcia and Machemehl (2020) suggest that e-scooters substitute public transport trips more than complement them.

Finally, the last trip reason is shopping and errands whose percentage mostly ranges from 10% to 20%. This is a secondary purpose, although with exemptions such as Calgary. This is a particular case where one out of every four trips are made only for errands and appointments since the evaluation report includes shopping in social activities, therefore, that percentage would even be higher.

3.4 Frequency of use of shared e-scooter trips

In France and Brussels, the results show that frequency of use has an impact on trip purpose. For those users that take the scooter almost every day, commuting can be as relevant as leisure; however, the weight of the work-related purpose decreases for occasional riders. The evaluation reports show that the frequency of use matches with leisure trips more than commuting trips. Among those survey respondents that used e-scooters at least once, only 6% recognized an everyday use, a similar portion in all the cities. The majority of riders take the scooter less than once per week, at least 60% of them, reaching four out of every five users in Santa Monica. Monthly use predominates in most of the cities in Figure 7, clearly in Oslo, Chicago and Portland. However, that is not the case of Paris and Brussels, where more than 40% of total riders show a rare frequency of use.

In short, its usage is not enough frequent to show a commuting behavior, being more appropriate for sporadic trips associated to social and recreational activities. This could also be in line with the concept of last-minute trip identified in Oslo (Fearnley et al., 2020), where users take the scooters when they are occasionally in a hurry to get a meeting or complete some kind of errand, circumstances that do not occur with enough frequency. Additionally, the study in France identifies that 44% of trips were only in one direction, but other mode was used for the return trip. In these trips, public transport was the main complementary mode in 57% of cases and walking was the second in 37%.



* ≥ 5 trips/week are considered as daily use; ** Distribution adapted to riders, removing the percentage of survey respondents that do not ride e-scooters (2% in Portland, 53% in Santa Monica, and 13% for shared and 58% for owned e-scooters in Brussels)

Fig. 7. Frequency of use of shared e-scooters.

Figure 7 includes the distinction between e-scooter owners and shared e-scooter clients about how often they ride this type of vehicle in Brussels. The results are as expected since owners have a more frequent use, where a half of them employ the scooter at least once per week, double than the clients of shared e-scooter services. The same occurs if we focus on the daily use, where 28% of owners do it while this portion is four times smaller for the others. This higher frequency of use for riders with owned e-scooters is also observed in Wien (Laa and Leth, 2020). Additionally, the evaluation report in Oslo distinguishes the usage during summer and fall. In summer, the frequency of use of scooters is higher, tripling the share of daily users and growing up to 70% for at least one ride per week. These differences reveal that weather is a relevant factor in the use of this mobility solution.

Other results also identify weather as a deterrent for the e-scooter use. In Arlington, the number of trips per month during the pilot is four times smaller in January (winter) than in May (spring). The distribution of trips was not uniform during the pilots in San Francisco and Tucson, being the scooters more demanded in October and November in comparison to December, January and February. The same occurs in Los Angeles where the period May-October has more trips than November-April. In Portland, the difference mainly comes from the trip distance since trips are longer during summer than in fall. Long journeys that we can associate to recreational trips. In this line, based on the surveys from France and Brussels, weather is identified as an inconvenient for the e-scooter use for 48% and 11% of respondents respectively.

Younes et al. (2020) observe an increase of the number of trips by e-scooters for higher temperatures or visibility and a decrease with the humidity, wind speed and rain in Washington DC. Mathew et al. (2019b), focusing on the data from Indianapolis, observe a reduction of the number of trips up to 80% and a utilization rate two-thirds smaller during winter months, when average length and time per trip dropped slightly. However, results from Chicago contradict this assertion since there are more e-scooter trips in rainy days; users try to make walking trips shorter. Maxwell (2019) identifies more and longer trips as higher temperatures are, but not a clear pattern with regard to precipitations. While there are less trips in Nashville and Portland, the volume of trips grows in San Diego. Regarding trip length, it is longer in Nashville and San Diego, but shorter in Portland.

3.5 Spatial distribution of shared e-scooter trips

The last issue is the spatial distribution of trips made by this transport alternative. According to the results from some of the cities above, we can get some general conclusions. Most of trips are concentrated in downtowns and other central focuses of demand. These results mean that e-scooters are mainly deployed in areas with high densities of residences, employments and activities, and mixed land uses, areas associated to high public transport supply. In these areas, the time between two consecutive trips by the same scooter is shorter than in others, that is, the usage rate is higher, making more profitable the business there.

In Austin, Jiao and Bai (2020) observe a similar behavior, where e-scooter usage decreases with the distance from demand focuses or public transport stations/stops, and grows in compact areas with high street connectivity, that is, urban environments where trip distances are shorter. For the same city, Caspi et al. (2020) observe that riders use shared e-scooters mainly in central Austin, downtown and University Campus. The analysis identifies a higher usage associated to areas with high employment rates and a good coverage of bicycle infrastructure. Moreover, the spatial analysis in McKenzie (2019) shows a distinction between weekdays and weekends. Trips are more concentrated in the downtown during weekdays, reveling a higher spatial clustering in comparison to weekends. This different level of spatial dispersion could be connected to trip purpose. Recreational trips, more frequent during the weekend, are more dispersed than work-related trips, which are weekday trips highly focused on the city core.

1.6 Shared e-scooters versus shared bicycles

According to the characteristics of the scooter and the associated mobility service, everybody can link e-scooter with bicycle and e-bike and the emerging shared micromobility solution with the already established bike sharing systems. Some studies compare the travel behavior and trip characteristics for these different alternatives in order to identify how similar they are. However, what the results identify are mainly differences. McKenzie (2019) and Younes et al. (2020) compare shared e-scooters and the bike sharing service in the city of Washington DC. The first difference observed is the trip length and speed. Users travel longer trips by bikes. However, the comparison of speeds depends on the type of bike user. The authors distinguish between member and casual bike riders. The former run at 10 km/h, that is, faster than casual users, which travel at 4 km/h. Scooter speed is in between with 6 km/h. In Arlington, the comparison of trip characteristics between dockless shared devices versus the existing docking bike sharing service confirms longer and faster bike trips versus e-scooter trips. The trip length is 3.16 km and 1.51 km respectively. However, the average trip duration is similar with 16 min and 14 min, showing a higher speed of cycling almost double than riding an e-scooter.

The previous papers show another disparity with regard to the temporal distribution of trips. Frequent bike users mainly take the service during weekdays and follow a standard temporal commuting pattern with two main peaks, one in the morning and other in the afternoon, clearly opposed to the e-scooter pattern explained above. On the other hand, casual bike riders show a similar pattern as e-scooters, where weekends and evenings predominate since social and recreational activities are the main purpose. Due to these disparities and similarities, Younes et al. (2020) observe that shared e-scooters reduce the use of shared bikes mainly attracting casual bike riders, but not competing for bike-sharing members. However, one limitation for this conclusion is the lack of a member subscription for the e-scooter sharing system, limiting a direct competition for frequent users. This factor leaves a possible negative impact on the use of bikes also for this group of clients.

NACTO (2018) summarizes micromobility statistics from the USA showing the growth of shared mobility services based on this type of vehicles. During the period 2010-2017, the implementation of dock-station bike sharing systems multiplied the number of trips. In the last year 2018, the number of trips is double, showing a big jump with regard to the last years. This sharply growth is a consequence of the arrival of shared e-scooter fleets. However, there is no evident change in the growing tendency of bike trips. We do not observe that e-scooter services have had a negative impact on the utilization of bike sharing systems, rather creating new micromobility trips.

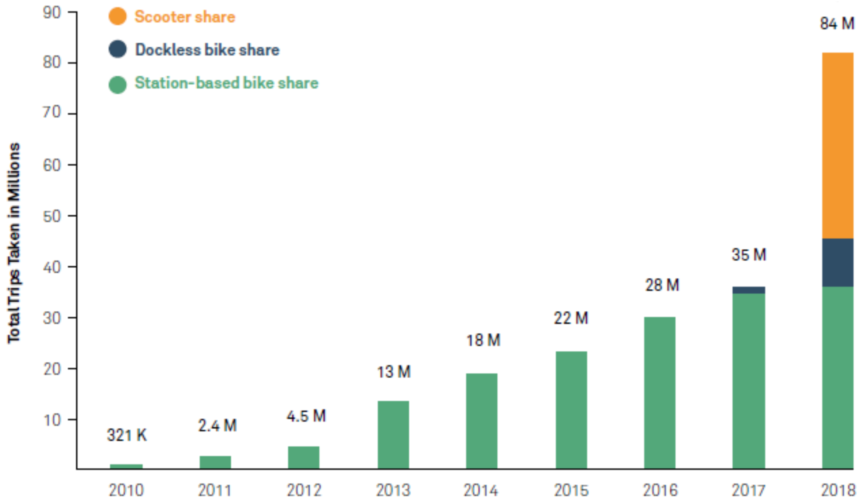


Fig. 8. Number of micromobility trips in USA from 2010 to 2018. (Source: NACTO, 2018)

In short, the characteristics of the scooter with a different riding than a bicycle and the distinct fare structure with no membership programs can be factors that explain shorter trips with lower speeds by e-scooters than by bikes. This new alternative transport mode becomes an intermediate solution between walking and cycling. For instance, von Stülpnagel (2019) compare the average trip length for these three modes: walking 0.90 km, e-scooter 1.84 km and bike 3.40 km. The distance traveled by scooter riders is double than pedestrians and a half of cyclists. Schellong et al. (2019) obtain similar results. However, as shown with more detail in the next section, shared e-scooters displace more walking than cycling trips.

On the other hand, we find other results from the pilot program evaluation in Arlington since that document includes a comparison between dockless e-scooters and dockless e-bikes, a type of bikes that also belongs to the fourth generation of micromobility services. Recreational purpose is even more relevant, around three times higher, for these e-bikes than for e-scooters, at the expenses of a lower participation in trips for shopping and connection to public transport. This last purpose represents 10% for e-bikes, half of the share for e-scooters. This lower combination with public transport could be related to a limitation of e-scooters to travel distances as long as e-bikes.

In line with the predominant purpose, the frequency of use is lower for e-bikes, where two out of every three survey respondents declare rare utilization. Regarding the e-bike riders, the main differences with regard to e-scooter users are age, being older since the main group of clients are over 40 years old, and level of education, which is higher. Finally, these two shared e-micromobility services have a similar impact on car substitution (33%), but e-scooters have a higher impact on walking since 37% of trips would have walked in case the service would not have existed while this percentage is 22% for e-bikes. This last mode substitutes other cycling solutions and public transport modes (8% and 7% respectively) more than e-scooters (4% and 5%).

In Denver, the trip length of e-bikes is 2.45 km on average, that is, 65% longer than the trips made by e-scooters. Comparing the usage rate for these two devices, e-scooters are used six times more than e-bikes; there are 2.5 e-scooters per e-bike, but 15 e-scooter rides per 1 e-bike ride. However, the results from Calgary show a shorter trip length by e-bikes, that is, 1.25 km versus 1.85 km by e-scooters.

3.6 Impacts of shared e-scooter services on the modal split

The next question is the origin of the e-scooter users, the transport modes that the new shared e-scooter services replace. In the different evaluation reports, the survey includes the question *"what transport mode would you have taken if an e-scooter was not available?"*. The answers are summarized in Figure 9, where we distinguish five alternatives: walk, private car, ride-hailing (taxi, car sharing and ride sharing, other transport solutions based on a car), public transport and bicycle. The numbers show a clear distinction between American and European cities.

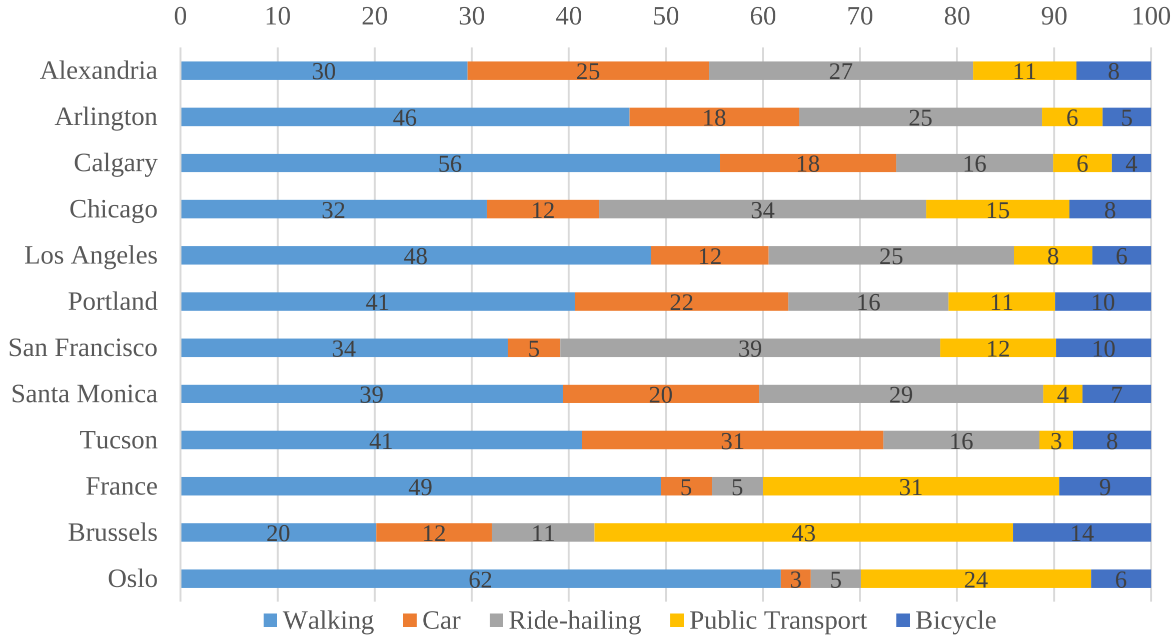


Fig. 9. Alternative transport mode in case an e-scooter is not available.

In the former, car in its different forms is the main displaced mode in more than 40% of cases, or close to the first position with a difference of less than 3%, with the exemption of Calgary and Los Angeles, where walking occupies the first position for approximately half of the cases. Walking is the second alternative with a percentage that ranges from 30% to 40%. Larger and denser cities, for instance Chicago and San Francisco, show a higher impact on public transport, in any case limited to 15%, than smaller ones such as Tucson or Santa Monica, where that share can be up to five times lower. In some of these cities, bicycle has a similar weight to public transport without being chosen in more than one out of every ten trips.

On the other hand, walking is clearly the alternative in France and Oslo, followed by public transport, whose share is three times higher than car and bicycle, which have less than 10% each one. However, public transport is the mostly chosen mode in Brussels, doubling the share of car or walking, which are tied in the second position. The authors of this last study distinguish public transport trips depending on the secondary mode that complements that trip: walking, cycling or car. The combination between public transport and walking occurs in three fourths of these trips.

We can distinguish between car-based modes and environmental friendly transport alternatives (walking, public transport and bicycle). In all these cities, at least half of the e-scooter trips replace eco-friendly modes. In America, this substitution varies around 50% - 60% of the total trips. However, this share reaches 80% or more in European cities, there is at least 20 points of difference between these two geographical areas.

The modal split and the associated urban form can condition these results. American cities are dispersed, not very dense, and consequently, more dependent on car, while European cities have an opposed design with high concentration and density, being public transport a competitive transport solution (Newman and Kenworthy, 1999). The substitution of a car-based mode is at least ten points higher in American cities than in European ones while the reverse occurs with the same difference when we compare public transport. Walking is significantly affected in all the cities, although on average slightly more in Europe since their cities are more walkable, showing the competition with e-scooters for trips with similar characteristics.

In Chicago, Los Angeles and Santa Monica, there is an additional question in the survey: *"How has the frequency of use changed for the other transport modes since you use e-scooters?"*. The results are in line with the answers of the previous question, being the car the most affected alternative mode. Two thirds of responses in Chicago recognize a reduction in the use of cars, being two thirds of them associated to ride-hailing services. In Los Angeles and Santa Monica, although a minority of users show an increase of the frequency of use of other modes, the introduction of shared e-scooter services mainly reduces the use of those modes in order to gain ground in the modal split. For walking, public transport and bicycle six out of every ten respondents declare the same frequency of use, that is, no impact on them. However, a similar proportion recognizes a reduction of car use in all of its forms of deployment in Santa Monica, which is reduced to 50% in Los Angeles. The survey in French cities shows a similar reduction in the use of public transport and car, slightly higher than one third. Regarding car use, two thirds of this reduction is derived from ride-haling services as in Chicago. In a second level, one fourth and one fifth of respondents also recognize a decreasing of walking and cycling respectively.

The previous percentages could be misunderstood if we do not contextualize the volume of shared e-scooter trips with regard to the total number of trips by the rest of transport modes. The study from France evaluates the impact of shared e-scooters on the modal split in Paris. Currently, the share of public transport is 26.4% and of walking is 60.3%. Assuming different scenarios of e-scooter impact, the reduction of those shares are 0.3-0.6 and 0.3-0.8 respectively. Therefore, the impact will be marginal and the modal share of e-scooters would range between 0.8% - 1.9%.

Finally, two of these cities evaluate the capacity of e-scooters to reduce the car ownership. A small percentage of users answer to have less cars, around 5% in Portland and 2% in Paris, showing that this impact is not significant at least in the short term.

4 Environmental impact

Energy efficiency of vehicles depends on vehicle mass and engine power. While in conventional fuel cars, the latter is a decisive factor of that efficiency, Weiss et al. (2020) show that the former factor has the highest impact on energy consumption for electric vehicles. Taking into account the progressive electrification of the transport system, promoting a shift from car use to light electric vehicles such as bicycles or scooters would improve its environmental sustainability. Based on these results, there exist the perception that e-scooters are an eco-friendly transport mode. In several pilot program evaluations, some e-scooter users indicate that this lower environmental impact is one of the motivations to ride one of these vehicles.

However, some authors have found environmental pitfalls in shared e-scooter services. In that line, Hollingsworth et al. (2019), Moreau et al. (2020) and Severengiz et al. (2020) make a Life Cycle Assessment (LCA) of this new mobility service taking as a reference Raleigh (North Carolina, USA), Brussels and Berlin respectively. Based on this analysis, the authors identified how sustainable shared e-scooters are in comparison to other transport modes and how to reduce their environmental impact.

4.1 Environmental impact of shared e-scooter services

In those three papers, the LCA analysis includes the environmental impact derived from the different stages during the life of a shared e-scooter. First, the initial impact related to the materials that compose the vehicle and the manufacturing process. Second, the transportation from the factory to the city where the scooter will operate. Third, the operating impact related to the electricity consumed running an e-scooter and the additional energy consumption of those auxiliary vehicles used for collection and distribution.

The environmental impact is expressed per passenger (i.e., equivalent to vehicle in case it is an individual transport mode) and kilometer traveled by the vehicle. Therefore, momentary impacts such as the first and the second are prorated over the total amount of kilometers traveled by one scooter during its lifetime. This total distance depends on the daily level of use and the length of that lifetime. For the third component, the electricity consumed is already given by kilometer, and the impact from auxiliary vehicles is prorated by the kilometers traveled by the scooter between two collection and distribution operations. In other words, the estimation of the environmental impact depends on the characteristics of the scooters and the service: usage vehicle ratio, vehicle lifetime, vehicle composition, swappable or not swappable batteries, driving distance and fuel-efficiency of auxiliary vehicles (van, e-van or cargo bikes), and renewable energy sources (solar panels).

Focusing on the global warming, it ranges from 60 g CO2 eq/pax-km to more than 500 g CO2 eq/pax-km according to the results from the three papers introduced above. This wide variation derives from the hypotheses assumed in the different scenarios evaluated with regard to the characteristics of scooter and service. Taking as a reference the base cases from the three papers, where the global warming ranges between 77-131 g CO2 eq/pax-km, we observe the contribution of each stage to the global warming impact. Material and manufacturing represent between 50% (Hollingsworth et al., 2019) to 79% (Moreau et al., 2020) of the total. In this last paper, the authors distinguish between material and manufacturing, being the share of each one 73% and 6% respectively. The following contributor is derived from the use phase, ranging from 18% to 43%. Collection and distribution of scooters and/or batteries dominate over electricity for charging. Finally, the emissions from the initial transportation are negligible.

Hollingsworth et al. (2019) extended the evaluation to other issues such as respiratory effects ($PM_{2.5}$ eq), acidification (SO_2 eq) and eutrophication (N eq). The share of material and manufacturing in these impacts is even greater than other components. In particular, aluminum frame is the responsible of 46% of particles derived from that stage and battery pack has a similar percentage of SO_2 eq. Moreau et al. (2020) also include particulate matter in the analysis and add mineral and fossil resource scarcity. Materials are the main emitting of particulates and consumer of resources, between 70% - 90% of total. Among the components of the scooter, aluminum is the main contributor with more than 30% of the material impact for all the categories with the exception of mineral resource scarcity. In that case, battery exceeds aluminum, almost representing 20% of the material.

For all the impacts evaluated in these two papers, collection and distribution are the second contributor. In Moreau et al. (2019), the share varies from 10% to 20%, having a higher impact for fossil consumption and global warming than emitted particulates and mineral resources. These shares exceed 20% in the estimations made in Hollingsworth et al. (2019), being the impact on acidification the main relevant followed by particulates.

The three papers include a sensitivity analysis with regard to the characteristics of the scooter and the service. The parameters that generate the widest variations are usage ratio and lifetime of the scooters. They are relevant due to their influence on the main contributor of the environmental impacts, that is, the materials. This is prorated over the kilometers traveled by the scooter, which is the product between those two factors: distance traveled per day and number of days in operation. When usage ratio or lifetime are short, the environmental impact grows sharply, and the opposite occurs in case we can make them higher or longer.

From the data provided in some of the pilot program evaluations (scooters in operation, total trips and pilot program period), we are able to estimate an approximation of the daily usage of shared e-scooters (Table 3). The number of trips per device and day is between 1 and 4, which derives in a daily traveled distance that ranges from 1.76 to 6.85 km. Von Stülpnagel et al. (2019) gather the value of daily trips per scooter in several European cities, showing similar values around 1.5 and 5 trips per device and day. In NACTO (2018), this number is below 4 in thirty USA cities. These usage rates seem low to get the lower bound of the global warming (60 g CO2 eq/pax-km) identified in the commented life cycle analyses. Severengiz et al. (2020) assumes 10.2 km/scooter-day to get 77 g CO2 eq/pax-km and Moreau et al. (2020) gets 58 g CO2 eq/pax-km in case the utilization reaches 20 km/scooter-day.

On the other hand, the lifetime should be closed to one year (9.5 months in Moreau et al. (2020)) to be competitive with regard to the displaced transport modes. Although two years would allow to reduce significantly the environmental impact from materials. This 24-month lifetime is one of the main objectives for companies such as VOI in order to reduce the current environmental impact (VOI, 2019). However, at the beginning, the lifetime of shared e-scooters was very short, for instance, only one month in Louisville (Griswold, 2019) or one month and a half according to Chester (2019). Consequently, the impact shoots up.

Table 3. Daily usage of shared e-scooters

City	e-scooters in operation	# daily trips	Daily trips per e-scooter	Avg. trip length (km)	Daily usage (km)
Alexandria	780	852 (230,000 trips in 9 months)	1.09	1.61	1.76
Arlington	863	1680 (453,690 trips in 9 months)	1.95	1.51	2.95
Calgary	1500	5556 (750,000 trips in 4.5 months)	3.70	1.85	6.85
Chicago	1722	3392 (406,984 trips in 4.5 months)	1.97	2.42	4.77
Los Angeles	-	-	2.1-2.7	1.56	3.28-4.22
Portland	2043	5836 (700,369 trips in 4 months)	2.86	1.85	5.29
San Francisco	Scoot 235 Skip 382	-	3.43 (Scoot 2-3; Skip 2-6)	1.61	5.52
Tucson	-	-	1.33	1.39	1.85

In a second order, there are two operational factors related to the collection and distribution of e-scooters for charging batteries or relocation. These two factors are the total traveled distance by the auxiliary vehicles needed and their fuel efficiency. Finally, there are other minor factors such as how clean is the energy source, the material composition of the e-scooter, and how they are carried from the factory to the city where they are deployed. In the different scenarios evaluated, these factors produce variations lower than 20%.

4.2 Comparison with other transport modes

Although the uncertainty of the estimations is relatively high due to the variability produced by some of the parameters, Hollingsworth et al. (2019) and Severengiz et al. (2020) compare the global warming impact between a shared e-scooter and other transport modes. According to the results, we can conclude that this new mobility service is more competitive than cars and bike sharing systems, but more contaminant than buses, trams, owned e-mopeds, e-bikes and bikes. However, in the worst performance scenario considered in Severengiz et al. (2020), shared e-scooter is never competitive in comparison to any other transport choice. Therefore, depending on the scenario this new mobility service could be counter-productive in order to achieve a sustainable transport system.

Shared e-scooters imply some additional environmental costs in comparison to owned ones, making them less eco-friendly than we could expect; a limitation also found in shared bicycles. Moreau et al. (2020) estimate the global warming of an owned e-scooter at 67 g CO2 eq./pax-km, that is, around the lower bound mentioned above for a shared one. In this case, this vehicle is also more sustainable than e-mopeds and similar to public transport.

Beyond the comparison mode by mode, it is more interesting the comparison with the mode displaced by shared e-scooters. Hollingsworth et al. (2019) and Moreau et al. (2020) compare the global warming impact derived from the current operation of shared e-scooters (125 and 131 g CO2 eq/pax-km respectively) with the impact of the average transport mode displaced (93 and 110 g CO2 eq/pax-km respectively). In the two papers, the shared e-scooter service increases the global warming, not being a sustainable solution for urban transport. However, there is space for improvement in the current services in order to reduce the environmental impact of the transport system.

The average transport mode displaced is a combination based on the degree of substitution of each mode by scooters. Figure 10 shows the portion of each transport mode assumed in Hollingsworth et al. (2019) and Moreau et al. (2020), and also the average of those shares for American and European cities included in Figure 9. The main discrepancy between the transport mode displaced in Hollingsworth et al. (2019) and the cities is an underestimation of car displacement in American cities and the opposite in European ones. It means that the results are pessimistic in comparison with the former and optimistic with the latter, being easier that shared e-scooters reduce the global warming in American cities.

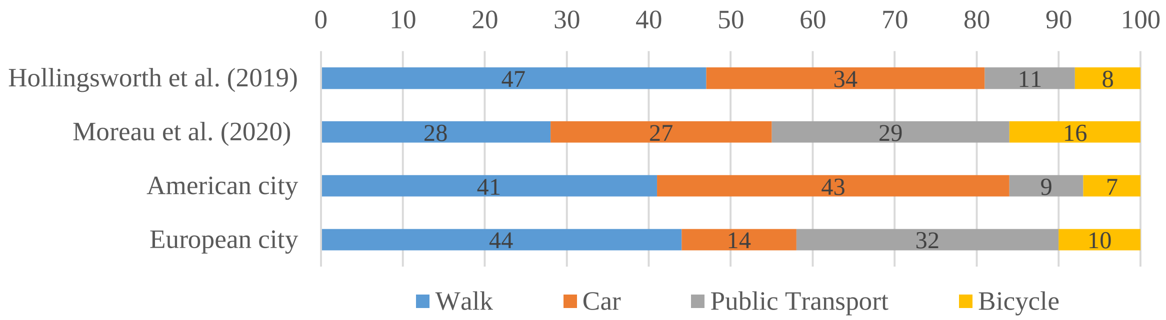


Fig. 10. Degree of displacement for transport modes by shared e-scooters according to Hollingsworth et al. (2019) and Moreau et al. (2020) and the average from American and European cities.

In Moreau et al. (2020), the average transport mode displaced presents more divergences. The authors underestimate the substitution of walking in both types of cities, which derives in a higher global warming. Regarding car, its displacement is lower than the observed in American cities, but higher than European urban areas. The last variation occurs in comparison to American cities where a higher estimation of public transport replacement compensates the lower reduction in car use. Due to these differences, the authors miscalculate the global warming of the trips displaced; we can expect a lower impact of them in comparison to shared e-scooters.

4.3 Measures for an environmental impact reduction

According to those results, the current shared e-scooter systems require changes to become a strategical tool for an improvement on transport sustainability. Beyond variations of the displaced transport modes, taking a higher share of car trips in front of walking or public transport, there are several ways to improve the environmental efficiency of this new mobility service. Based on each component of the impact, the authors of the above-mentioned papers identify solutions to reduce the environmental impact stemmed from shared e-scooters.

To extend the e-scooter utilization, there are two ways: traveling longer distances per day and having longer lifetimes. Regarding the former, current services should improve their performance increasing the number of users without adding more scooters or removing vehicles without losing riders. The latter depends on scooter design and use and maintenance of these devices during the service. Inappropriate use (two people on the same scooter, users that go up the edges of sidewalks at high speeds, etc.) and vandalism deteriorate scooters faster than expected. For instance, scooters in Paris were ridden by more than one person in 10% of trips. Due to this kind of behavior, devices have to become more robust as Moreau et al. (2020) emphasize since companies that survived in Brussels after one year of operation were those ones that got an improved design of their scooters.

To reduce the emissions of auxiliary vehicles, there are several measures to look for a shortening of the length traveled by these vehicles and more efficient fuel consumption. Regarding the former, operation in high-density areas makes the average distance between scooters shorter. Additionally, charging only when the battery is completely discharged and allowing scooters during the night on the street reduce the number of times that scooters are collected. Finally, swappable batteries avoid the collection of scooters for charging and increase the time that a device is in operation (Intelligent Transport, 2019), and charging stations along the city reduce the distances. Users can be incentivized to leave the scooter at those stations to charge it at the end of the trip without needing collection. On the other hand, more fuel-efficient vehicles (e.g., electric vans or cargo bikes) are alternative solutions for the reduction of these emissions. In this line, other measure is the use of renewable energy sources (e.g., solar panels) for charging e-scooters and auxiliary vehicles.

The last aspect is the material that composes the scooter, being aluminum a half of it. The remainder materials are steel, plastic, lithium batteries, electric motor and wheels, with shares around 10%. Consequently, aluminum is the main responsible of material impact. New designs with less percentage of this material or the use of recycled aluminum decrease the final impact. Although new improved scooter models appear, Severengiz et al. (2020) recommends not replacing all the old scooters at the same time by the new ones. The authors consider that a better solution would be to wait until the end of the lifetime of the existing devices.

However, some measures have opposite effects. For instance, less aluminum implies a lighter scooter that would have a short lifetime since they are less resistant to the same usage conditions. Other example is an operating strategy where scooters are left in the middle of the street overnight reducing the impact derived from collection, but they would be unprotected against vandalism, a factor that also reduces the lifetime.

5 Infrastructure

The introduction of a transport mode in urban areas adds a new competitor for public space and transport infrastructure, which are already scarce and highly demanded, and new requirements of design. On the one hand, we can identify two main impacts derived from the arrival of e-scooters. First, shared e-scooters consume urban space for their parking while they are not in use. Second, these vehicles compete with other transport modes for sidewalks, bike lanes and traffic lanes. On the other hand, the vehicle characteristics, which are equipped with small wheels, require pavements in good conditions. In Markvica et al. (2020), the survey results from Wien show that the main problems are related to infrastructure (65%) due to insufficient cyclist lanes and defects on the existing infrastructure. The third one (13%) is derived from sharing roads and sidewalks with other users.

Different results obtained in the evaluations of e-scooter mobility from the cities introduced in Section 3 show the relevance of these aspects. In Chicago, the reasons for a negative experience with e-scooters for approximately 60% of non-riders are derived from where e-scooter users park and ride the vehicles on sidewalks and how they do that, creating an unsafe feeling for the rest of people. Possible obstructions on the sidewalk and an inappropriate riding increase their negative effects when the person affected has some kind of disability. Two thirds of complain calls refer to improper parking or abandoned scooters. Due to these perceptions, two thirds of non-riders suggests to cancel the shared e-scooter service.

The calls and correspondence between Calgary city and citizens show the main concerns with regard to this type of mobility service: riding on sidewalks (39%), riding behavior (27%) and parked scooters (21%). These conflicts mainly occurred in streets with high pedestrian flows, narrow sidewalks and no dedicated lanes for micromobility vehicles. In Alexandria, 66% of complains are parking-related, and consequently, the main concern for three out of every four respondents, although closely followed by unsafe behavior for two thirds of them. In line with this result, more than half of survey participants would not allow parking on sidewalks. Similarly, the main complains in the mobility inbox are related to parking (in 50% of e-mails) and riding on sidewalks (in 36% of e-mails) in Arlington.

Regarding these issues, authorities and operators have to pay particular attention on the interaction between e-scooters and pedestrians. The latter is the weakest competitor in the transport system. The new vehicle runs faster than walking speed producing an unsafe feeling for pedestrians. On the other hand, they also compete for public space when they are parked since users can leave them in any location according to the current operation of this type of mobility service, that is, the free-form nature of dockless systems. The main impact for pedestrian is shown in Oslo where 30% of them declare annoying the interaction with e-scooters, almost ten point higher than cyclists and car drivers. Regarding parked e-scooters, this percentage grows up to 50%, again ten point higher than cyclists and three times more than car drivers. This percentage is 24% for the same e-scooter riders, a sign that shows that familiarity with this vehicle determines the perception that people have about it.

Similarly, 57% of pedestrian respondents in Arlington feel unsafe when there are e-scooters running around; this percentage is 62% for car drivers. These values are clearly higher than the portion of respondents that feel the same around bicycles. However, the results show a clear discrepancy between respondents that do not use micromobility services than those that ride shared e-scooters. For the former, the unsafe feeling exceeds 70% of respondents, while this percentage is around 15% and 20% for pedestrians and drivers respectively from the second group. Similarly, two thirds of non-users often find these devices obstructing the sidewalks when they are parked; however, this perception is only 16% for e-scooter riders.

5.1 Riding infrastructure

The riding behavior described in most of the cities (Arlington, Santa Monica, Portland, French cities, Brussels and Oslo) shows that the majority of e-scooter users ride on bike lanes. Traffic lanes, where e-scooters share the infrastructure with cars, are the second alternative in most of cases. Therefore, the results do not show a generalized use of sidewalks. Asking about where they would like to ride, survey respondents show a clear desire to use segregated lanes for micromobility vehicles, instead of shared spaces with cars or pedestrians, more than they use today. This reflects the idea that there is a deficit of this type of infrastructure, being for example, one of the main barriers for the use of e-scooters in Santa Monica, Portland, Tucson, France or Brussels due to an unsafety feeling. This feeling is also observed in cities where bike lanes are not the most used infrastructure such as Alexandria and Tucson. However, most of riders express that they would prefer these riding places.

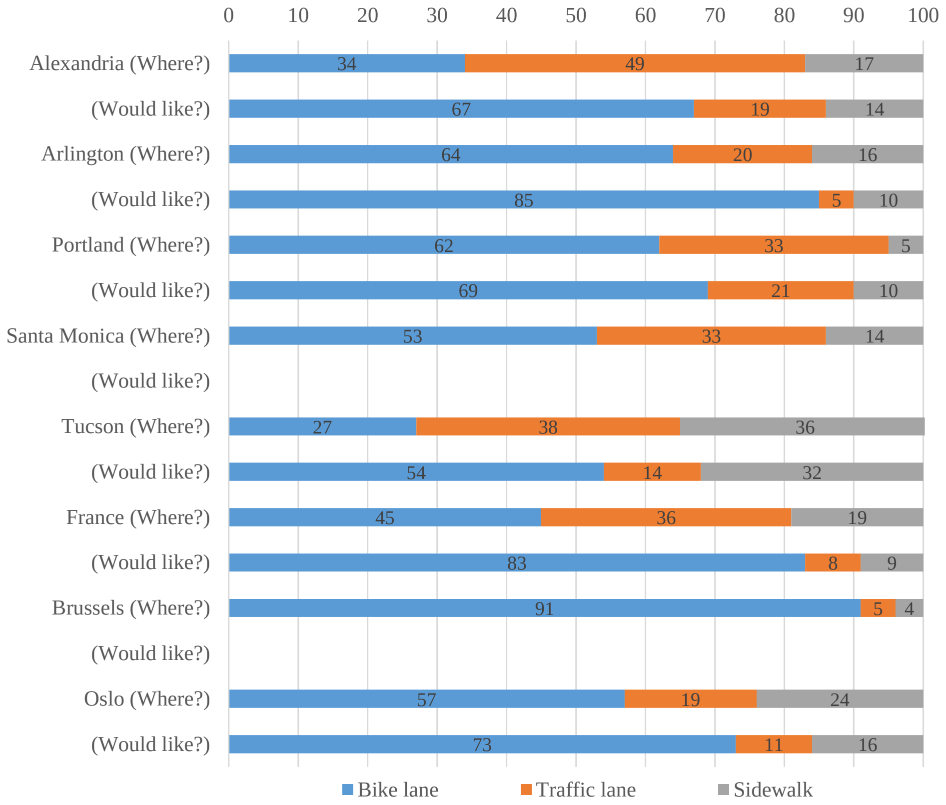


Fig. 11. Where users ride the shared e-scooters according to type of infrastructure (Where?) and where users would like to ride the shared e-scooters (Would like?).

In absence of exclusive infrastructure for micromobility in streets with large volumes of cars running at high speeds, users feel more comfortable riding on sidewalks. In Chicago, 10% of riders in streets with bike lanes ride on the sidewalk, a percentage that grows up to 15% when this segregated infrastructure does not exist. Similar results from Portland show the relevance of infrastructure for micromobility vehicles and speed limits in traffic lanes in order to reduce the riding on sidewalks. The percentage of scooters riding on the sidewalk varies from 39% in streets without that infrastructure, to 21% and 8% where there is a bike lane without or with protection respectively. Regarding the allowed speed for motorized vehicles, if it is higher than 50 km/h, more than a half of riders opt to ride on the sidewalk. However, this percentage is only 18% when the limit speed is around 30 km/h.

James et al. (2019) present the results of a survey from Rosslyn (Virginia, USA). They asked for how safe respondents feel when they interact with e-scooters on the infrastructure; that is, when they are walking on sidewalks or driving on traffic lanes and cross with a moving e-scooter. For three fourths of pedestrian respondents that do not ride scooters, the interaction with this device produces an unsafe feeling. However, when these respondents are familiarized with riding e-scooters, the results are opposed, being 24% who feel unsafe. If we focus on drivers, a similar difference occurs. 80% of drivers that are not familiarized with scooters feel unsafe while this percentage is 47% in case drivers also ride scooters. This question about safe feeling was extended to other micromobility vehicles such as bicycles in different forms: personal bikes, docked-shared bikes and dockless-shared bikes. For the first two types, 11% of pedestrians and 16% of drivers felt unsafe. For the third one, these percentages are 29% and 21% respectively. In any case, bikes produce less unsafety than scooters. This results evidence that the arrival of any new vehicle creates uncertainty for pre-exiting ones.

5.2 Parking e-scooters

Most of shared e-scooters are parked on sidewalks without any criterion in a messy way as declared by riders in France being two thirds of the total. Another 28% are also parked there, but in an orderly manner, that is, closer to other micromobility vehicles and bike sharing stations. In Los Angeles, almost a half of them are in the amenity zone of the sidewalk, but one fourth occupies the pedestrian zone and 9% the frontage zone. As commented above, this unregulated parking has become the reason behind most of complains for other users of urban space, in particular, pedestrians. For that reason, most of people demand more designated spaces for this purpose, for instance, 73% of respondents in Alexandria. However, the evaluation of how well e-scooters are parked based on observations does not reflect a generalized incorrectly parking. In Protland, Tucson and Chicago, a percentage that ranges from 70% to 80% of these vehicles are properly parked. Similarly, 20% of parked devices in Los Angeles obstruct the pedestrian zone in the sidewalk, 7% block access for ramps and 8% of devices are tripped over.

Other studies present this type of examination about parking issues. In San Jose (California, USA), Fang et al. (2018) evaluate how often scooters are parked improperly. Due to a lack of parking regulations for scooters, the authors take as a reference the standards for bike parking in the city. A well-parked scooter has to stand upright, occupy the periphery of paths or areas that already have obstacles (urban furniture such as trees, signs, streetlights, etc.), without impeding the flow of pedestrians or other modes or blocking the access to buildings or infrastructures. The results show that almost two thirds of observed scooters were parked on sidewalks; however, no one was parked inappropriately. Among these scooters, 90% were located on the edge of the sidewalk or furniture area. Among the others that occupies the walking area, only 3% really impedes the pedestrian flow. The reminder scooters were parked on adjacent properties (23%), pedestrian streets (5%) or vehicular right of way of streets. Additionally, only 3% of scooters were not upright.

Brown et al. (2020) evaluate the level of violations on bike and scooter parking in five USA cities (Austin, Portlan, San Francisco, Santa Monica and Washington DC). In total 865 micromobility vehicles were observed and only 0.8% impeding movement of pedestrians: 0.3% of bikes and 1.1% of scooters. Therefore, scooters tend to be not well-parked four times more frequently than bicycles. However, the percentage of violations in any case is very low to accept the negative picture on micromobility parking compliance. Half of devices were parked in the furniture zone, 36.8% in parking racks or corrals, and only 1.3% were not upright.

Additionally, this study includes the violations derived from parked motor vehicles. The authors observed 2631 of them, which 24.7% obstructing access for other users of streets. This percentage is clearly higher than micromobility devices. In particular, this high violation rate is a consequence of taxi, ride-hail, delivery and commercial vehicles, which made 61.1% of total when they are only a 23.8% of the total motor vehicles observed. However, the authors identified an interesting difference since the duration of the interruption was short for motorized vehicles, on average 5 minutes, time enough to pick up or drop off passengers or goods. This time (i.e., the time between a user leaves the device and the next user take it again) was 2 hours for 86% of bicycles or scooters. Beyond the novelty of micromobility vehicles, this difference of times could be an extra factor that explains the negative perception for many people about these new mobility services. The duration of parking violation per 100 vehicles was around 124 minutes for cars, 36 minutes for bikes and 132 minutes for scooters, being this last one the longest.

In Austin, Bai and Jiao (2020) evaluated the response time for parked scooter complains reported through the service request platform of the city. Most inappropriate parked scooters obstructed sidewalks, parking lots or public properties; the reminders were located in private properties or parks or were simply damaged devices. The median response time reaches 17 hours with a mean longer than 2 days. This time varies along the week, day, type of complain and company. During weekdays, the median time is 12 hours, ranging from 3 hours in the morning to 17 hours in the afternoon. During the weekends, that time is clearly longer up to almost two days (41 hours). The shortest time occurs during the morning on weekdays, although this is the period where more complains exist, that is, 35% of the total. Collection in parks requires longer times around one day and a half while the other complains are solved in 15-20 hours. Finally, the capacity to answer these complains among companies differs from 11 hours by Jump, which is the faster, to several days for the lowest ones.

James et al. (2019) also presents how scooter are parked in Rosslyn (Virginia, US). Based on the observation of 606 parked scooters, 16% of them were improperly parked, but only 6% really blocked pedestrian right of way or access to different street furniture. Among these, the main problems were that these devices were not upright (28%), others blocking pedestrian right of way (23%), 22% located on private property and around 14% obstructing access to furniture or bus stops. Other minor problems were the access to hydrants (6%), damage on properties (5%) and obstruction of car lanes (1%) and bike sharing stations (1%). Additionally, these results based on real observations are complemented with the perception of riders and non-riders of scooters through a survey. The question was "*how often do the respondents encounter blocked sidewalks due to improperly parked dockless e-scooters?"*. 28% of riders often or always found this problem while the rest only sometimes or less. This perception is different for non-riders where 75% of them complain that often or always the scooters obstruct the path.

According to the previous results, there is a weak support of the negative perception shown by urban space consumers with regard to micromobility parking. This seems a visual or aesthetic impact more than an obstruction or accessibility issue.

5.3 State of riding infrastructure

Other infrastructure issue is the condition of riding spaces since they have an impact on accident risk of scooters. On the one hand, a good maintenance should avoid irregular surfaces and holes on them and a good design should avoid slippery surfaces and water accumulation. On the other hand, there are infrastructure elements that make scooter riding difficult such as rails or sidewalk edges. According to the evaluation reports from several cities, infrastructure state is one of the main causes of accidents. In Oslo, these factors are responsible of one third of accidents and two thirds of situations that could become an accident. The percentage of accidents caused by infrastructure-related factors is 40% in France, 33% in Brussels and 31% in Sweden (Transport Styrelsen, 2020).

6 Safety

The proliferation of any transport mode becomes a new hazard for mobility safety, and e-scooters are not an exemption. The growth in the number of trips by this type of vehicle comes with an increase of accidents and injuries where it is involved. Several medical reports evidence that increase based on data from emergency departments, comparing periods before and after the implementation of shared e-scooter services (Badeau et al., 2019; Bekhit et al., 2020; Aizpuru et al., 2019; Blomberg et al., 2019). Due to the data sources, these reports only reveal the increase of those incidents that require some kind of medical assistance, but they are an insight of the higher accident rate of e-scooters.

Although the accidents reported in those papers come from emergency department statistics, most of them only caused minor injuries. For instance, they were 56% of presentations in Badeau et al. (2019). In Bekhit et al. (2020), 68% of patients were attended in primary care facilities, where most of cases were soft tissues, and 32% in hospitals, where the injuries are more severe such as fractures and concussions. Similarly, most of patients had mild or moderate severity in Brownson et al. (2020), Kobayashi et al. (2019), Trivedi et al. (2019) and Blomberg et al. (2019). However, around 20% of patients presented in hospitals required an operation according to Bekhit et al. (2020) or Brownson et al. (2020). On the other hand, none of these studies report fatalities, although there were some deaths derived from e-scooter crashes since the arrival of shared services (Griswold, 2020; Yang et al., 2020).

Asking for safety issues, most of survey respondents in Brussels that had an accident did not need any kind of assistance: 6% only declare material damage, 46% consider the accident no important and 30% had some kind of body pain without a visit to a health facility. According to Transport Styrelsen (2020), most of reported injuries related to e-scooters in Sweden were mild skin lacerations. On the other hand, some studies (Bekhit et al., 2020; Aizpuru et al., 2019; APH, 2019; Trivedi et al., 2019; Brownson et al., 2020; Blomberg et al., 2019) identify the anatomic distribution of injuries. They are mainly located in upper and lower limbs and head, being this last location the most worrying since its associated consequences are more severe.

Almost all of patients involved in the reported e-scooter accidents were the same riders, and only a small percentage were non-riders. In Bekhit et al. (2020), only two presentations at hospitals were pedestrians, which means less than 1% of the total. APH (2019) reveals a similar percentage of non-riders where one was a pedestrian and the other was a cyclist. In Trivedi et al. (2019), the number of pedestrians involved were 21 over 249 registered patients, that is, 8%, where half hit by a scooter and the other half tripped over a parked scooter. The distribution of injured non-riders between those two causes is the same as in Copenhagen (Blomberg et al., 2019), but the proportion of non-riders is higher there, around 14%. The evaluation report from Calgary informs about 33 patients, being only one pedestrian. In Chicago, 6% of emergency department visitors related to e-scooters were non-riders, 10 pedestrians and 1 cyclist. Finally, Portland identifies only two injured pedestrians involved in e-scooter accidents over 176 patients.

These results are in line with the type of accident reported since most of them only involved an isolated e-scooter, where a majority are falls and a minority are caused by vehicle malfunction or collision with objects. They represent more than 90% in Brownson et al. (2020), Trivedi et al. (2019) and Blomberg et al. (2019). This weight is the same in Sweden (Transport Styrelsen, 2020) where these accidents are a consequence of an inappropriate riding in 59% of cases and derived from infrastructure in bad conditions in 31%. Similarly, this factor is the responsible of 7 and 8 out of every 10 accidents according to the evaluation reports from Brussels and Portland respectively. The percentage of collisions with a motorized vehicle ranges from 3% in Brownson et al. (2019) to 18% in Brussels. In this last city, the report also provides the collisions with other micromobility vehicles (7%) and pedestrians (4%), which are less relevant in the other documents.

Some of the main causes of accident are related to infrastructure issues as commented in Section 5.3, while the other predominant group are associated to driving behavior: vehicle control, paying enough attention, high speed, traveling in the opposite traffic flow direction and limited vision due to bad weather conditions (Brussels; France; Bekhit et al., 2020; APH, 2019). One of the factors of an inappropriate driving behavior is the lack of experience with this vehicle for most of riders. APH (2019) observes that the number of accidents decreases with the familiarity of riders with scooters: 33% of injured users were during the first ride while this percentage progressively decreases with the number of trips traveled up to 15% for users that rode at least thirty times before the incident. Other factor identified in the medical reports is alcoholic intoxication, although the presence of this intoxication varies across the different studies from 5% (Trivedi et al., 2019) to 38% (Kobayeshi et al., 2019). Additionally, double riding, two people on the same scooter, is reported as a risky behavior (Trivedi et al., 2019; Todd et al., 2019).

The interaction with other modes is a secondary source of this kind of accidents. However, Yang et al. (2020) identifies the hit with motorized vehicles is the main cause of accidents, around two thirds. Additionally, this study also reports more severe injuries or even fatalities than other documents. This is a consequence of the data source since media pays attention on the most relevant accidents, omitting collisions or fallings with mild injuries. In the same line, ITF (2020) identifies that 80% of fatalities riding e-scooters involved a motorized vehicle in the crash. In e-scooter crashes, when there was a fatality, the victim was the same rider in 9 of every 10 cases, the same proportion as bicycles, but between two and three times greater than cars. Therefore, although this kind of accidents are less usual, their severity is greater.

Regarding the location of the accidents, the study on French cities reveals that two fifths of accidents occurred on traffic lanes, one third on sidewalks and one fourth on bike lanes. Comparing these percentages with where users ride the scooters (Figure 11), sidewalks almost multiply by two their presence in accidents while it is slightly higher for traffic lanes and nearly half for bike lanes. According to this case, we can suspect that sidewalks are the most risky place to ride a scooter and segregated infrastructure for micromobility devices should be promoted as the safest solution, which is also require by riders (Section 5.1). Other studies also provide information about the location of accidents. In Austin (APH, 2019), traffic lanes were the location for 55% of accidents and sidewalks for 33%. The media report in Yang et al. (2020) also shows that traffic lanes are the most common place for e-scooter accidents. In Calgary, the positions are switched, being sidewalks the location for 38% of accidents and traffic lanes for 29%. Additionally, 21% of accidents occurred in pathways and only 4% in bike lanes. Similarly, 44% of accidents registered in Badeau et al. (2019) were on sidewalks.

Bekhit et al. (2020) estimate an accident rate of e-scooters in Auckland of 60 injuries per 100,000 e-scooter trips, being 20 of them hospital presentations. In Chicago, there were 23.36 persons injured per 100,000 trips, that is, a daily accident rate of 1.6 injuries. These values were 20 and 2 respectively in Austin (APH, 2019). The estimation of the accident rate in Calgary report is 67 e-scooter accidents per 100,000 trips and only one of them requires hospitalization. In any case, most of riders (87% in Tucson and Brussels according to the results of their evaluation reports) were never involved in accidents.

In Calgary, the study also compares the number of emergency visits due to accidents by scooters (33), bicycles (197) and cars (463). In Arlington, there were 2535 crashes by car, 92 by e-scooter, 61 by bike and 125 pedestrians involved. However, these comparisons are unclear since these gross numbers should be normalized according to the total number of trips per mode. As e-scooters represent a lower share than other modes, the normalized crashes will be significantly higher for them. For instance, scooter-related injuries were 5% of total traffic-related injuries in Portland, a percentage higher than the modal share of this new vehicle.

In order to reduce the accident rate for e-scooters, the authors of the previous reports demand policies to promote a more safe driving behavior, wearing a helmet and even wrist guards. Currently, the riding rules for e-scooters vary depending on the city (Sikka et al., 2019). Some legislations forbid the riding on sidewalks, at least in high demanded zones, require helmet mostly for adolescents, or directly these group of people cannot use these mobility services, and limit speeds. However, the type of trip completed by scooter are short and riders perceive low risk of accident. For that reason, most of users do not follow strictly the rules or recommendations.

In this line, a low level of wearing helmet by e-scooter riders is observed. According to the medical reports, most of riders that required health assistance did not wear helmet, less than 10% of presentations wore it (Bardeau et al., 2019; APH, 2019; Trivedi et al., 2019; Brownson et al., 2020; Kobayashi et al., 2019; Todd et al., 2019; Blomberg et al., 2019). Similarly, the observation of riders in Chicago, Portland

and Tucson corroborates that low level of use since less than one out of every ten riders were wearing the helmet. This percentage is 5% according to the survey in Oslo. On the other hand, asking users about how often they wear a helmet, the results are in the same line as Figure 12 shows, where less than 10% of respondents always wear it. However, that share is almost half of riders of owned e-scooter based on the results from Brussels. In Sweden, the percentage of e-scooter riders that wear a helmet is 17%, that is, lower than cyclists, which is 37% (Transport Styrelsen, 2020).

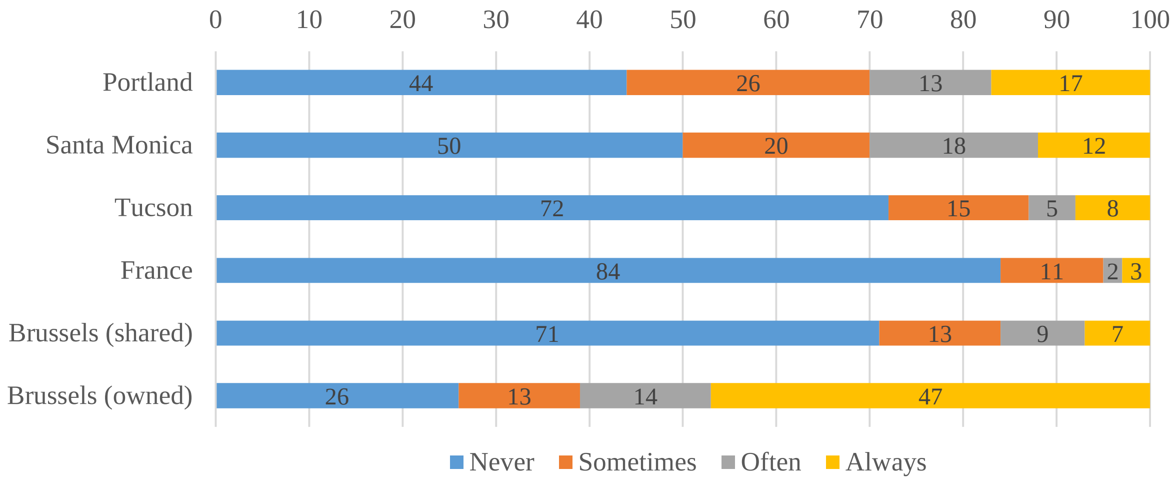


Fig. 12. Frequency of helmet use.

Besides user behavior, suppliers of e-scooter shared services should have a permanent control of the state of their vehicles to be sure they are in good conditions to be ridden without risk. As a reference, 19% of injured riders in Austin believed that malfunction of e-scooters were the cause of their accident (APH, 2019). In this line, cities require companies to ensure that the whole fleet are in good conditions to be riding in a safe way, blocking and removing those ones that do not accomplish it. For instance, Santa Monica requires operators to have a maintenance strategy where they should include regular inspection, repair and replacement of damage parts and batteries, and a record of these tasks for each device.

7 Measures and Policies

Shared e-scooter services based on free floating fleets without the need of special infrastructure and the absence of specific legislations make their implementation easy, which have allowed a quickly proliferation of these services in many urban areas. In most of cases, this implementation has been an uncontrolled process, resulting in chaotic scenarios that demand rules for an improved management of the systems and a better coexistence with other transport modes and activities in the urban space.

The simplest solution from a legislative perspective is the extension of the existing regulatory frameworks for cycling to other kind of micromobility vehicles. For instance, e-scooter riders have the same rights and responsibilities as cyclists with regard to parking and riding regulations in cities such as Chicago or Tucson. In other cities, this device is considered as a motorized vehicle since they have electric power assistance; this is the case of German cities. However, cities have introduced new administrative and management rules for this particular form of transport. One example is the strategy followed in American cities where the shared e-scooter services were cancelled and reintroduced again following certain instructions and restrictions in a pilot program monitored by public authorities (e.g., Calgary, 2019). The final utility of the pilot program is to determine if these services can have or not a role in urban mobility, and therefore, if they should continue operating or be definitively removed.

There are different publications that provide guidelines related to the regulation of shared e-scooter mobility such as Agora Verkehrswende (2019), Goodman et al. (2019) and other documents with a more general overview about shared micromobility (NACTO, 2019) and shared mobility (Shaheen et al., 2019). Below, we summarize some relevant measures and policies that have been applied: limits on number of operators and fleet size, fees and fines, equity policies, riding and parking rules, safety, education and communication, transport integration and evaluation.

7.1 Number of operators and fleet size

In most of cities, the arrival of shared e-scooter services occurred without any kind of regulation. As other transport services, full deregulation derives on inefficient scenarios due to on-road competition between operators. This can have counter-productive consequences for the own users, and of course, for the management of the transport system and urban space. To order the messy proliferation of scooters in the streets, cities have introduced some limitations with regard to the number of companies and vehicles in operation.

With this goal in mind, local authorities introduce a permission for companies that want to operate their shared e-scooters in the city. This is the first filter to avoid a chaotic proliferation of operators. Any company must get that permission before launching the service. The number of permissions is limited to a maximum, being the companies chosen through a competitive selection process. Additionally, the total number of scooters in operation is lower and upper bounded for the service region, allocating a fixed amount of scooters for the whole city or per company. In that way, the market becomes an off-road competition, rationalizing the supply and the urban space consumption.

Janssen et al. (2020) compare these measures for nine USA mid-sized cities. Austin and Nashville do not restrict the number of operators, although they fix an upper bound of 500 and 1000 scooters per company respectively. On the other side, Raleigh has the most restrictive policy, reducing all the service to only one operator. Regarding the fleet size, most of these cities have an upper bound that ranges from 250 to 1000 scooters per company, and in few cases, they also fix a minimum of 250-500 scooters per company.

These boundaries are a first estimation of the service dimension. For instance, San Francisco planned a pilot program for up to five companies and an initial total fleet of 1250 scooters, which could be extended to 2500 in a second period of the program. After the application process, only two companies got the permission for 625 devices each one. However, the companies were rarely operating that number of scooters, on average the available fleet was around a half. This was a static fleet dimensioning before the operation of the service without any specification about how to manage the fleet size once the service is running.

An alternative approach in some regulatory frameworks includes a dynamic fleet adjustment based on the utilization rate of scooters. In this case, each company periodically evaluates the average number of trips per scooter and day of its fleet. When that number is smaller than a minimum rate required, the operator has to remove scooters from the service. If the utilization level is above an upper bound, the fleet can be expanded. As a reference, Janssen et al. (2020) report that a usual requirement for a fleet expansion is a usage of at least 3 times per day and the boundary to avoid a reduction of the fleet is no less than 2 times per day. In this way, operators are encouraged to improve the exploitation of their resources.

Santa Monica pilot program includes a combination of these static and dynamic dimensioning measures. The city allowed two companies to operate their shared e-scooters, assigning a minimum of 250 vehicles per company and a maximum of 1000 vehicles for the whole fleet. This means that there is a margin of 500 vehicles that could be assigned or not to the companies depending on the performance of the service. Every two weeks, companies have to inform about the utilization rate of their fleets. In case this utilization is higher than four trips per scooter and day, the company can apply for an increase equivalent to that amount of vehicles that would adjust that utilization rate to the value of four trips per scooter and day. If that rate is smaller than that boundary, the city will require to the company a reduction to meet again the four trips per scooter and day. However, this increase or decrease is limited to the minimum fleet per company (250 devices) or the maximum total fleet (1000 devices).

7.2 Fees and fines for operators

Shared e-scooter services are a business that extensively consumes public space, either running scooters on car/bike lanes and sidewalks or standing the vehicles in the streets. For that reason, there exist the opinion that companies that supply these services should pay some kind of tax such as other transport vehicles and businesses that use public space (e.g., restaurants, cafes, shops). On the other hand, someone has to fund the costs associated to infrastructures such as segregated lanes for micromobility vehicles and parking boxes or docking stations. Finally, a new mobility service adds new workload to public authorities for management and control, that is, administration staff, transport planners and managers, studies and evaluations, etc. This is what happens in the pilot programs developed to set these services and assess their impacts. All these costs should be recovered in some way from the same shared e-scooter system, and with that objective in mind, different kinds of fees are considered.

One of these fees is charged to any company that applies to get permissions for the operation of the service. This application fee is a fixed cost at the beginning of the process for the administrative expenses derived from the evaluation of the application, independently if the company gets or not the permission to operate in the city. In case the company gets the permission, cities ask for additional taxes. One of them is associated to the operation license, which is independent of the fleet size and has a validity period. This fee is a recurrent payment at the beginning of each period for the renewal of the license. The period can be either the duration of the pilot program or a more common annual solution. Other types of charges are associated to the service dimension as a right-of-way payment. They can be a charge per scooter and day or year, independently of the usage rate of the device, and alternatively, they can include this last factor associated to the scooter usage where the city charges a fee for each trip.

Regarding taxation, cities have opted for a wide range of solutions from the ones that do not charge any kind of fee, at least at the initial stages, to others that implement different levels of taxes at the same time (Zack et al., 2018). In the same way, we can identify a high variability of the amount of money charged at each level. For instance, Alexandria only charged a permit fee of $5000 for the participation in the 9-month pilot program. On the other hand, Santa Monica did not ask for an application fee. However, the city annually charged $20,000 for operator permit license and $130 per device. Additionally, there was a right-of-way fee of $1 per scooter and day. In Portland and Tucson, there were application ($250 and $4000 respectively) and annual permit ($5000 and $7500) fees, but the right-of-way fee was per trip ($0.25 and $0.20) instead of per scooter and day as in Santa Monica.

The introduction of these charges for the companies has an impact on the final price of these services (Johnson, 2019). If currently they are expensive in comparison to other mobility solutions as commented in Section 2.3, these fees reduce the competitiveness of shared e-scooters, having a negative impact in case we want to promote them.

Finally, besides previous fees for operating license and right-of-way, other kind of charges can be claimed by cities in case companies do not fulfill the agreement related to the operation of the shared e-scooter service. Several fines can be considered: level of service and number of scooters in operation according to the planned fleet size, spatial distribution of scooters in the required proportion or removal of inappropriate parked scooters within a fixed reaction time.

7.3 Equity policies

Micromoblity services are a potential transport solution for underserved areas or population with limitations in the accessibility to other transport modes (Zack, 2018). To meet an equity transport system, local governments compel shared e-scooter suppliers to remove the barriers that limit the accessibility to this new mobility service for some citizens. Some issues such as discount programs, payment options, non-digital access, and sidewalk obstructions for disabled people have been commented above. Here, we add two other equity measures: opportunity or priority areas and vehicle design.

Due to economic productivity, companies exclude from the service residential areas that are mainly with low densities and low-income inhabitants. To guarantee accessibility for their residents, which in general have less transportation options, to this new mobility service, local governments encourage or force operators to allocate a portion of their fleets in those areas. This strategy tries to extend the e-scooter services to a wider population range. For example, Chicago created two of these zones in its pilot program called priority areas. The requirement was that companies had to distribute at least 25% of their scooters in each priority area at the beginning of the service every morning. According to Figure 13, this goal was mostly achieved in the early morning, but not after the utilization of the scooters during the day. The devices tend to concentrate out of those areas as people use the service since most of destinations are out of the own priority areas. Therefore, the efficiency of this equity policy was limited due to the absence of a rebalancing regulation, which would be needed to ensure the same level of service along the day.

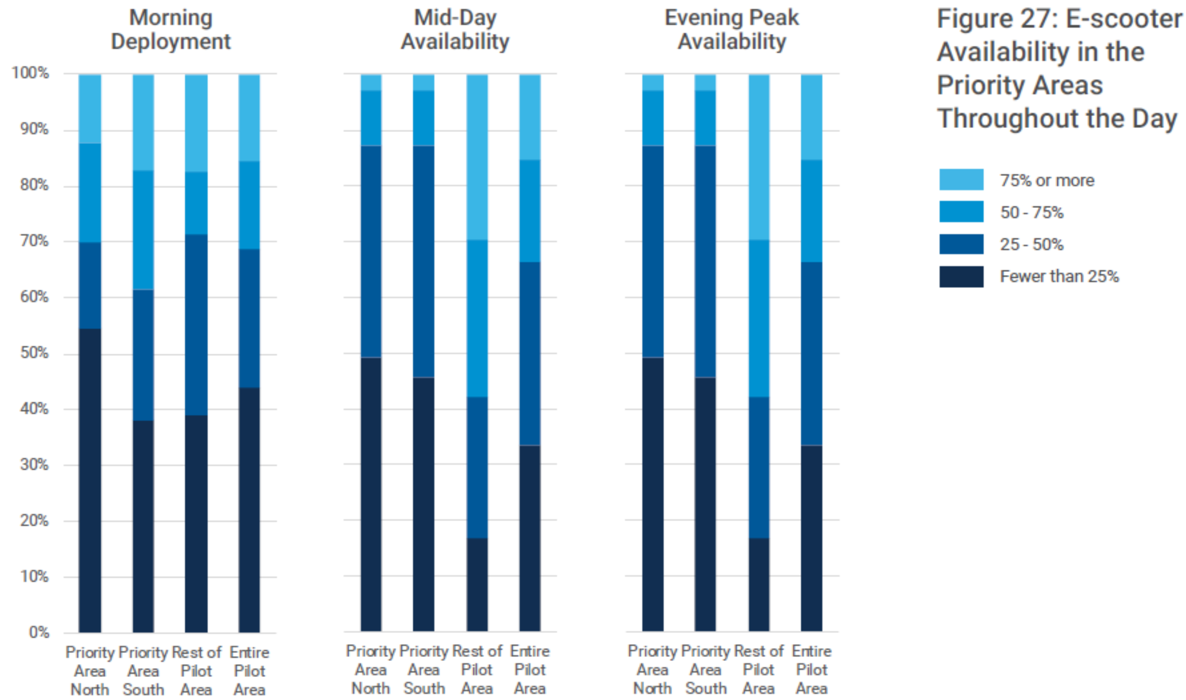


Fig. 13. Percentage of e-scooters in the priority areas and the remainder service area in Chicago (Source: City of Chicago, 2020).

Portland also includes the requirement of deploying at least 100 scooters per company every day in the area called East Portland. This is approximately 15% of 683 scooters that each company can operate and a minimum of 300 scooters in total since three companies got a license. However, only one of the companies complied with this goal, and as a consequence, the average number of devices in the area was only 243.

Instead of the requirement of deploying a minimum percentage of the fleet in priority areas, Tucson introduced a bonus for those companies that decided to operate in the five opportunity areas defined in the city according to their socioeconomic characteristics and transportation options. Beside the 500 scooters allowed per company, each of them could add up to 250 more vehicles on the condition that they were deployed in those areas. Similarly, Los Angeles allows between 2500-5000 devices more for those companies that serve Disadvantaged Communities. Although initially operators deployed the service in these areas, they progressively removed devices, showing that this policy could fail if this is costly and unprofitable for companies.

Another example is San Francisco where the city did not define a specific equity criterion about this kind of priority areas. The companies were the responsible to define equity plans taking as a reference the Communities of Concern defined by the city, which are neighborhoods that require special attention. In the application proposal to get the license, the company proposes its service area, which does not have to be coincident with the whole city, and how the service integrates the Communities of Concern. The two companies that got the permit license proposed to maintain at least 20% of their fleets in the Communities of Concern inside their service areas. However, although there was certain flexibility for companies to decide the equity plan, they also failed to achieve it.

To get these spatial equity measures, companies will have to make an effort on balancing tasks. However, this additional collection and distribution of devices will make the service more expensive from the operating side and more contaminant from an environmental perspective.

Other issue is the vehicle design; standing scooters are not an easy-riding solution for the whole population. In this line, a new design has appear equipped with a seat and bigger tires, being a solution in between the most extended scooter design and a bicycle or motorbike. In that sense, Santa Monica considers as a positive aspect in the evaluation process those shared e-scooter operators that include in their proposals fleets partially composed by scooters with three wheels (City of Santa Monica, 2019b), which are more stable for impaired persons. In 2019, Portland allowed two companies to introduce an alternative e-scooter designed with seat and bigger tires (Theen, 2019). The company Wheels provides a service based on a hybrid design between scooter and bicycle as shown in Figure 14b (Wheels, -).

(a) E-scooter with seat and bigger wheels (b) Hybrid device between scooter and bicycle

Fig. 13. Alternative designs for micromobility devices.

7.4 Parking management and infrastructure

One of the advantages of mobility services based on floating fleets is that they are door-to-door solutions, at least at the end of the trip. However, a floating fleet located in the public urban space creates a chaotic image of the city and obstructs pedestrian or other vehicle flows or urban activities. At the same time, from an operating perspective, these fleets are expensive due to the distance traveled for collecting scooters. To avoid it, cities and companies propose alternatives that restrict where to park the scooters, although if these measures were spatially restrictive, they would reduce the attractiveness of a floating fleet. Similarly, scooters interact with other users of transport infrastructure when they are running, and we need a balance in order to get a comfortable scooter riding without creating undesirable feelings in other users.

The most restrictive measure is the definition of non-riding and non-parking zones such as high-demanded pedestrian streets in the old town, parks, university campuses, etc., where there is no free space for additional uses or the management of the fleet is complex there. Other measure is a general prohibition of riding on sidewalks in any street and circumstances. However, this prohibition should be complemented by an expansion of micromobility infrastructure, as commented in Section 5.1, where it is possible. If it is not, the introduction of speed limits for traffic in those streets where scooters have to share the space with cars is important since riders will feel comfortable, avoiding the temptation of riding on the sidewalk.

Regarding parking, cities define some basic guidelines about how to park a scooter properly. These devices should be parked upright, in the furniture zone of sidewalks, leaving in any case some clearance meters to avoid obstruction of flows or access to buildings or other kind of infrastructure. In high-density streets or transport hubs, to control the high demand for scooter parking, users have to park the vehicles in specific parking corrals, which helps for a better organization of their parking. To be sure that users properly park the shared scooters, some companies ask users to take a picture of the scooter at the end of the trip to validate if the device is properly parked or not. However, this system does not seem enough accurate to identify incorrect locations or possible obstructions (e.g., Chicago).

In San Francisco, they tried lock-to technology where scooters are locked to street furniture as a solution to prevent from scooters in the middle of sidewalks and they got reduction of parking complains. However, users can have problems to find fixed objects where the locking fixes well. Therefore, additional parking infrastructure is needed in order to accommodate the whole fleet. On the other hand, this technology reduce the vulnerability of shared scooters in front of vandalism. The number of lost or stolen scooters reported in San Francisco decreased after the implementation of this technology. Other cities such as Chicago have introduced this requirement; scooters must be equipped with this type of locking technology in the extension of the pilot program for 2020 (Chicago, 2020).

Other alternative is docking stations where scooters park and charge their batteries. This solution can be useful for cities to order the disorganized deregulated scenario, and at the same time, for companies. As commented in Section 4, one of the pitfalls of this type of service is the distance covered by auxiliary vehicles for collecting, balancing and charging the scooters. Having these stations distributed along the city makes the traveled distance shorter and the service more environmentally efficient. Additionally, docked scooters are more protected against vandalic acts. A flexible operation could be an option combining a floating fleet during the day and working with docking stations during the night.

Finally, local authorities require companies to manage their parked scooters with two different measures. On the one hand, to avoid abandoned scooters, these vehicles cannot be in the same location without moving during a certain period of time (e.g., 7 days in Alexandria or 48 hours in Santa Monica (The City of Santa Monica, 2019b)), being companies forced to remove or relocate the vehicles. On the other hand, after any complaint related to a scooter not well parked, companies have to relocate it according to the reaction time fixed by the city. In this case, the solution for the complaint has to arrive within 2 hours in Alexandria and Los Angeles or 1 hour in Santa Monica. However, 32% of complains in Los Angeles were not solved within the required time. These times are too short in comparison to the long response shown in Bai and Jiao (2020) commented in Section 5.2.

7.5 Geofencing

This technique combines different geospatial data to delimitate real geographical zones through virtual boundaries or geofences. In this way, it is possible to control GPS-equipped vehicles when they cross the boundary of a specific area. In case that a vehicle crosses the geofence, the system automatically will reduce the speed until the vehicle stops at a certain distance from the boundary. This technology becomes a useful tool for operators and cities in order to limit the service area for e-scooters.

As commented above, local governments prohibit e-scooters from accessing to or parking in some areas (pedestrian streets, green areas, around emblematic buildings, etc.), and limit the cruising speed in crowded environments. For this purpose, geofencing technology is a suitable tool to control where and how scooters operate. For instance, Chicago applied this technology in order to set this type of prohibitions. The pilot program showed that these measures were effective for large areas (neighborhoods, parks, etc.). However, the results were negative for small, narrow zones since current technology is not enough accurate to be effective in these cases. Similarly, Tucson forced companies to geofence the University campus, a more feasible constraint.

On the other hand, companies try to maximize the efficiency of their fleets operating exclusively in specific areas with enough densities, increasing the usage ratio of vehicles and reducing the distance traveled due to recharging and balancing operations. Moran et al. (2020) describe and compare the distinct geofences designed by the six suppliers that operate in Wien. In this case, the city does not have any requirement with regard to a geofencing strategy, leaving the design of these zonifications to each company. The authors observe that companies does not cover identical zones. There is certain overlapping in the inner districts since the demand is high enough for a profitable business in competition. However, the covered areas in the city periphery diverge significantly among operators. In these zones, there is no enough demand to be attractive for companies to supply the service or at least to compete for clients.

This technology is also useful in order to control the scooter speed. If these vehicles are equipped with a speed governor, the own vehicle will reduce its speed in case riders exceed the maximum limit allowed (Brankovic et al., 2015). This speed limit can vary between different zones of the city or streets, identifying the vehicle the respective limit by means of geofencing. If the scooter crosses one of this geofences, and therefore, the new speed limit is lower than the previous one, the device will automatically reduce the speed according to the new maximum. In this line, the City of San Jose (-) in California requires a technology plan for companies in order to avoid riding on sidewalks. Operators have to specify what kind of technology they integrate in their scooters to identify when users are riding on sidewalks and reduce in those zones the speed to 5 mph (8 km/h).

7.6 Education and Communication

Another important factor for a good cohabitation between shared e-scooters and the transport system, pedestrians and urban activities is that scooter users, and the rest of citizens if it is possible, are well informed and educated with regard to this new mobility service. Cities play a role providing a clear set of rules for riding e-scooters, giving information on their websites (City of San Diego, -; PBOT, -), distributing flyers (SDPD, 2018) and putting signals on the main e-scooter paths or parking areas.

On the other hand, companies also have a relevant participation in education and communication since they are in direct contact with users. In some pilot programs, one of requirements for the companies is an educational campaign for safe riding and proper parking (wearing helmet, obeying laws, riding on bike lanes, speed limits, parking areas, etc.). This campaign can be supported by different means. Companies' websites and apps provide information about how and where to ride and park according to the regulatory framework of e-scooters. In Chicago, companies inform clients about the riding rules before unlocking the scooters, and clients have to agree to follow those regulations if they want to ride. Companies can send messages to riders to emphasize different issues about safety and proper scooter use as in Figure 15a and b.

(a) (b) (c)

Fig. 15. Education supports for better knowledge of riding and parking rules

Besides that on-line support, instructions can be on the same scooters as laminated cards for example (Figure 11c). Other solution are in-person events involving users, local institutions and community associations. This type of meetings are useful to inform, but at the same time, they are a good opportunity to get feedback from the different stakeholders involved in this mobility service and promote a constructive debate among them. For instance, the program Lime Action (Lime, 2020a) promotes campaigns for a safer, more suitable and more equitable shared e-scooter service. This program includes activities to teach how to ride and park e-scooters correctly (Lime, 2020b). This is a requirement in many pilot programs such as in San Francisco or Chicago for example.

Finally, Voi (-c) launched the campaign "Ride like Voila", which is an on-line traffic school where riders learn the appropriated way to ride and park Voi's vehicles (Nilsson, 2019). A test, which is supported by the European Institute for Road Safety, allows users to validate their knowledge of rules and if their riding behavior is the correct. This test is adapted to the different cities where Voi operates. This is in the same line as Santa Monica pilot program, where the city requires to shared e-scooter operators the implementation of a driver license for their users. This license guarantees that riders know the driving law of scooters before traveling by them. In Los Angeles, it is mandatory to have a valid driving license for riding an electric micromobility device.

7.7 Riding rules and safety

Legislators have reacted in front of nonexistent laws about riding a scooter with the assimilation of this vehicle as a bicycle or motorized vehicle and the implementation of several rules (ITF, 2020), some of them already commented along the document. These polices are not uniform across different urban environments. For instance, the most radical decision in front of the arrival of these new services was their prohibition (Hirst, 2019), although it was momentary until the authorities take the control of the situation for a regulated implementation of services (Department for Transport, 2020). However, this decision is not generalized since many cities allow shared scooters, although with restrictions such as no operation during night or a minimum riding age for users of these shared scooter services.

Regarding riding, there is a discrepancy if sidewalks should be or not a place where scooters can run. Due to the negative impact on pedestrians, some local authorities prohibit riding on sidewalks (Chicago, Portland or Tucson), but others allow it such as Alexandria or Calgary. This last city forbids scooters riding on traffic lanes (City of Calgary, 2020). A combined solution allows riding on sidewalks in case the street does not have bike lane and road speed exceeds certain limit (around 50 km/h), but scooters must run at speeds below 10 km/h on sidewalks (i.e., Denver, 2018).

On the other hand, speed limits have been implemented, at least, a general restriction for the whole city. This limit is commonly around 25 km/h (15 mph) (i.e., Portland, Santa Monica, Alexandria or France) although in some cases it increases up to 30 km/h (20 mph) (Janssen et al., 2020). However, these values are too high in comparison to pedestrian speed, for that reason, the authorities reduce the limit on sidewalks, where different options are considered from 10 km/h in Alexandria to 15 km/h in Calgary. A similar policy is applied in high demanded environments, which are classified as low-speed zones. This policy can be a strategy in order to encourage riders to take alternative infrastructures or paths instead of sidewalks or crossing those areas. In this line, a solution to be sure that riders will not exceed the speed limits is adding a speed limiter in the scooters. Kastenbauer et al. (2017) propose a dynamic limiter with the ability to adjust the speed or stops the electric power assistance in case an ultrasonic sensor detects obstacles, including pedestrians, close to the scooter.

Another controversial issue is the helmet use. Helmet is a protection that can reduce the negative consequences of any accident riding a scooter and wearing it could be mandatory, however, this requirement is not widely imposed. In this kind of mobility services, as users can decide to take the vehicles without a previous plan, they do not have a helmet with them. For instance, Portland is one of those cities where riders must wear the helmet. According to the results of its survey (Figure 12), most of them never or rarely use it, although this percentage is lower than in other cities where helmet is not obligatory. To promote the helmet use, operators were required for a distribution plan of free helmets among their clients in Portland. This measure was also included in San Francisco pilot program, a city where helmet is not mandatory. Lime (2019b) offers discounts on helmets in several USA cities for its clients. Other option for the promotion of this protection could be vehicles equipped with a helmet, and then users do not have to bring it.

Finally, to enforce riders to follow the rules, authorities determine several fines in case of law violation as any other vehicle. The issues included are related to exceeding the speed limits, riding on sidewalks or other zones where it is prohibited, imprudent riding with especial attention on interferences with pedestrians, more than one person riding on the scooter, inappropriate parking, etc. In case a user accumulates several violations, cities can progressively increase the fine cost up to an unacceptable number of infractions where companies have to cancel temporarily or permanently the subscription to the service. Therefore, companies have to elaborate a register of users and their inappropriate behavior.

7.8 First/Last-mile solution and Mobility Platforms

As commented before, shared e-scooters have been advertised as a potential feeder solution for public transport systems. However, the results in Section 3 from several cities about how frequent is the combination of these two transport modes is not clear, rather users ride scooters as an independent mode and not being a complement for public transport. According to this initial results, cities, transport authorities and companies should work together in order to reduce the current barriers that limit the role as a first/last-mile solution for scooters.

Grosshuesch (2020) emphasizes the flexibility of dockless micromobility devices in front of those based on docking stations. The latter reduce the opportunities for potential users since these stations are not available in any origin or destination, and they can present capacity constraints. However, these limitations disappear when the vehicles have incorporated their own lock system. E-scooters are an attractive solution faster than walking and skipping traffic congestion. However, to encourage this role for shared micromobility services, this author proposes several measures that are extended in a more general overview in Oeschger et al. (2020).

On the one hand, there exist the need of infrastructural measures such as the development of lanes for micromobility vehicles to connect in a safe way public transport stations/stops with their surroundings by this type of devices, complemented by traffic calming measures. Additionally, cities should properly plan e-scooter parking space around public transport hubs. On the other hand, from the service perspective, cities should promote or encourage the supply of shared e-scooter services in those areas where public transport accessibility is limited, that is, suburbs outside the city center. Finally, another relevant issue for a good combination is the creation of an integrated ticketing system, for instance, using both services with the same smartcard or mobile phone app. Transport authorities should consider the subsidization of this type of trips in order to offer discounts and loyalty programs for frequent users, increasing the attractiveness of this type of trips. This system can also include real time information for a more convenient combination of modes.

Similarly, it is relevant to achieve certain integration of the different shared e-scooter services in operation in the same city. Currently, each company has a different app, a factor that reduces the capacity of users to make use of the different services in the most efficient way. For example, to find the closest e-scooter, users have to check all of the apps, an annoying situation that dissuades potential riders. To solve it, integrated technology would be useful if users can manage the scooters from the different providers through the same app.

An example of this type of common platform for several mobility services is the app Transit (transitapp, -), which has been adopted in cities such as Chicago (Freund, 2019). Through this app, users can check the location of available scooters from any company in only one map, knowing the level of battery of each device and its company. Once user chooses the scooter, the app derives him to the provider of the selected scooter following the regular process. Additionally, Transit app provides information about other micromobility services and public transport, and the option of planning trips taking into account all these transport alternatives in the same app.

7.9 Evaluation and data sharing

There are two different types of evaluation with regard to shared e-scooter services. One is an evaluation during the application process where the different candidate companies are rated in order to identify which of them are the best candidate as a supplier for the city (Chicago, 2020; City of Saint Paul, 2020). In the application form, companies have to answer several questions about characteristics of the vehicles, education and safety plans, riding and parking strategies, pricing plans, equity plans for spatial, economic and technological accessibility, operating plans for relocation, vehicle maintenance, environmental improvements, complement for public transport, and the results of each company in their previous experiences in the same or other cities.

Once selected companies are in operation, the city develops a second evaluation for the monitoring of the services. This consists on the elaboration of periodical examinations about how the global system works and, in particular, each operator manages its fleet. This evaluation should also focus on similar issues such as safety, equity, transport infrastructure and urban space management, environmental impact, effects on other transport modes and collaboration in multimodal trips, among others. All this topics should be evaluated in a quantitative or at least qualitative way to identify what aspects require more attention and what companies perform correctly and better or worse than others do. An example of this type of evaluation is applied in San Francisco through evaluation report cards shown in Figure 16.

To complete a good evaluation, a key factor is an active participation from the operators providing data of their fleets and users. Local authorities have to compel companies to share that data periodically or in real time. The data reports can include different information about service (time and spatial availability of scooters, usage ratios), mobility (number of trips, origins and destinations, routes, length and time), safety (accidents, collisions, injuries, inappropriate riding), parking (obstructions, removals), complains and response time, and sustainability (scooter timeline, collection and distribution distance, auxiliary vehicle characteristics). Companies that get an operating license have to accept the provision of that data in standard formats to guarantee its processing and analysis. Furthermore, companies have to collaborate with the distribution of surveys among their users.

		Scoot	Skip
Safety	Permittees' operations must be consistent with the City's goal for achieving Vision Zero and ensuring public safety and security. State law establishes legal requirements to ensure the safe use of electric scooters in the public right-of-way, and the following complaints received during the unpermitted deployment of Scooters in spring 2018 should be directly addressed by permittees: illegal and unsafe riding on the sidewalk, unsafe riding without a helmet, use by minors including illegal use of scooters by individuals without a driver's license, and illegally riding a scooter with a passenger.	F	F
Disabled Access	California Vehicle Code Section 21235 prohibits motorized scooters and other objects from blocking pedestrian paths on the sidewalk, and Section 63 of the San Francisco Police Code generally prohibits the obstruction of sidewalks. Strategies to ensure properly parked scooters, including locking or tethering, should result in parking that does not block the right of way.	S	S
Equitable Access	Permittees' approach to providing service to low-income residents, including diverse payment options and fare discounts, should reduce barriers to participation. Permittees' programs must be available to all, including groups who have historically lacked access to mobility benefits. Service must be available in diverse geographic areas and that service is available to low-income residents through discount programs and varied payment options.	P	P
Collaboration/ Outreach	Permittees must undertake robust community outreach to ensure that any scooter services reflect community feedback and target a diverse set of users. Outreach approaches must include strategies to ensure that low income residents are aware of service and how to participate.	F	F
Labor	Permittees must ensure service reliability by understanding operational needs and adjusting resources as necessary. Scooter share operators should support San Francisco's local hire principles, and promote equitable job training opportunities. A trained and motivated workforce is necessary to ensure the safe and reliable operation of scooter share services.	S	F
Sustainability	Permittees must support sustainability, including helping to meet the City's greenhouse gas (GHG) emissions reduction goals, promote use of all non-auto modes, and support efforts to increase the resiliency of the transportation system. Approaches to operations and disposal should demonstrate commitment to environmental sustainability.	S	F
Transit	Permittees must support, rather than compete with public transit services, and must account for the operational needs of public transit and encourage use of high-occupancy modes	S	S
Accountability/ Compliance	Permittees must share relevant data so that the City and the public can effectively evaluate the powered scooter share systems' benefits to and impacts on the transportation system. Permittees must also comply with all terms of the scooter share permit.	S	F

Rating Definitions

S	**STRONG** ratings were given in areas where permittees performed particularly well. Permittees with strong ratings substantially exceeded the minimum program requirements as spelled out in the permit Terms & Conditions and/or communicated by the SFMTA.
F	**FAIR** ratings were given in areas where permittees performed adequately but unexceptionally. A fair rating demonstrates a moderate level of commitment and ability to solving known challenges and concerns, and meeting or somewhat exceeding the minimum program requirements as spelled out in the permit Terms & Conditions and/or communicated by the SFMTA.
P	**POOR** ratings were given to permittees whose performance in a given area requires significant attention and improvement for the remainder of the Pilot. Permittees were given a poor rating for demonstrating a low level of commitment and ability to solving known challenges and concerns. Failing to meet the bare minimum program requirements as spelled out in the permit Terms & Conditions and/or communicated by the SFMTA also resulted in a poor rating.

Fig. 16. Evaluation Card for shared e-scooter suppliers in the city of San Francisco (SFMTA, 2019)

Part B: Empirical Analysis of Travel Patterns

8 Introduction to Empirical Analysis

We have conducted an empirical analysis of trip data from Voi e-scooters in Stockholm to understand how the scooters are used in terms of trip destinations and purposes. This information makes it possible to draw conclusions about general user behavior, both in what end point types are popular and what geographical areas that contains the most traffic during different hours of the day. The work has been conducted in the form of a MSc thesis by Eric Lansner, KTH. The full description of the work and more extensive results will be presented in his MSc thesis report.

The practical part of this work is to combine the Voi trip dataset with another dataset consisting of different POIs that was extracted from OpenStreetMap. Using these two datasets in junction makes it possible to analyze user intention with the e-scooter trips. Every trip has an end point, defined by two GPS coordinates. Coordinates also define every POI in the OpenStreetMap dataset. By taking the trip end point and doing a search in the nearby area for POIs it is possible to link possible destinations to every trip. It is not certain that these POIs are the true destinations for the users, but it is only an approximation. After the initial data processing has been done as explained above an array of different approaches opens to analyze the result and visualize it in multiple ways. Through analyzing the visualizations the aim is to assess whether it is possible to find spatial and temporal pattern in the user trip purpose that appears from the end point analysis.

It is important to find the distinction between the two types of usage patterns mentioned. The first of the two is “location-based” usage patterns. These patterns are linked to the geographical space available in the Stockholm area, often referred to as “grid squares” , since that is the unit used in this work when talking about different locations. The second type “time-based usage patterns” are linked to time exclusively, for example different times during the day, days of the week or different seasons. These two patterns can be combined, which could look like “Activity of the Stureplan grid square during hours 04-05".

9 Travel Pattern Analysis Methods

This section explains the steps of the work, from data extraction and processing to multiple algorithms, what the goals of the steps above are and the important underlying concepts that are present. The purpose of the analysis is to accurately estimate user trip end positions in electric scooter trips around Stockholm. In short, the steps needed are the following:

- Electric scooter dataset extraction and processing
- OpenStreetMap dataset extraction and processing
- Connecting electric scooter datapoints to OpenStreetMap POI locations
- Visualizing and interpreting results

The most essential part of the data are the coordinates for the OpenStreetMap POIs and e-scooter trip end points. Some important fields are the timestamp of the trip and a type-field linked to the OpenStreetMap Point of Interest (abbreviated POI). The next step is to connect these two datasets to each other. This is done by iterating through the e-scooter dataset and attempting to connect every trip with the most probable end POI destination. There are some parameters one could tune to connect the trips with the POIs, with the most obvious one being the POI search radius of a scooter trip end point. In this work a rather tight radius limit of 14m from the end point has been set. Anything beyond that it will not be registered. Using a large radius would most probably result in many trips assigned to the wrong end point.

Every visualization method has its strengths and weaknesses. In this work heatmaps and bar plots were used almost exclusively. These are two very powerful tools, especially heatmaps, when working with two- or three-dimensional data. A large part when analyzing is to find spatial patterns, which is convenient when comparing different heatmaps. Other visualization tools could be used and there is much room to explore different options in future work.

For the sake of delimitation, the study area has been restricted to central Stockholm where most of the shared scooter activity is located. Figure 1 shows the relevant area for this analysis.

9.1 Voi Dataset

The dataset used to analyze shared scooter user behaviour was supplied by Voi. It is a large dataset, consistsing of 3.5 million data points in total. Every data point has 8 fields representing the starting location of the trip given in longitude and latitude, the end location of the trip given in longitude and latitude, the local starting time of the trip, the local ending time of the trip, a hashed customer id and vehicle id information. All fields are used here except for the vehicle id. The main strength of this dataset is the amount of data points and the weakness is the relatively small amount of information stored in it.

The coordinates are the most important data for this research, since the core idea is to link every trip's destination coordinates with a POI and analyze the results. The time variables are also very important, since analyzing the destination coordinate patterns during different time segments is desirable, with the end goal being to categorize different behaviour depending on the time. The time segment can be defined over the course of a day, different days of the week, or different seasons. Some analysis using the hashed customer id is also possible but extensive analysis of the customer patterns might be an infringement on people's privacy. This is the main reason that the analysis of specific customers was avoided in general.

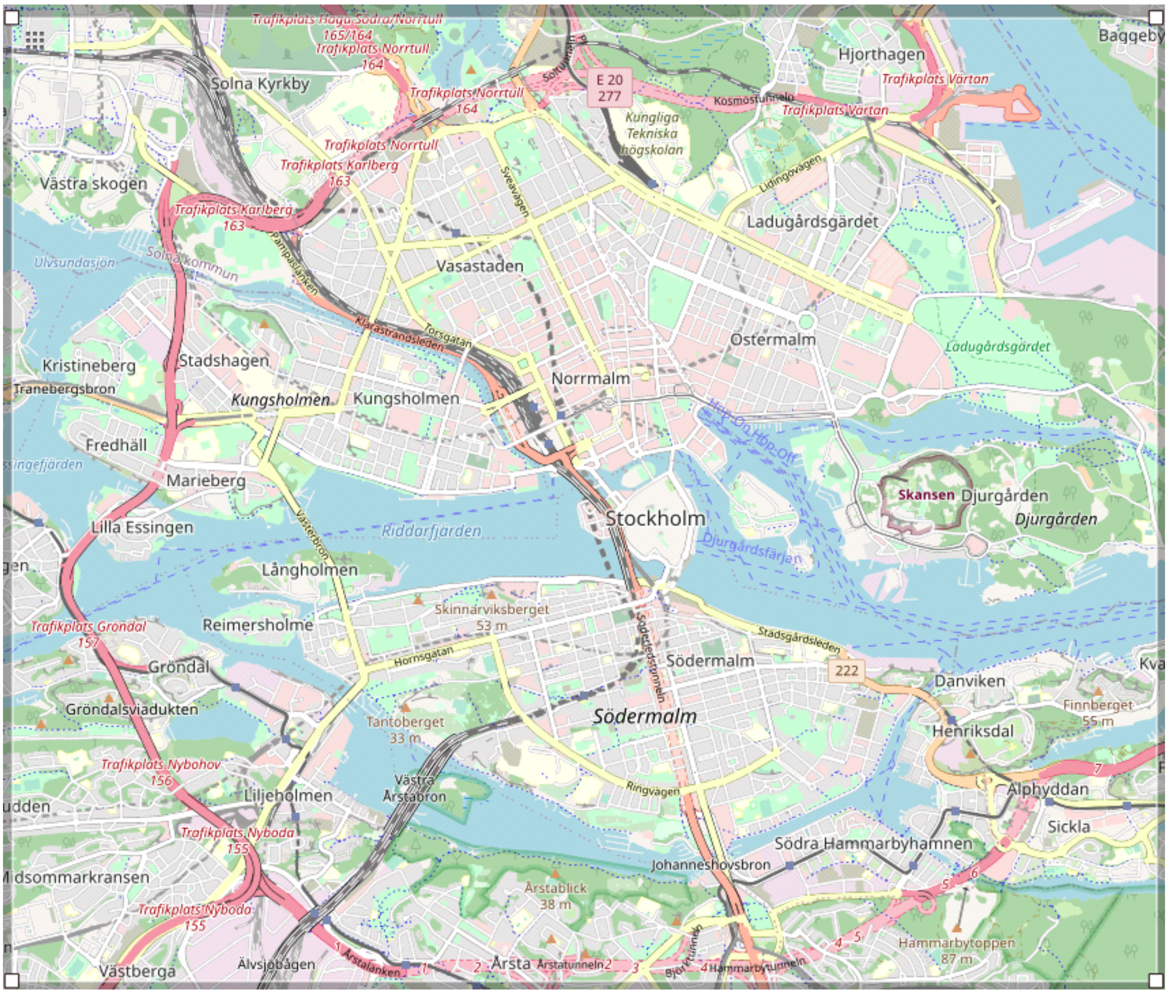


Fig. 17. Study area for analysis of trip purposes.

9.2 Places API

We used OpenStreetMap data to extract multiple POIs across Stockholm. Some positives with OpenStreetMap are that the dataset is extensive, containing circa one and a half thousand more points than Google Places in the Stockholm area. To make sure that the information was sound we used our own knowledge about the public transport layout in certain areas and double-checked the given locations for different subway entrances.

The OpenStreetMap data model consists of three key elements: nodes, ways, and relations. A node is a single point in the space defined by its node id, longitude, and latitude coordinates. For this project only nodes are considered since the other parts are hard to deal with when analyzing.

Overpass is a read-only API where you can fetch OpenStreetMap data via queries. This was used in combination with Overpass Turbo to grab and inspect all data needed to do the analysis of combining points of interests from OpenStreetMap and voi data points. The query language is extensive and has much information available at the OpenStreetMap wikipedia. For this work the queries used to retrieve data was not complicated at all. First step would be to limit the bounding box to the Stockholm area and then query different types of amenities, all of which can be found under the Key: amenity OpenStreetMap wikipedia page. The rest of the data gathering was selecting the interesting amenities, things such as restaurants, night clubs, schools, bus stops, railway entrances etc and fetching the data.

Overpass Turbo is a handy tool that allows you to run queries on the OpenStreetMap database directly in the browser and displays the results with a very nice GUI, easily usable and indications of all the nodes, ways or relations that was returned. Other points of interests are also displayed that the query did not return, and they are clickable so retrieving information about specific ones are easy. All the points of interests are displayed on an interactive map which is very user-friendly. On the OpenStreetMap wikipedia there is information available on Overpass Turbo and some examples of use cases. One of these being “Converting OSM data to the geoJSON data format” which was useful for this work.

9.3 Programming in Python and libraries

The programming language of choice was Python. There lies much emphasis on flexibility, being able to implement things easily and not worry about underlying issues with segmentation faults and pointers. Another huge selling point of python is that working with libraries, which this project requires many of, is effortless. Since the dataset is large and the computational resources are limited the execution speed suffered a lot during the majority of the project. A brief description of each library and its use in the project will be declared in the following section.

The first library worth mentioning is Pandas. Pandas is used both as the main data structure but also to store to and read easily from file. There is built in search- and filter functionality, easy indexing and adding new fields to the existing data is effortless. The main data structure of Pandas is the dataframe. This structure has columns and rows, where each column has a label representing some variable name, and the rows are observations for each of the variables. With this structure it is possible to apply queries, use boolean expressions, visualize using matplotlib, solve missing data problems, work with both categorical- and text data, etc.

When dealing with geospatial data, different coordinate reference systems (CRS) become relevant. The Pyproj library deals with transformations between different CRS and was used multiple times in this project for different conversions. The Geopandas library extends pandas with functionality that helps work with geospatial data. In this project there are two times this library is relevant: once when the background map is generated and once when calculating the distances between voi data points and OpenStreetMap POIs in the core of the algorithm. Last but not least, the Contextily library is responsible for generating the background map.

9.4 Divide and conquer search algorithm

Combining the information about POIs in Stockholm and Voi trips is an integral part of the task at hand. The naïve approach is to iterate through each Voi trip and then check the distance to each POI. Since there are around 3.5 million Voi trips and more than 7000 POIs, this will take too much time to be feasible. There are multiple solutions to this problem and the one implemented here was based on dividing up the Stockholm area into smaller pieces. The implementation handles different resolutions, but the basic idea is to divide up both axes of the area into sub distances, creating a grid. Most of the work done has the resolution 40 by 40, meaning the x-axis is divided up into 40 smaller distances and same for the y-axis. After this step is complete all the OpenStreetMap POIs were iterated through, placing each one into the corresponding grid section depending on the POI location. This way when iterating through Voi trips and searching for nearby POIs, the only POIs searched are the ones in the grid where the Voi trip had its end point. This solution leads to some issues, with the most prominent one being POIs not detected when they are located in a neighbouring grid section but still within the searching distance of the Voi end point. This problem is not dealt with in this implementation, but the solution would be to search all of the neighbouring grid sections, making the run time significantly slower.

For every Voi data point the algorithm uses built-in Geopandas functionality to calculate the distance from the trip end point to every POI inside the grid square where the trip endpoint lies. To filter out non-relevant POIs, a distance threshold is chosen. This distance threshold is quite arbitrary, but large ones leads to many hits of POIs that does not seem relevant to the current trip. For this work a rather small threshold of 14m was chosen. Only the closest POI will count as a hit. A record is made with metadata of this “hit” with fields:

- Amenity of POI
- Day of trip
- Distance from trip endpoint
- Latitude and longitude of the trip endpoint
- Grid index for both axes
- Name of POI
- Season when trip was conducted
- Time of day when trip was conducted (what 2-hour segment)

9.5 Generating results

After all the hits were generated it is necessary to post-process the results in order to be able to visualize them. The previously mentioned grid comes in handy at this stage, since it provides a good base of visualization, treating the Stockholm area as a two-dimensional histogram. To generate the heatmap of the combined POI activity it is a simple matter of creating an array that is as long as there are grid squares, iterate through all the “hits” and extract which grid square the “hit” was registered in, then add one to the array index corresponding to that grid square. After the iteration is done the array will contain the grid activity and can be visualized via different plotting techniques.

When generating results keeping track of all hits on places might be misleading since some places are further away from the voi endpoint than others. If one assumes that the person riding the voi is more likely to visit a place closer to the end point than another place further away, simply counting the number of occurrences does not encode that information. Because of this reason a scoring function was implemented to relay this information. This function behaves similarly to an exponential function. For distances lower than 10m, the function returns 1. For values higher than 10m, the function decreases exponentially as the distance grows larger than 10m.

10 Results

10.1 General findings

Figure 18 shows the distribution of the number of trips conducted per user. There are circa 400,000 unique users with most of them being low trip users. The Y-axis is logarithmic. Every staple after 600 trips conducted are only single users with all of them being outliers, and the one at 1200 being an extreme outlier.

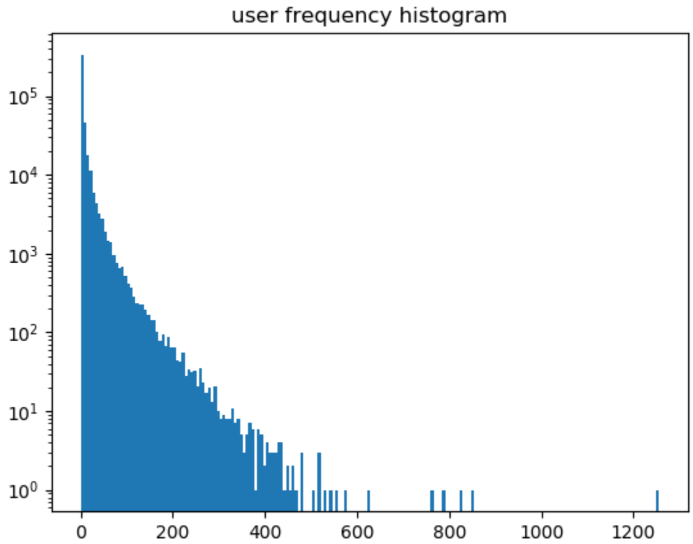


Figure 18: Y-axis number of users X-axis number of trips conducted.

Figure 19 shows the distributions of trip length (as the crow flies) in km and trip time in minutes. Both distributions reach a maximum early and then fall off rather quickly. Similar to the user trip frequency statistics above, there is a clear cluster of "normal" users, with a small number of outliers.

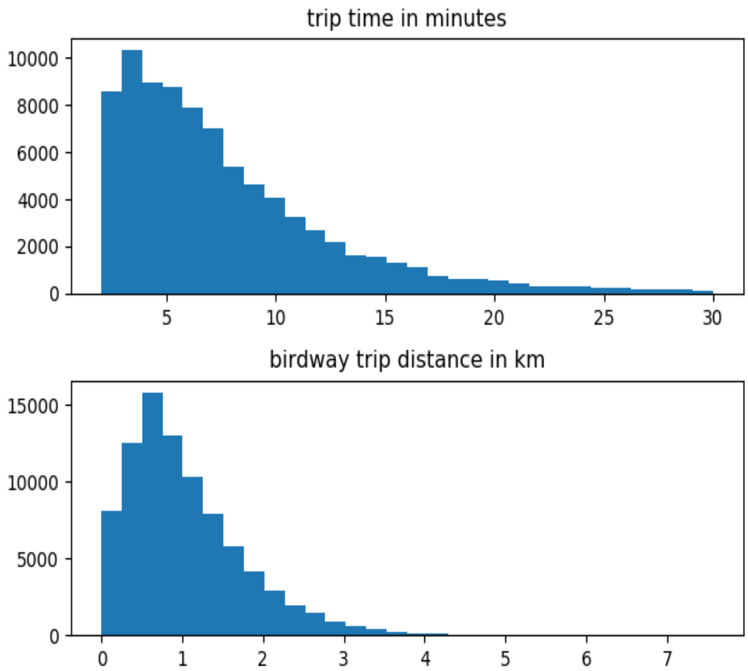


Fig. 19. Distributions of trip length and trip time.

10.2 Temporal distribution of activity categories

The following images are generated from running one million Voi trips through the divide and conquer search algorithm, extracting only the closest result, which has to be within a 14 m radius from the connected Voi trip end point. In the bar plots the general layout is that the x-axis consists of twelve different discrete values, every value representing a two-hour segment, i.e “00,01” will be all activity during those two hours (00:00-01:59 to be clear). At every discrete x-axis value there is one bar for each category representing the respective categories’ activity at that two-hour segment.

Figure 20 shows that the relative activity does not change by much during the day. The categories that make up for most of the activity (Shops, Sustenance, Bus and Subway) are at the same position at every time step, although some variance occurs within their respective position. The smaller categories (Healthcare, Entertainment, Education) are changing positions during the day. However, during intervals 22-23, 00-01, 02-03 and 04-05 most of these establishments are closed so their activity does not represent the usage but rather noise that is generated by the method in which the “hits” are counted. The dataset does not provide opening hours for all of the POIs which makes it hard to filter out POIs that are closed at the time of the trip.

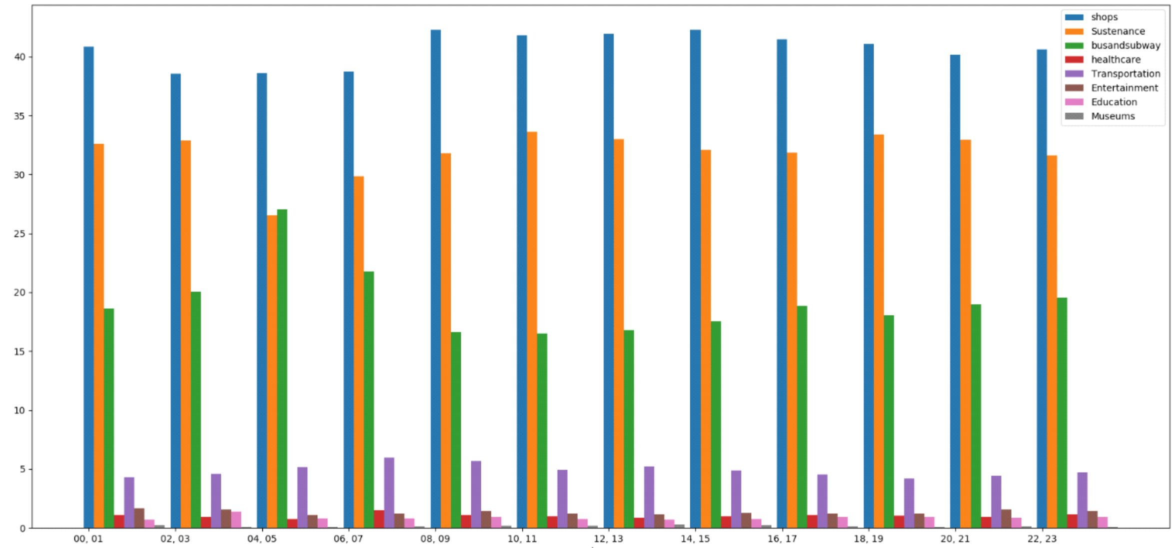


Fig. 20. Category activity distribution during the day. The x-axis is divided into 12 different time slots, each being two hours long. The Y-axis is displaying the percentage of the total activity each category constitutes.

Figure 21 gives more information about what level the activity is on during different parts of the day. It is apparent that during the night, especially hours 04-05, the activity is significantly lower compared to other parts of the day. The general trend looks like a bell curve, with the Bus and Subway category showing a strictly ascending to descending trend. Both Shops and Sustenance categories display a dip during the 14-15-hour period although it is not very significant. All activity peaks at 16-17, which corresponds to rush hour in Stockholm. The most significant relative increases are during morning hours between hours 04-05, 06-07 and 08-09. The descending part of the graph is not as drastic as the ascending one. For the Shops category the activity slowly descends from 16-17 to 04-05.

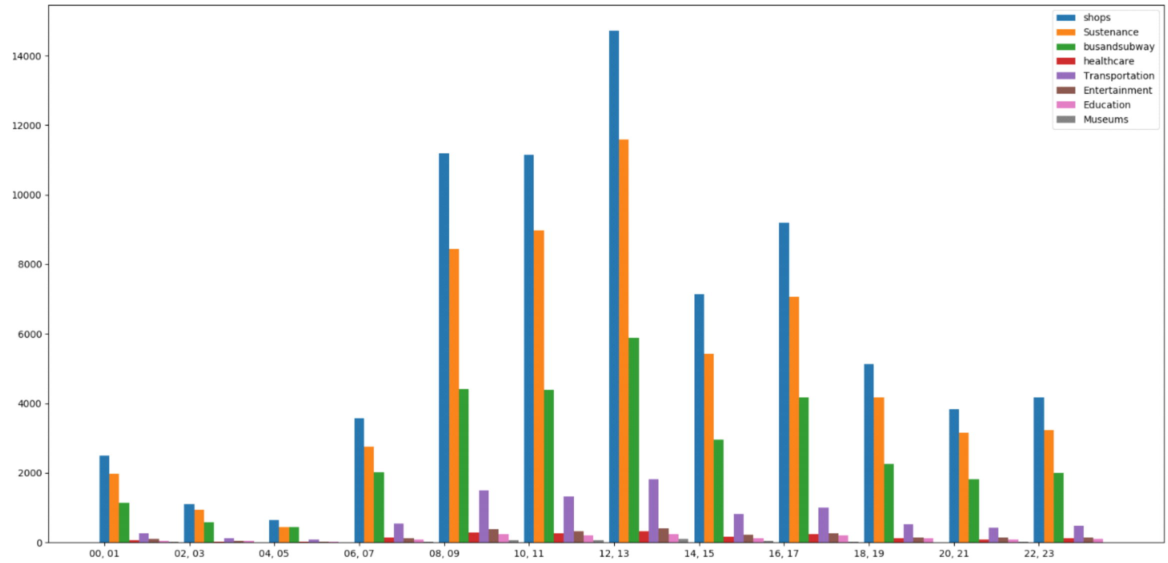


Fig. 21. Category activity distribution during the day. The x-axis is divided into 12 different time slots, each being two hours long. The Y-axis is displaying the amount of hits for all the categories at every time-interval.

10.3 Activity heatmaps

As Figure 22 shows, the peak activity lies in the Stureplan area, probably because of the large amount of shop activity in that area. Other notable places are Östra station near KTH displaying an orange colour, Fridhemsplan, on the left side of the map having a slightly more yellowish color than the red surrounding it, and Odenplan, the yellow grid square in the top left corner of the picture. In general, for a grid square to have a high level of activity it is most likely a location that has a heavy public transport impact on the surrounding areas, has many shops or many food establishments. Some slightly higher activities of a redder nuance can be found in the bottom parts of the picture, with the majority of those being easily matched with large public transport hubs such as Södra station, Hornstull and Slussen. Another interesting observation is that Södermalm does not have any significant amount of activity when comparing to other parts of the city.

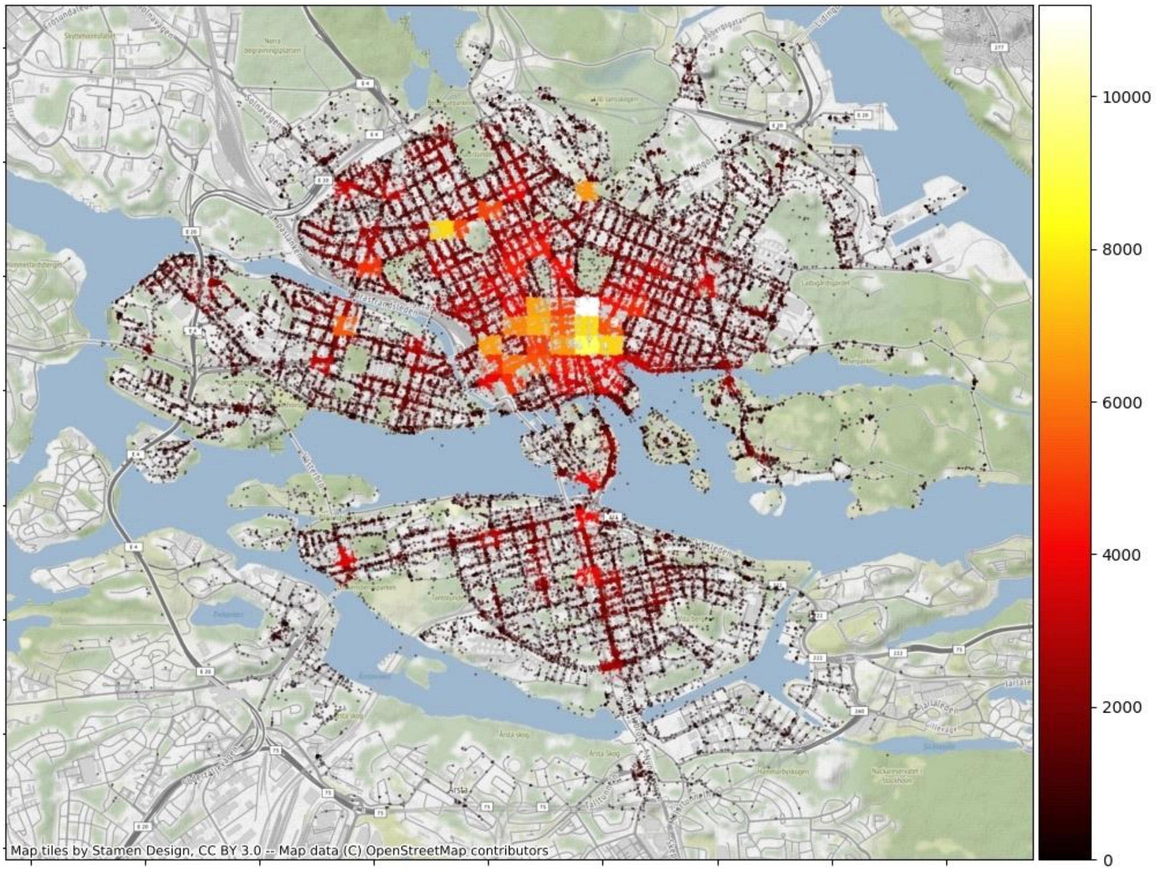


Fig. 22. Heatmap including all activity in the stockholm area.

The three most frequent activity types are, in descending order, Shops, Sustenance and Bus and Subway. Figure 23 shows the heatmaps for the Shops and Sustenance categories. The Shops heatmap shares many features with the overall activity heatmap in Figure 22. Some outliers can be found, for example Östra station. The second most popular category, Sustenance, has a distinctly different heatmap. The activity is central like the Shops type activity, although more spread out with some other interesting grid squares. The peak activity is in places around Centralen, which have very low activity in the Shops type heatmap. The Shop category locations with high activity are leaning heavier towards the East side of the city center, with the Sustenance category have its peak activity on the West side of the center.

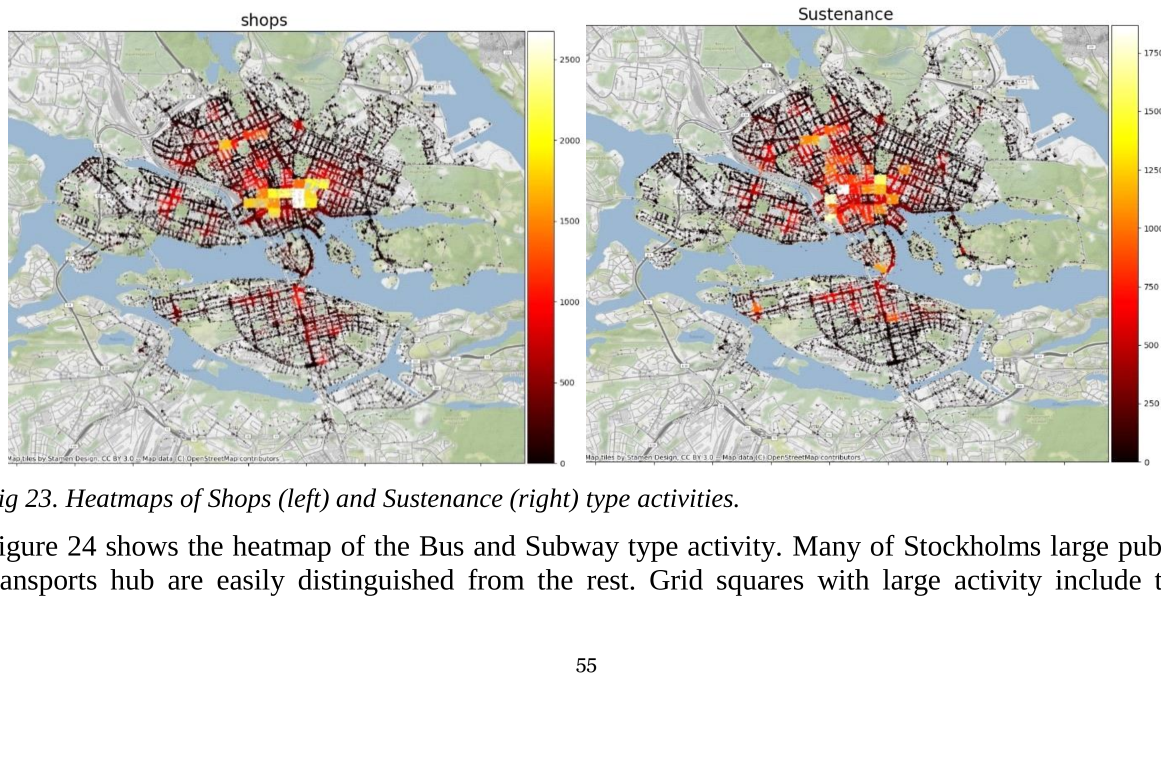


Fig 23. Heatmaps of Shops (left) and Sustenance (right) type activities.

Figure 24 shows the heatmap of the Bus and Subway type activity. Many of Stockholms large public transports hub are easily distinguished from the rest. Grid squares with large activity include the following public transport hubs: Odenplan, Fridhemsplan, Vasaplan, Hötorget, Skanstull, Medborgarplatsen, Östra station and Karlaplan.

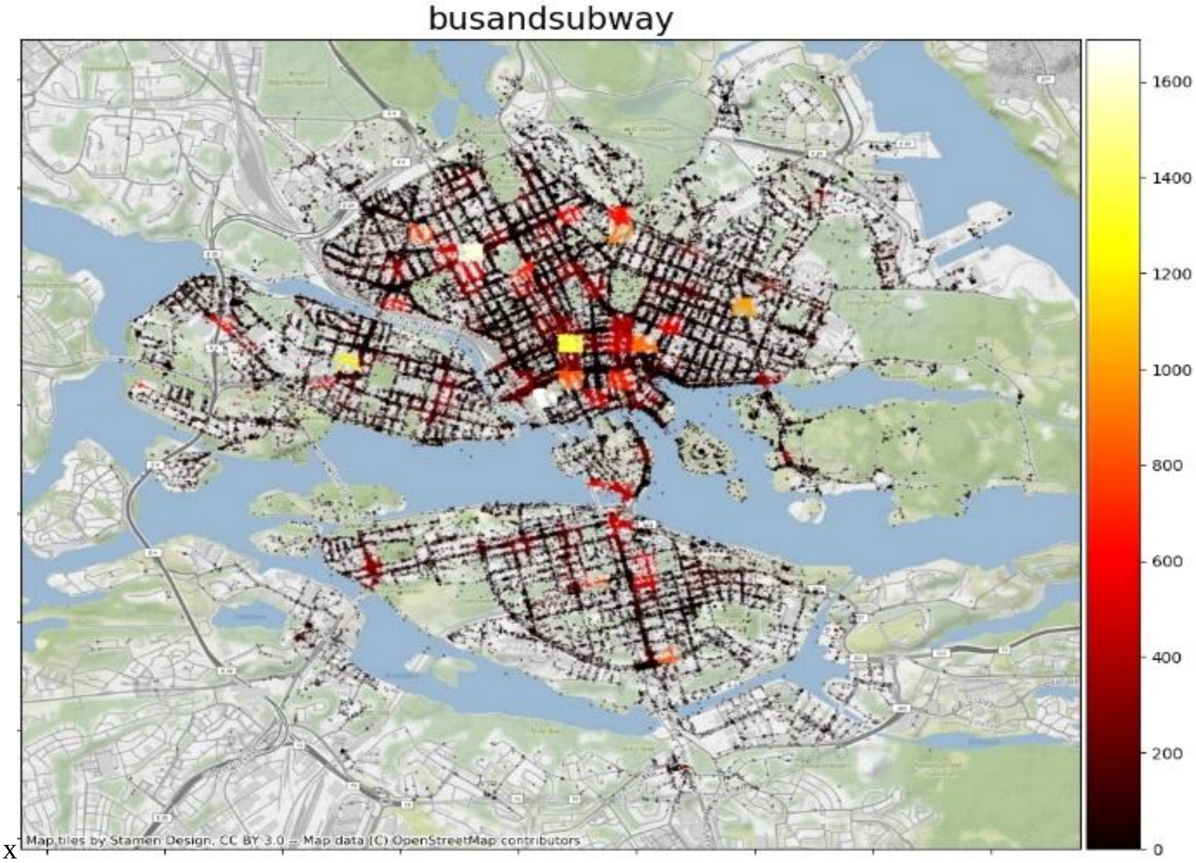


Fig. 24. Heatmap of Bus and Subway type activity.

Part C: Feedback from Stockholm Transport Authorities

11 Feedback from Stockholm Transport Authorities

Based on the overview about shared e-scooter services, we identify that several private companies have implemented their shared e-scooter services in the last years in many cities around the world. This new mobility solution has been promoted as a contributor of a sustainable transport system, reducing the car dependence and traffic congestion, and increasing public transport accessibility working as a last-mile solution. However, the arrival of any new transport vehicle and the uncontrolled fast proliferation of these services has derived in several conflicts as presented along this document: urban space management due to parking on sidewalks, safety issues derived from interactions with pedestrians and other vehicles, deficits related to environmental impacts, a counter-productive displacement of walking and public transport instead of car trips, etc. To grasp the perception of transport authorities in Stockholm, the study complements the world overview with interviews to city managers and public transport planners.

11.1 Questionnaire

We elaborate a questionnaire as a starting point for a constructive discussion that includes several questions about usage, planning and operation of shared e-scooter services in the city. This questionnaire consists of the next set of questions:

1. What is the perception about shared e-scooters as a transport mode? Do you think it is a temporal trend that will not become a consolidated transport solution or you expect its consolidation? Do you think cities should promote this type of services (actively or passively) or cancel its operation?
2. Do you think shared e-scooters are a threat for public transport? Have you perceived a reduction of public transport trips due to the arrival of shared e-scooters? Do you think it is an opportunity for public transport? Can shared e-scooters complement public transport as a feeder service, increasing the accessibility?
3. According to several studies from different cities, shared e-scooters are mainly used for leisure trips with a peak demand in the evening or weekends and an occasional use frequency. Therefore, this type of service does not seem a solution for day-to-day. Which is the role that you expect from this type of mobility services? What kind of measures should be consider in case we want to change the current situation to promote other type of role?
4. Current price could be one of the reasons of the previous situation. Shared e-scooters are expensive in comparison to other transport modes such as bike sharing or public transport, two subsidized solutions. Is subsidization a possible alternative for the promotion of this service? Could be integrated in a wider type of subscription including public transport for an easy combination of these modes?
5. In some cities, there are different types of equity programs for reduced prices and spatial distribution of scooters in some areas. What do you think about this type of solutions? On the other hand, are there equity plans for people with disabilities?
6. Shared e-scooter trips are concentrated in central areas where there are high volumes of pedestrians and a good coverage of public transport. On the one hand, interactions and safety issues appear between scooters and pedestrians. On the other hand, scooter trips displace walking trips and public transport does not require a feeder solution in these areas. Do you think that constraints with regard to areas of service can improve the situation to avoid zones in direct competition with pedestrians and promote zones where last-mile solutions can make public transport more accessible to reduce car usage?
7. To promote the last-mile solution role, could shared e-scooter services be integrated in a wider type of subscription including public transport?
8. What kind of measures should be considered to reduce the negative impacts of riding and parking? Extension of bike lanes (micromobility infrastructure), rules related to driving behavior (helmet), speed limits, rules for appropriate parking, docking stations, parking corrals, limitations of number of companies and fleet sizes.

9. Have you observed conflicts between public transport fleet and e-scooters? (accidents, risky situations, etc.)
10. Are there requirements to the companies to collect inappropriate parked scooters?
11. Is Stockholm asking for permission fees and other kind of charges in order to transfer to companies the cost of the use of urban space, infrastructure development (lanes, stations, etc.) and other kind of expenses?
12. What kind of education activities should be promoted to reduce inappropriate riding or parking?
13. Regarding environment, the main limitations today are short lifetimes, low usage rates, distribution and collection tasks. What kind of measures could change the current situation? Vandalism, robust scooters, fleet dimensioning, charging stations over the city, collection every night or when scooters are totally uncharged, fuel efficient vehicles for these tasks, e-scooters with swappable batteries.
14. What do you think about a common platform for all the companies where users can take scooters from any company with only one subscription?
15. Do you require data sharing from companies to analyze and control this type of mobility? How do authorities make use of that data?
16. What are the most recurrent complains received in Stockholm about shared micromobility services?
17. What are the main research topics that should be considered in future research?

11.2 Results

The vision of the City of Stockholm on micro mobility services is that it is not a temporal trend but rather a permanent transport mode that will grow over the years. However, they do not consider that these services will truly represent a direct competitor with the current transport system since micro mobility companies handle much lower volumes of users compared to the rest of transport modes in the city. The “big picture” of the transport system of Stockholm is not going to be affected by micro mobility in the future years. Stockholm Public Transport Authority has a similar opinion since they have not perceived any reduction in the use of the SL service. The numbers of scooter riders are too small to compare them to the volume of users by public transport.

Micro-mobility is having a bigger impact in the inner city, since in the outer areas are probably not very profitable. In Stockholm, the pick hours of usage are in the morning and late afternoon and most of riders take a scooter for the last mile of their trips. It is believed that the best thing that can happen for the city is a changing from car to scooter, it has been noticed that taxis has lost some trips because of scooters, and the worst is from walking to scooter.

Additionally, this mode of transport can fill some black holes in the public transport system. The first and last mile solution is basically how they see the e-scooters companies are playing an important role in the mobility system that actually complements the public transport in a positive way since it helps users to reach places the public transport cannot nowadays. As a feeder complement, the city of Stockholm can take some measures to create hubs for scooters close to public transport and make transfers between them more comfortable. Today, active communication is maintained with companies to know where it is appropriate to place these platforms. They are open to consider the idea of creating a MaaS that incorporates public transport and different e-scooters companies in order to give more flexibility to the users

However, Stockholm does not plan to subsidize shared scooters in order to promote this role as last mile solution; in general, they are not planning to subsidize other kind of programs for equity reasons. In the same line, Stockholm has not thought of generating constraints on service zones to promote any role over others. Not only multimodal trips would improve the current mobility, public transport planners see positive that parallel scooter services take public transport passengers especially during rush hour. This loss of demand can be beneficial to the system by reducing the pressure on public transport for short trips and focusing it on longer trips.

Besides the current great polarity in the citizens of Stockholm about acceptance or rejection of these services, the city supports this type of mobility having a good cooperation with the service providers in order to reduce the negative perception. The main complain received in Stockholm about shared micromobility service is the parking of the scooters and that many users of this service ride on sidewalks that can be dangerous since they usually go in a higher speed compared to pedestrians. The latter can be solved by a good cycling infrastructure, then, riding is not a problem, and parking becomes the biggest issue with the e-scooters. Due to these problems, Stockholm has considered the introduction of restrictions in specific zones for safety reasons. For instance, zones where speed should be reduced and in the same way where the parking of scooters is not allowed in order to protect pedestrians.

Stockholm works under the general rules of Sweden, that is, there are bureaucratic limitations when some policies want to be implemented or some requirements are demanded to the companies. Currently, there are not enough rules to regulate scooters at the country level, limiting what municipalities can do. Moreover, when creating a rule to regulate the use of scooters, this rule will also apply directly to other means of transport (bicycles, e-bikes, etc.). However, they believe that the best measure is to generate different rules for each of them, taking into account their different characteristics such as speed, parking area, helmet use, among others.

Due to this lack of laws, Stockholm is not allowed to charge fees to companies and companies cannot be forced to share their mobility data, this is voluntary. Today Stockholm is working with a company that helps processing the data they receive from the companies.

Another course of action is the education of riders, the city tries to inform users how to use and park the scooters. Moreover, there are some agreements between Stockholm and the companies in order to attend to any complaint of inappropriate parking or use of the service and companies are responsible for providing more education to users.

Regarding environmental issues, these services have followed a progressive improvement. For instance, scooter lifetimes are longer now, most of the companies are starting the distribution with electric car since the regulation says that they cannot use any fossil fuel distribution cars, and most of companies use swappable batteries. They experimented with charging stations, but since it is manually, there is no reason for the user to do it.

Finally, these stakeholders identified the main areas where we should focus future work. The main topic is to understand the current mobility patterns of shared e-scooters, trip characteristics and displaced modes. We should determine if micromobility is attracting new travelers or it is changing the current behavior of travelers, choosing a more sustainable solution, in competition to the existing transport modes. In particular, there is the interest to understand the profile of the different users of bikes and scooters, and the principal reasons to choose one mode over the other.

The other relevant topic is to identify the potentialities of shared e-scooters as a first/last-mile solution in the suburbs. The first question is to evaluate if the deployment of this service in those areas is feasible and profitable. The second is to evaluate how micromobility can improve the accessibility to public transport and reduce the environmental impacts of transport system. The last factor is to understand what kind of measures the current system needs to promote the combination of these two modes.

12 Conclusions

In recent years, relevant changes in shared micromobility started what is called the fourth generation of this type of services. Dockless security systems allow free-floating fleets, making the implementation of this service easy since they do not need infrastructure as docking stations. A new vehicle, the e-scooter, that is slighter and cheaper than bicycles, which is the most extended micromobility device, facilitates its distribution. It is also equipped by an electric power assistance that widens the potential users of these services. Additionally, as a new vehicle, the regulations regarding this device and the mobility services associated do not exist or are limited, leaving a wide margin for private companies for a fast and uncontrolled proliferation of these services. This proliferation became a chaotic phenomenon that requires to be studied in order to understand its impact on mobility, environmental sustainability, infrastructure and urban space consumption or safety.

The average trip by shared e-scooters is one mile and ten minutes long, running at speed below 10 km/h. This is an intermediate solution between pedestrians and bicycles. Several factors limit the trip length. Besides a lower speed than other modes such as cycling, the standing riding is not comfortable for long distances, and the price of the service, which is dependent on the trip time length, is relative expensive in comparison to other subsidized competitors such as public transport and bike sharing systems. In this line, a very small portion of clients takes these shared scooters daily, and at least a weekly usage frequency is a minority in front of the generalized sporadic use. This result shows that this mobility service is not enough consolidated as an everyday transport solution until now. Occasional use is coherent with the most common trip purpose, which is mainly leisure associated to social and recreational activities. Leisure trips occur during weekends and evenings after work in the weekdays, just when these services are more demanded. This temporal pattern has only one peak in the evening, differing from the global mobility, but being coincident with casual users of bike sharing systems.

Shared e-scooter services have been promoted as an eco-friendly transport that would reduce the current environmental impact. However, several issues have emerged that contradict this initial perception. First of all, the displaced mode by scooters. As commented above, it is a solution between walking and cycling, being the former the main origin of new scooter trips. This mode displacement is counter-productive from an environmental perspective, although it is compensate in some cities by the reduction of car-based trips. So far, the current number of scooter trips is small in order to have a relevant impact, but the current tendency with regard to the mode displacement should be adjusted in order to focus on car instead of pedestrians. In this line, another reason for the promotion of scooters would be as a supporter of public transport trips as a first/last-mile solution, and this collaboration could be more effective to increase car substitution. The results from the cities included in this analysis do not show a clear predominance of this role in shared e-scooter services.

Apart of mode substitution, other factors such as short scooter lifetimes, low usage rates and the environmental impact produced by those vehicles involved in collection and distribution tasks also deserve especial attention in order to scooters become a real eco-friendly transport solution. Currently, inappropriate use and vandalism reduce to few moths the time in operation for scooters and few trips per day derives in a high disutility, factors those increase material and manufacturing impacts due to an inefficient exploitation of resources. Daily collection and distribution or long distance traveled during these tasks belong to the other main impact, in this case, during service operation. This type of mobility service should reduce that distance and promote the use of sustainable auxiliary vehicles.

On the other hand, uncontrolled spread of scooters in cities has increased the pressure on transport infrastructure and urban space, creating conflicts with other vehicles and activities. The main frictions are the flow obstructions due to inappropriate parked scooters and unsafe riding on sidewalks, being pedestrians the main victims. Although the existing studies show that most of scooter riders have an appropriate behavior, there is space for improvement in order to reduce riding on sidewalks and put in order the parked devices. To overcome these problems, the system requires measures and regulations starting with the extension of exclusive lanes for micromobility vehicles, definition of non-riding and non-parking zones, and riding and parking behavior rules. For the success of these policies, driving scooter education and fluent communication are essential. Additionally, regulations in order to limit number of operators and fleet sizes allow cities to control the chaotic proliferation. These limitations should be evaluated permanently according to several metrics in order to validate the performance of the companies and the suitability of service dimension.

According to previous studies and their results, we identify three main research lines from strategic to operational level that we miss in the current literature. Most of the current documents identify the trip characteristics of shared e-scooters, but authors do not contextualize this mobility with regard to the rest of transport modes. Knowing the current patterns of these new services, we can identify the trips made by other transport modes where e-scooters could be a potential competitor. In that way, we could forecast their market niche of shared e-scooter services. Surveys to riders or potential riders complement the analysis of real travel data as an alternative source of travel behavior and, at the same time, in order to identify key factors that influence travel decisions (e.g., operation, urban environment, supply of other modes, etc.). For instance, most of companies have introduced membership programs recently, making more affordable a frequent use of their services from an economic perspective, and most of current studies do not reflect it.

The previous analysis will be useful to identify the current role of shared e-scooters in the mobility and the consequent displaced modes depending on how and where companies operate the service. This is the first input for an effective planning in order to introduce shared e-scooter services in that way they will help for a more sustainable transport system. Cities need clear policies and measures to get it. Once we understand how people use e-scooters and the threats and opportunities of these services, the second level of analysis focuses on how to design these new services in the most appropriated way. At this strategic level, several question should be discussed: fleet size, service areas for riding and parking, density of parking corrals, environment characteristics where this service is more effective, etc.

Finally, the third level of analysis is related to operating strategies to increase the efficiency of the system. Companies regularly have to collect and distribute the scooters for charging or relocation. How these strategies are deployed has an impact on the final monetary and environmental cost of the service. On the one hand, a more efficient management of these tasks reduce the cost, and possibly, the current high price. On the other hand, the second main contributor to the environmental impact is derived from auxiliary vehicles for these tasks. Shorter traveled distances per scooter and lower number of times when collection is required are essential for a reduction of the current environmental assessment. These services need this reduction to become a real sustainable transport mode.

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