Policy implications of shared e-scooter parking regulation: an agent-based approach

Paul Hurlet*[1], Ouassim Manout[1], and Azise Oumar Diallo[2]

[1]Transport, Urban Planning and Economics Laboratory (LAET), ENTPE-CNRS-University of Lyon, France
[2]IFPEN, BP 3 - 69360 Solaize - France

Short summary

This work addresses the challenges of implementing shared e-scooter services (SSS) in urban areas. Despite their potential for sustainable mobility, issues like road safety and street cluttering persist. Policy regulation is crucial, and recent efforts have focused on free-floating e-scooter parking legislation. To assist decision-making, this paper proposes an agent-based framework to design SSS parking supply and evaluate its impact. The methodology is applied in Lyon, France, where the SSS is gaining more and more territory. The main outcomes show parking regulation can introduce conflicting objectives, with a reduction of SSS use due to an increase in the access and egress walking distance.
Keywords: Shared e-Scooter Services (SSS); Micromobility; Regulation; Parking; Agent-Based Model (ABM); MATSim

1 Introduction

Since their advent, shared electric e-scooter services (SSS) have been introduced in major worldwide cities. In theory, SSS can contribute to the sustainable transition of urban mobility by fostering the use of car-alternative means of transportation Abduljabbar et al. (2021). In practice, however, their diffusion was not always seamless. In various cities, the introduction of SSS posed serious challenges to urban planners and citizens. These challenges include road safety, competition against active travel modes, street cluttering, vandalism, or their reliance on the gig economy Gössling (2020). To meet these challenges and to ensure favorable conditions for the development of SSS, policy regulation is needed Latinopoulos et al. (2021); Button et al. (2020). The absence or failure of such a regulation, or the unwillingness to adhere to it are detrimental to SSS and can conduce, as in the case of Paris or Montreal, to their total ban.
First attempts to regulate SSS focused on isolated measures like fleet capping, service geo-fencing, speed limitations, authorized road network, minimum registration age, or helmet use. These measures can alleviate some of the negative externalities of SSS, but are less effective when it comes to the issue of street cluttering, one of the most negative externalities associated with free-floationg mobility services, in general, and e-scooters, in particular. This persistent issue calls for appropriate and effective regulation measures. Lately, various cities introduced free-floating e-scooter parking legislation to tackle this issue Klein et al. (2023). Parking regulation consists of the assignment of dedicated or shared physical or virtual parking facilities to SSS. These facilities are often notified to SSS users through mobile phone applications of SSS providers and can also be marked off on the street if they are physical. Users are incentivized or required to end their rentals at these designated facilities, otherwise, these users or their service providers can incur penalties. The introduction of SSS parking regulation bears, therefore, various conflicting objectives and requires many trade-offs to ensure appropriate conditions for the sustainable development of this mobility service with an integrated mobility and urban system.
This literature review shows that SSS parking legislation is both an important lever for the regulation of SSS and a complex measure to design and implement. Cities trying to introduce SSS parking regulations are often faced with two questions:

1. How to design an appropriate parking supply (parking capacity and location) to meet SSS conflicting objectives?
2. How to evaluate different parking scenarios?

To answer these questions, stakeholders need decision-aid tools. This paper proposes an agent-based framework (ABM) to design parking supply for SSS and to evaluate the impact of this regulation on travel demand and service provision and operation. This methodology is tested in Lyon, France to help local policy-makers and service providers with the regulation of SSS.
This methodology can help stakeholders assess the impact of parking regulation on the use and operation of SSS or other shared free-floating mobility services (shared bikes, moped vehicles, or cars), and can guide the design of appropriate parking policies.

2 Methodology

MATSim

The simulation of shared e-scooter services with parking regulation is based on MATSim, the Multi-Agent Transport Simulation framework. The agent-based modeling (ABM) approach has been used for the simulation of various mobility scenarios, including shared micromobility services Tzouras et al. (2022). In comparison with conventional transportation models, the ABM approach is more adapted to the simulation of new mobility services like SSS or carsharing, because it allows for a detailed description, tracking, and interaction between travel demand and supply. MATSim, in particular, is one of the most used open-source agent-based simulation software adapted to large-scale mobility scenarios. It has been applied to the simulation of different multimodal mobility scenarios in various spatial contexts from different countriesBastarianto et al. (2023). For a detailed description of MATSim, please refer to (Horni et al., 2016).
The simulation of mobility scenarios in MATSim relies on the daily activities of individuals or agents. Each agent competes for available mobility resources (road capacity, public transport capacity, shared vehicles, etc.) to conduct its activity plan. Depending on their capabilities and constraints, agents can choose different travel modes, departure times, and roads to perform their activities. Agents learn to optimize their daily mobility choices iteratively. At the end of each iteration, an agent scores its choices by assigning a reward for the performance of activities and a negative score for travel. Agents are programmed to be utility-maximizers. Agents can introduce plan mutations to their daily plans by changing their mode, route, or departure time, in search of the maximum utility given their constraints. After several iterations, the system reaches a quasi-equilibrium state where no significant increase in the total utility of agents can be achieved.
The core of MATSim can simulate various mobility scenarios. It can also be extended to include different algorithms and modules for the simulation of new mobility scenarios, like e-scooters, for example. Here, we extend a recent contribution called *Shared Mobility* Balać & Hörl (2021), designed for the simulation of shared mobility services, to simulate the impacts of parking regulation on the use and operation of shared free-floating services, with an application on the case of shared e-scooters in Lyon.
MATSim has already been applied to simulate various mobility scenarios in Lyon Diallo et al. (2023); Manout et al. (2023); Manout & Diallo (2023), including shared micromobilty services. Travel demand and supply were adapted from a previous work of the authors Diallo et al. (2023); Manout et al. (2023). The integration of parking regulation is described in the next subsection.

Shared-Mobility contribution

The *Shared-Mobility* module Balać & Hörl (2021) is designed to simulate most shared mobility services, including carsharing, bike-sharing, and e-scooter-sharing systems. The extension includes two possible schemes: Free-Floating (FF) and Station-Based (SB). The operating principles of the module are:

- Booking activity: the agent books the nearest available shared vehicle (Step 1 in Fig. 1).
- Walking journey to the vehicle: the agent walks to the booked vehicle (Step 2).
- Pick-up activity: the agent picks up the vehicle [Pick-up point] and identifies the available location for vehicle drop-off as close as possible to its final destination (Steps 4 and 5).
- Renting leg: the agent travels with the vehicle to the Drop-off location. In the case of SB, if the capacity of the chosen station is reached, the agent looks for the nearest available drop-off location to its destination and goes back to Step 5 (Step 6).
- Drop-off activity: the agent drops off the vehicle [Drop-off point] (Step 8, 9 or 10).

- Walking journey to the destination: The agent walks to his destination (Step 11a).

The default pricing scheme considers a *base-fare (€)* to unlock the vehicle and a *time-fare (€/min)*. This pricing system can be modified to accommodate any other type of pricing, such as subscriptions for example. To avoid excess access and egress walk, the *Shared-Mobility* module also takes into account a maximum walking distance to reach a vehicle and from a station to the final destination.
The current version of the *Shared-Mobility* module does not take into account the parking constraint for SSS. The module has often been used for the simulation of FF services. In this paper, we extend this module to account for the constraints of parking regulation in the simulation of such services.

The extension of Shared-Mobility

For the inclusion of parking regulation in the operation of FF shared mobility services, a new operating scheme, dubbed Semi-Free-Floating (SFF), was created. SFF can account for different shared services that operate in areas combining districts with and without parking obligations, DPO and $\overline{DPO}$, respectively. The approach is inspired by the *Shared-Mobility* module and combines the FF and SB scheme to build SFF (Fig. 1).
Steps 1, 2, 4, 6, 8, 9, 10, and 11 in Fig. 1 are kept in the SFF. The conditions redirecting to these steps might change as explained below. The additions are highlighted in orange in the Fig. 1 and detailed below: ***Step 3***: offers the possibility to rent an e-scooter wherever the e-scooter is: at a station (SB) or on a road link (FF). If the e-scooter is on a station, the algorithm uses the SB scheme and releases one parking slot in the corresponding station. Otherwise, the default FF scheme is used.
Step 5: the agent searches for and compares the distance to the nearest available station (within the DPO) to its destination and to the nearest authorized drop-off link (within $\overline{DPO}$) and chooses the nearest of the 2 as the drop-off location.
Step 7 offers the possibility to drop off the rented e-scooter wherever the drop-off location is possible and near the final destination: at a station (SB) or on a road link (FF). If the nearest location is a station whose capacity is reached, go back to step 5 to determine a new drop-off location, or fill a parking slot in the corresponding station. Otherwise, the default FF scheme is used.
The *SFF* schema therefore requires the following additional data:

- Parking facilities and their capacity.
- Limits of the districts with parking obligation (DPO).
- Outside DPO, road segments where SSS parking is possible.

3 The case study of Lyon

General presentation

Métropole de Lyon, for the metropolitan area of Lyon, is the third most populated area in France with a population of 1.4 million. 49% of this population lives in the cities of Lyon and Villeurbanne where 1.8 million daily trips are made. The average trip distance in these two cities is 6.5 km and more than 50% of trips are less than 1.9 km. Nearly, 50% of the trips are made by foot, 25% by public transport, 20% by car and 5% by bike. Shared e-scooters have a marginal share with only 13000 daily rentals. The average e-scooter trip distance is 2.3 km and 11 minutes.
SSS were first introduced in Lyon in 2018. Shortly after, numerous competitors entered the race. In 2019, up to 8 service providers were in fierce competition on the market and thousands of shared e-scooters and bikes flooded the city. Consequently, public perception of the service went low and as a reaction, public authorities banned the service in Villeurbanne and imposed a regulation in Lyon. The latter city decided to limit the provision of the service to two providers and to cap the fleet to 4000 shared e-scooters via a 4-year contract. In its latest version, this contract enforces strict parking legislation that divides the city of Lyon into two zones (Fig. 2a):

- Districts with parking obligation (DPO), where e-scooters are required to park at designated physical parking facilities.
- Districts without parking obligation ($\overline{DPO}$), where e-scooters are authorized to park anywhere possible.

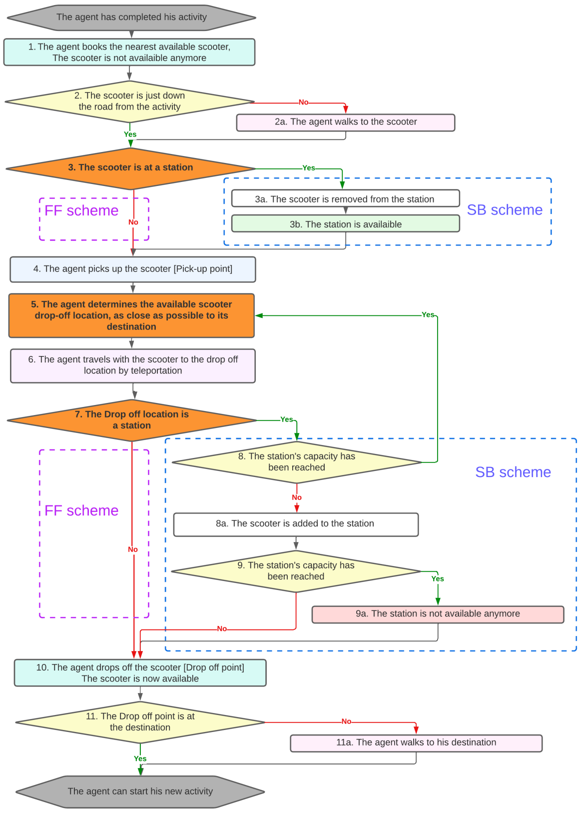


Figure 1: SFF operating flowchart

The *DPO* zone covers 35% of the total service area of SSS where the most important mobility attraction and production are located (Fig. 2a). The *DPO* zone has 306 parking facilities with a total nominal capacity of 3131 for 4000 e-scooters. It is noteworthy that 30 parking facilities with a total capacity of 300 slots are located outside of the *DPO*. These facilities are designed for the parking of rebalanced e-scooters.
SSS parking occupancy varies in space and time (Fig. 2b). The average parking occupancy is 46% ($median = 30\%$ and $std = 66\%$). 12% of parking facilities exceed their nominal capacity with an average parking saturation of 177% and a maximum saturation of 630% (Fig. 2a). Due to the non-constraining *nominal* capacity of parking facilities, we assume that the physical maximum capacity is two times the nominal capacity.

SSS Parking scenarios

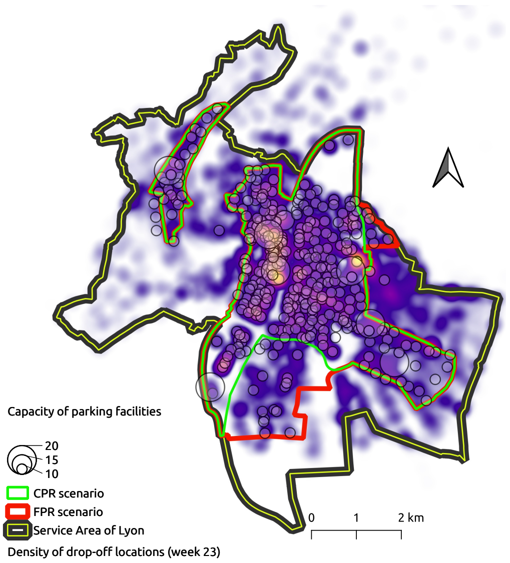
To demonstrate the contribution of the new framework, three parking scenarios are studied in this paper. These scenarios have been co-created with the City of Lyon and local service providers to assess the impacts of existing parking regulations and co-design new and more efficient parking scenarios for the future. The three scenarios are:

1. The Current Parking Regulation (CPR) scenario describes the SSS parking regulation in effect in Lyon until the Summer of 2023 (Fig. 2a). *DPO* covers 35% of the total service area and offers a nominal parking capacity of 3131 for 4000 shared e-scooters.

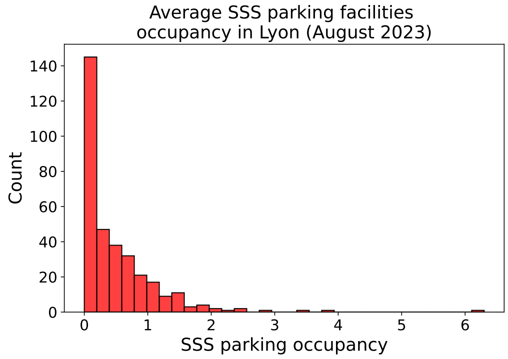
2. The No Parking Regulation (NPR) scenario describes a past situation when parking regulation has not been introduced in Lyon (Fig. 2a).

3. The Future Parking Regulation (FPR) scenario describes a city plan to extend the area of parking obligation (*DPO*) to include two new districts of $\overline{DPO}$ (Fig. 2a). This scenario extends the *DPO* area to cover 44% and offers 324 parking facilities with a nominal capacity of 3560 e-scooters.

The CPR scenario is the reference to which both NPR and FPR are compared. The comparison with the NPR scenario allows the measurement of the implications of the introduction of parking



(a) Map of parking regulation and use in Lyon



(b) Distribution of SSS parking occupancy average for the first week of August at 1 a.m. in Lyon. 1 means 100%

Figure 2: Parking regulation in Lyon

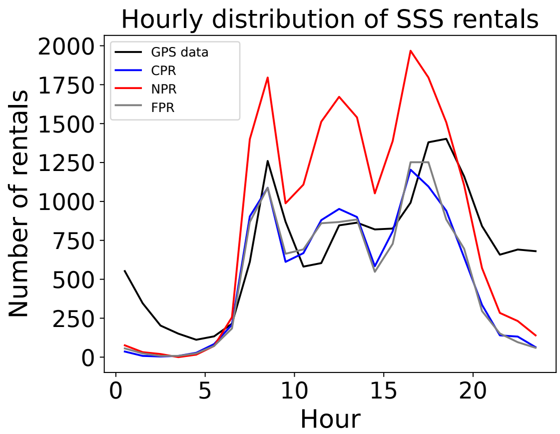


Figure 3: Distribution of observed and simulated daily SSS rentals in Lyon

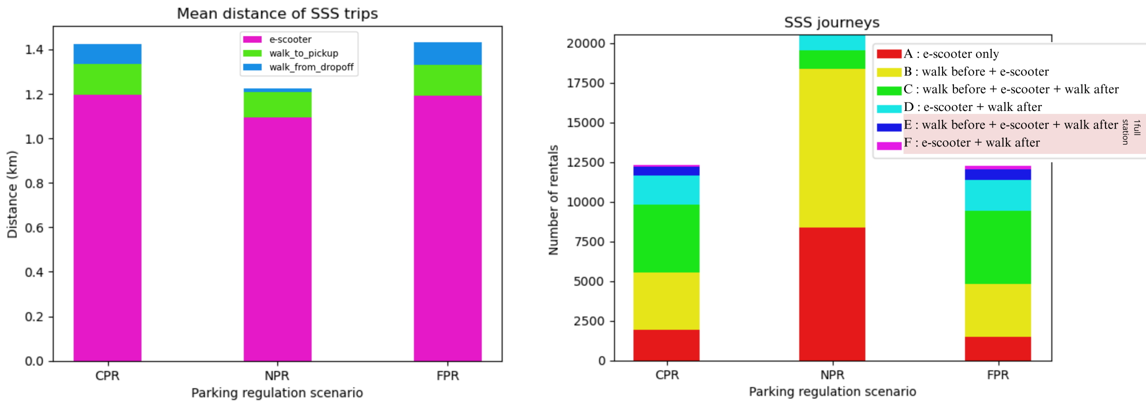
regulation on the adoption and use of the service. The comparison with the FPR scenario allows the assessment of the extra impact due to the extension of parking regulation to new districts. The comparison of these scenarios can give interesting insights into the impact of parking regulation on the adoption and use of shared e-scooter services and informs decision-makers on the design of future parking scenarios.

The reference scenario CPR is calibrated to reproduce observations on the current adoption and use of e-scooters in Lyon. This scenario is calibrated using one-week GPS e-scooter records provided by the local service operators, DOTT and TIER (see Fig. 3).

4 Results

Calibration of the framework

In comparison with observations, simulation results of the CPR scenario show that the framework is capable of reproducing the daily number of e-scooter rentals, and to some degree, their time distribution throughout the day (Fig. 3). 12500 daily rentals are predicted by the simulation for an average 13000 observed rentals. The replication of the rental distance is less satisfactory. The average simulated rental distance is 1.2 Km vs. an observed value of 1.7 Km.



(a) Impact of the parking scenarios on access and egress

(b) Impact of the parking scenarios on the number and patterns of e-scooter use

Figure 4: Parking regulation in Lyon

Impacts of parking regulation on the adoption and operation of shared e-scooters

The comparison of the NPR and CPR scenarios informs on the impact of parking regulation on the adoption and use of SSS in Lyon. According to the simulation, the introduction of this regulation reduces the number of SSS rentals by 37% (Fig. 4b). A similar drop in demand was observed by one of the two operators when the parking legislation was enforced in Lyon. The introduction of parking regulation also influences the trip patterns of SSS use. Simulation results show that parking regulation increases the walking distance needed to access and egress SSS (Fig. 4a). In comparison with the NPR scenario, the walking distance needed for the access and egress to SSS in the CPR and FPR scenarios increases by 22%. Most of this increase is due to egress. More specifically, we can distinguish 6 possible SSS trips: A: door-to-door use of the e-scooter (no walking), B: walking before using the e-scooter only, C: walking before and after using the e-scooter, D: walking only after using the e-scooter, E: walking before and after using the e-scooter in the event that the drop-off station requires the scooter to be dropped off elsewhere, F: walking only after using the e-scooter in the event that the drop-off station requires the scooter to be dropped off elsewhere. In comparison with the NPR scenario where agents are more likely to pick-up and drop-off an e-scooter near their origin and final destination, the access and egress walking distance to the shared vehicles increases. SSS trips that do not require egress walking (A&B) represent 89%, 45%, and 39% in the CPR, NPR, FPR scenarios, respectively (Fig. 4b). In the NPR scenario, 10% of SSS trips (C&D) use e-scooters to get near a destination outside of the SSS service area. Hence, e-scooters are dropped off at the border of this area. This case shows the potential for extending the service area of SSS to Villeurbanne for example (North-east of the service area in Fig. 2a). The FPR scenario that extends the parking regulation to two new districts has a greater number of parking facilities that reach their capacity limits and require SSS users to change their travel plan and look for a new parking facility far from their final destination(E&F). In the FPR scenario, 7% of SSS trips need to chain two e-scooter journeys to find an available parking spot in comparison with 5% in the CPR scenario. This result calls for an increase in the capacity of parking facilities in the FPR scenario. This increase should not be uniform and needs to target specific areas that are identified by this framework. Finally, parking regulation induces an increase of 9% in travel times and distances of SSS trips in the CPR and FPR compared to the NPR scenario.
By using the same assumptions and estimates of e-scooter maintenance and operation costs as Manout et al. (2023), we find that parking regulation decreases the net revenues generated by SSS due to rental loss. The loss of profit for the operators is estimated to be 52% and 54% for the CPR and FPR scenarios, respectively.

5 Conclusion, limitations and future work

This paper introduces and evaluates the contribution of an ABM to simulate the impact of parking regulation on free-floating shared mobility services. The methodology extends the *Shared-Mobility* MATSim module designed for the simulation of FF or SB shared mobility services, but which used to lack a proper method to account for SFF services. The application of this methodology to the

case of SSS in Lyon highlights the contribution of this work. Our simulation results show that parking regulation has a significant impact on the adoption and use of e-scooters. A reduction in travel demand is likely to follow the introduction of such a regulation. The usage patterns of e-scooters are also likely to be impacted by increasing the walking distance, especially to the destination. All of this translates into a reduction in the profitability of service providers. Nevertheless, this reduction and the benefits lost are likely to be recovered or more than compensated due to a more socially acceptable service and favorable conditions for the sustainable development of the service.
The primary aspects requiring enhancement in the present study revolve around incorporating SSS memberships and various pricing schemes in to the simulation. Notably, numerous SSS users in Lyon and elsewhere, hold passes and memberships to reduce their total rental costs. First results from the comparison of the trip patterns of members and non-members show a significant difference in terms of e-scooter usage. Furthermore, directing the focus towards younger demographics, who are the primary users of SSS, could lead to a more accurate representation of rental dynamics and travel distances. This can be achieved by implementing a more appropriate utility function for SSS mode choice. Fortunately, MATSim provides the flexibility to configure such scenarios by defining sub-populations and corresponding utility functions. Upon establishing this configuration, we will incorporate all remaining parking stations into the model. Additionally, we will explore the integration of SSS with public transport as last-kilometer access/egress modes.
Acknowledgement The authors are grateful to Ville de Lyon (City of Lyon), DOTT, and TIER for their support and to EGIS (Chaire EGIS-ENTPE-LAET, SIMVAL) for its financial support. The authors are also grateful to Ariane Moucheroud for her help.

Acknowledgements

The authors are grateful to Ville de Lyon (City of Lyon), DOTT, and TIER for their support and to EGIS (Chaire EGIS-ENTPE-LAET, SIMVAL) for its financial support. The authors are also grateful to Ariane Moucheroud for her help.

References

Abduljabbar, R. L., Liyanage, S., & Dia, H. (2021, March). The role of micro-mobility in shaping sustainable cities: A systematic literature review. *Transportation Research Part D: Transport and Environment*, *92*, 102734. Retrieved from https://doi.org/10.1016/j.trd.2021.102734 doi: 10.1016/j.trd.2021.102734

Balać, M., & Hörl, S. (2021). Simulation of intermodal shared mobility in the San Francisco bay area using MATSim. In *2021 ieee international intelligent transportation systems conference (itsc)* (pp. 3278–3283).

Bastarianto, F. F., Hancock, T. O., Choudhury, C. F., & Manley, E. (2023). Agent-based models in urban transportation: review, challenges, and opportunities. *European Transport Research Review*, *15*(1), 1–20.

Button, K., Frye, H., & Reaves, D. (2020, December). Economic regulation and e-scooter networks in the usa. *Research in Transportation Economics*, *84*, 100973. Retrieved from http://dx.doi.org/10.1016/j.retrec.2020.100973 doi: 10.1016/j.retrec.2020.100973

Diallo, A. O., Gloriot, T., & Manout, O. (2023). Agent-based simulation of shared bikes and e-scooters: the case of lyon. *Procedia Computer Science*, *220*, 364–371. Retrieved from http://dx.doi.org/10.1016/j.procs.2023.03.047 doi: 10.1016/j.procs.2023.03.047

Gössling, S. (2020, February). Integrating e-scooters in urban transportation: Problems, policies, and the prospect of system change. *Transportation Research Part D: Transport and Environment*, *79*, 102230. Retrieved from https://doi.org/10.1016/j.trd.2020.102230 doi: 10.1016/j.trd.2020.102230

Horni, A., Nagel, K., & Axhausen, K. (Eds.). (2016). *Multi-agent transport simulation matsim.* London: Ubiquity Press. doi: 10.5334/baw

Klein, N., Brown, A., & Thigpen, C. (2023, January). Clutter and compliance: Scooter parking interventions and perceptions. *Active Travel Studies*, *3*(1). Retrieved from `http://dx.doi.org/10.16997/ats.1196` doi: 10.16997/ats.1196

Latinopoulos, C., Patrier, A., & Sivakumar, A. (2021, November). Planning for e-scooter use in metropolitan cities: A case study for paris. *Transportation Research Part D: Transport and Environment*, *100*, 103037. Retrieved from `http://dx.doi.org/10.1016/j.trd.2021.103037` doi: 10.1016/j.trd.2021.103037

Manout, O., & Diallo, A.-O. (2023, June). Better be private, shared, or pooled? implications of three autonomous mobility scenarios in lyon, france. In *2023 8th international conference on models and technologies for intelligent transportation systems (mt-its).* IEEE. Retrieved from `http://dx.doi.org/10.1109/MT-ITS56129.2023.10241708` doi: 10.1109/mt-its56129.2023.10241708

Manout, O., Diallo, A.-O., & Gloriot, T. (2023, March). Implications of pricing and fleet size strategies on shared bikes and e-scooters: a case study from lyon, france. Retrieved from `http://dx.doi.org/10.21203/rs.3.rs-2670644/v1` doi: 10.21203/rs.3.rs-2670644/v1

Tzouras, P. G., Mitropoulos, L., Stavropoulou, E., Antoniou, E., Koliou, K., Karolemeas, C., ... others (2022). Agent-based models for simulating e-scooter sharing services: A review and a qualitative assessment. *International Journal of Transportation Science and Technology*.