ETH zürich

ETH Library

Simulation of intermodal shared mobility in the San Francisco Bay using MATSim

Working Paper

Author(s):
Balać, Miloš; Hörl, Sebastian

Publication date:
2021-05

Permanent link:
https://doi.org/10.3929/ethz-b-000481951

Rights / license:
In Copyright - Non-Commercial Use Permitted

Originally published in:
Arbeitsberichte Verkehrs- und Raumplanung 1618

This page was generated automatically upon download from the ETH Zurich Research Collection.
For more information, please consult the Terms of use.

Simulation of intermodal shared mobility in the San Francisco Bay using MATSim

Milos Balac[1] and Sebastian Hörl[2]

***Abstract*— This paper proposes a generic shared mobility simulator based on an agent-based model - MATSim. The implemented module can simulate both human and engine powered vehicles, docked/station and dockless/free-floating services, and multiple operators. The module is employed in a case study based in the San Francisco Bay Area that focuses on potential benefits of docked bike-sharing services to serve as a first/last mile solution for public transit. The initial results indicate that the current BayWheels docked bike-sharing service can potentially reduce travel time for 1049 765 trips through intermodality compared to current transit travel times. By focusing our analysis on these trips that could benefit from bike-sharing as a first/last mile solution we present the quality of service indicators for different levels of adoption and two fleet sizes.**

I. Introduction

Shared mobility systems have traditionally been composed of cars and bicycles. The most widely used concept has been based on stations where the vehicle would need to be returned either at the station where it was picked up (round-trip) or at any station with available space (one-way). With technological advancements, more flexible free-floating services have arrived where rented vehicles can be returned to any available parking spot for cars or almost anywhere on sidewalks for bicycles. In the last few years, e-scooters have appeared across the world as another type of shared mobility, and together with bike-sharing are part of so called micromobility.

Besides the change in the types of service (station-based, free-floating) and vehicles offered (cars, bicycles, scooters), the sharing systems evolve in terms of pricing and membership structures, power source (internal combustion, human-powered, electric), market penetration, and competition. The number of these emerging mobility solutions offered substantially complicates the modeling of mobility behavior. The dynamic nature of these emerging mobility concepts (i.e., heterogeneous availability of vehicles in space and time) requires developing new modeling frameworks to assess their impacts on mobility behavior. Consequently, agent-based models are predominantly used to forecast the impacts of policy and planning decisions of these services.

This paper proposes a generic shared mobility module as an extension of the Multi-Agent Transport Simulation (MATSim [1]) to simulate and forecast the impacts of emerging shared modes on transportation systems. The generic nature of the module allows to simulate station-based and free-floating services, define complex cost structures, service areas, different operators, modes of travel (bicycle, cars, scooters), with the possibility to pair it with modules for the simulation of electric vehicles, thus allowing analysis of charging and discharging operations on the quality of service.

The case study presented here showcases some of the extension features by looking at the potential of shared micro-mobility services in San Francisco Bay to reduce the transit travel time through intermodality.

The paper is organized as follows. Section II presents a a short overview of the background information relevant to this study. Section III presents the developed sharing module. Section IV presents the inter-modal case study for the San Francisco Bay Area. Section V discusses the findings and puts them into persepctive, before Section VI concludes the paper.

II. Background

Micromobility, similarly to car-sharing previously, has been expanding exponentially in recent years [2]. Docked bike-sharing systems have been a predominant contributor to micromobility and have spread on every continent. Recent technological advances have enabled the spread of dockless services that go beyond bike-sharing and also offer scooter-sharing. A study by [3] suggests that just in the USA, the market potential for micromobility could include between 8 to 15 percent of trips under five miles.

[4] evaluated the micromobility situation in San Francisco by analyzing the empirical data gathered from both docked and dockless bike-sharing models in 2018. The authors found that dockless bike-sharing trips were, in general, longer in distance and duration compared to docked trips. Moreover, they find a high intensity of trip arrivals around the Civic Center and departures at Caltrain and Embarcadero train stations, suggesting that there are already many intermodal trips in San Francisco using bike-sharing systems. [5] reports that scooters are frequently used as a first/last mile option for public transport in San Francisco. Moreover, the author finds that scooters have a higher potential to reduce vehicle miles traveled (VMT) when combined with public transport.

[6] provide a comprehensive review of the current literature on micro-mobility and its integration with public transport. They cover both shared and private micro-vehicles. Based on the extensive review of 48 articles, they conclude that future research should focus on three topics: (1) environmental, social and economic impacts, (2) different types of micro-vehicles, and (3) data collection.

[1]Milos Balac is with the Institute for Transport Planning and Systems, ETH Zurich, Switzerland milos.balac@ivt.baug.ethz.ch

[2]Sebastian Hörl is with the IRT SystemX, Paris, France

In terms of simulation, there are currently few documented efforts that allow the simulation of shared micromobility services beyond station bike-sharing systems [7], [8], [9], [10]. [10] present a docked bike-sharing extension of MATSim. They also propose the framework that allows the simulation of intermodal trips and electric vehicles. However, their approach lacks generality and does not include dockless service implementation. Whether the implementation is open-source is also not reported. [11] evaluates the impacts of mobility as a service composed of ride-hailing, free-floating car-sharing, and dockless bike-sharing services on social welfare in Zurich, Switzerland. The implementation of the dockless bike-sharing service is rudimental and cannot be easily extended to handle the current market complexity of several operators or specific service or vehicle characteristics.

The work presented here presents a module that enables the simulation of shared mobility and can help answer research questions raised by [6] through simulation. Furthermore, it provides further analysis of the potential of combining docked bike-sharing with transit in the San Francisco Bay Area.

III. Sharing Module

MATSim has been developed as a modular agent-based simulation framework. This has led to the development of many extensions that allow either the simulation of different transportation services (i.e., automated vehicles, demand-responsive transport, car-sharing) or their analysis (i.e., emissions, externalities, accessibility). The increase in popularity of shared modes, especially bike- and scooter-sharing services, required the development of the module capable of simulating these emerging mobility solutions.

The developed module is available as open-source[1] and is designed to have the following features:

- Simulation of both human and engine-powered vehicles (bicycles, scooters, and cars).
- Simulation of station (docked) and station-less (dockless) services. For station services, each station is characterized by the currently available vehicles and parking spaces
- Simulation of multiple operating systems offering their services in the simulated area
- Definition of the service area for each operating system
- Infrastructure to easily read in information using the General Bikeshare Feed Specification (GBFS)

MATSim is designed as an iterative simulator of network and mobility dynamics and subsequent decision-making by agents, in which aggregated information from the dynamic simulation is incorporated to evaluate agent decisions. During the decision-making phase, a sharing mode trip is assigned the following sequence of activities and legs (legs in MATSim represent segments of the trips):

- **Booking activity:** during which an individual will decide which vehicle to rent
- **Walking leg:** walking segment to the desired vehicle
- **Pick-up activity:** the vehicle is rented, and the individual can begin the sharing mode trip.
- **Sharing leg:** this segment contains information on the route between the pick-up and drop-off activities
- **Drop-off activity:** the individual is assigned to drop off the vehicle at the closest link or station for dockless and docked services, respectively
- **Walking leg:** a walking segment from the location where the vehicle was left to the destination activity location

The booking, pick-up, and drop-off activities are called interaction activities in the MATSim context, distinguishing them from the activities that are the cause of travel, such as going to work, home, or to a restaurant. During the simulation, the agent makes several decisions during the sharing mode trip:

- During the booking activity, an agent decides which vehicle to rent (optionally, the vehicle can already be bindingly reserved at this moment).
- During the pick-up activity: the vehicle is rented, and the individual can begin the trip. In case the desired vehicle became unavailable in the meantime, the agent has to either rent another vehicle at the same location or walk to the next available vehicle or station with an available vehicle. These steps are repeated until the agent finally finds an available vehicle in the system.
- The sharing leg of the trip is updated and an appropriate route is selected based on the newly defined pick-up and drop-off locations.
- During the drop-off activity, the agent tries to terminate the vehicle rental. In case there are no available parking spots, the agent takes the vehicle to the next closest station with an available parking space. This process is continued until an available parking space is found.

It is clear that some agents might end up walking or cycling from location to location, searching for an available vehicle or parking space. This information is collected and can, through the iterative approach, provide information to agents that the demand exceeds the supply and that switching to another mode is probably a better alternative.

It should be noted that the proposed sharing module is not a replacement of the car-sharing module already existing in the MATSim environment [12], as it currently does not allow to simulate round-trip station-based services, nor does it provide some of the additional features specific to car-sharing systems. However, it allows to simulate and investigate the impacts of most of the sharing transport systems available today (i.e., bike-sharing, car-sharing, scooter-sharing). Furthermore, it allows to easily integrate the electric vehicle MATSim module [13].

IV. Case study

The following describes the investigated problem, methodological approach, and data.

a) Problem definition: The first and last-mile transit problem can potentially be alleviated with shared mobility.

[1] https://github.com/eqasim-org/matsim-sharing

Admitting that shared mobility solutions are not suitable for all segments of the population, it is worthwhile to investigate how current shared systems can increase accessibility to transit and potentially its ridership.

b) Bike-share supply: The bike-sharing station-based service studied is BayWheels[2]. The designed module allows to directly load stations and vehicles from a publicly available data feed. Therefore, the location of stations and vehicles before 6 AM is obtained using the standardized GBFS feed provided by Baywheels[3].

The BayWheels system currently has 471 operating stations. In total, there are 10 297 docks for 5268 bicycles.

c) Synthetic travel demand: The study focuses on the potential of an existing station-based bike-sharing service in the San Francisco Bay Area to reduce intermodal transit travel time. To do this, we investigate if the bike-sharing system can provide faster transit trips for each trip conducted in the study area. The potential demand is obtained from the synthetic travel demand of the nine-county San Francisco Bay Area developed earlier [14] using the *eqasim* framework [15]. The synthetic travel demand consists of individuals characterized by socio-demographic attributes and a daily plan. An individual's plan consists of all activities, their sequence, start and end time, and location. In total, there are 28 929 803 trips conducted in the region.

d) Transit Routing: The routing of trips with public transit in MATSim is performed using the RAPTOR algorithm [16] and allows for the inclusion of the pre-selected access and egress modes to the public transport stations. In general, intermodal trips can be pretty complex, i.e., rail - bike-sharing - rail - scooter-sharing. However, the current implementation of the router focuses solely on the first/last mile intermodality (i.e., walking - rail - bike-sharing). In cases where it is faster to walk, the router will suggest a walking trip, similar to how the standard route planning services work.

The public transit schedules of 35 agencies are obtained from publicly available GTFS files. The transit feeds are merged and converted to the MATSim transit schedule using pt2matsim module[4].

Cycling and walking speeds are obtained from Google routing for the San Francisco Bay Area and are set to 14.5 and 4.4 km/h respectively.

e) Scenarios: We investigate four sets of scenarios:

- Baseline scenario: there is no intermodality, and individuals can only walk to and from public transit
- Scenario I: the bike-sharing system can solely be used as a first/last-mile service from public transit, but each station has an unlimited number of bicycles and docks
- Scenarios II: current bike-sharing can only be used as a first/last-mile service for public transit with different levels of adoption rate ranging from 5 - 100%; each station is characterized by the number of docks and vehicles that currently exist
- Scenario III: current bike-sharing can only be used as a first/last-mile service for public transit with different levels of adoption rate ranging from 5 - 100%, but with the increase of the number of vehicles. Additional bicycles are added to each station equal to half of the free docking capacity. In this case, there are 7902 bicycles.

The baseline scenario enables us to compare the improvements in travel times that intermodality brings. Scenario I shows the potential of the current service if the number of bicycles was unlimited, and Scenarios II and III aim to show how the system would perform if a share of the potential users (those that can benefit from the faster travel time) would be willing to adopt bike-sharing as a first/last mile solution. Here agent-based methodology becomes vital as it allows to capture the interaction of the agents' decisions and the limited bike-sharing supply.

Before the scenarios are simulated, the synthetic trips that are not suitable for intermodality are filtered out in several steps. Based on French data, [17] report that the likelihood of individual walking more that 500 meters to pick up a shared vehicle is close to zero. Therefore, we assume that all trips that do not have either the origin or destination activity within 500 meters from a bike-share station are not eligible for intermodal service. Furthermore, we filter out all trips that are faster traveled by walking compared to public transit. Finally, 1938 196 remaining trips are considered potentially suitable for intermodality, which is close to 7% of all trips.

f) Results: Interestingly, given its current location of stations and with an unlimited supply of bikes, the bike-share system has the potential to reduce the travel time for 1049 765 trips (Scenario I). This is a substantial potential given that the service is available only in the part of the studied region. Figure 2 shows the 20 most popular stations in the system. As expected, most of the demand is concentrated in downtown San Francisco, followed by Berkeley, Oakland, Fruitvale BART station, and, finally, downtown San Jose.

The histogram representing the potential reduction of transit travel time with the current bike-sharing system is shown in Figure 3. On average, the travel time can be reduced by 5 minutes and 17 seconds. However, 10% of the trips have a minimal potential to save time. The further burden of transferring between modes could make these trips unsuitable for intermodality. With this in mind, we perform further simulations with different levels of adoption, with the results summarized in Table I.

The trips where intermodality is beneficial are on average 2.3 kilometers longer than all trips (see Figure 4). Out of the 10.5 kilometers, which is the average length of the intermodal trip, 1.46 kilometers, or around 14.5%, is performed with a bike-sharing service (see Figure 5).

With the increase of adoption, the average access time to bike-sharing vehicles increases. Therefore, the best performance of the system is achieved with the lowest adoption rate. The increase in the average access time and the share of rejections are the smallest in this case. Even though increasing the adoption rate increases the number of rides,

[2]https://www.lyft.com/bikes/bay-wheels
[3]https://gbfs.baywheels.com/gbfs/gbfs.json
[4]https://github.com/matsim-org/pt2matsim

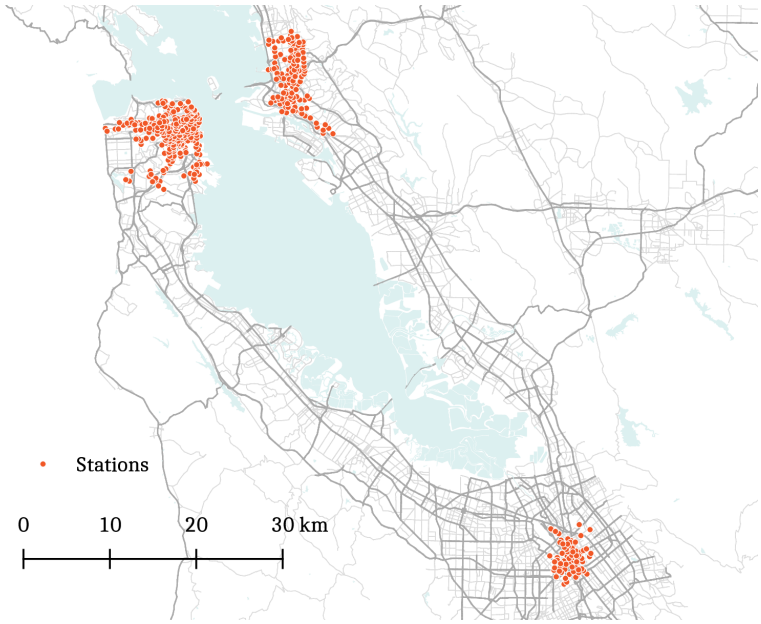

Fig. 1. Location of BayWheels bike-sharing stations in the San Francisco Bay.

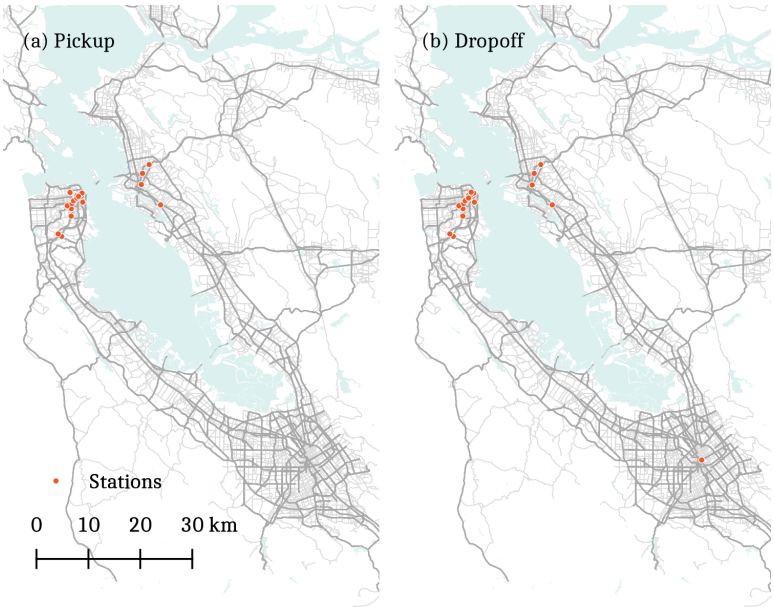

Fig. 2. Location of 20 most frequently used stations for pickup and dropoff.

the marginal increase of the number of rides decreases as the adoption level rises. On the other hand, the egress time remains stable for all adoption levels. This is the indicator that the stations have reasonably high capacities compared to the number of vehicles available in the system. Therefore, to further test the capabilities of the current infrastructure, we simulate Scenarios III, where the number of vehicles is increased, but the stations' capacity is maintained. The results of the simulation with different adoption levels are summarized in Table II. In all cases, the number of rejections is reduced at the price of an increase in average egress time. The increase in the average egress time is especially evident for low adoption rates. For cases with 5 and 10% adoption levels, the increase in average egress time is larger than the decrease in average access time. This implies that, on average, the system performs worse than in Scenario II for these adoption levels in terms of accessibility. However, in general, a further increase in the number of bicycles would benefit the system. Even with an increase in the bicycle fleet size, the current station capacities provide a high quality of service when individuals search for an available dock. With the highest adoption rate, around 1.4% of all trips can currently be served with bike-sharing as a connector to transit.

TABLE I

RESULTS FOR SCENARIO II

Adoption rate	Avg. access time [s]	Avg. egress time [s]	Avg. access time increase [s]	Avg. egress time increase [s]	Executed rides	Rejections	Rejections [%]
0.05	161	113	71	5	43 244	9244	0.18
0.1	170	110	81	3	76 169	28 807	0.27
0.2	182	108	93	1	129 637	80 316	0.38
0.3	192	107	103	1	173 645	141 284	0.44
0.4	202	106	112	0	212 702	207 204	0.49
0.5	210	106	120	0	245 625	279 257	0.53
0.6	218	105	128	0	276 137	353 722	0.56
0.7	224	105	133	0	305 073	429 762	0.58
0.8	232	105	141	0	333 439	506 373	0.60
0.9	240	104	148	0	358 857	585 931	0.62
1.0	243	104	151	0	389 903	659 862	0.63

TABLE II

RESULTS FOR SCENARIO III

Adoption rate	Avg. access time [s]	Avg. egress time [s]	Avg. access time increase [s]	Avg. egress time increase [s]	Executed rides	Rejections	Rejections [%]
0.05	142	155	52	48	45 917	6571	0.12
0.1	154	136	65	28	82 299	22 677	0.22
0.2	165	122	75	16	143 836	66 117	0.31
0.3	173	115	83	9	196 198	118 731	0.38
0.4	179	113	90	7	242 796	177 110	0.42
0.5	188	112	98	6	281 533	243 349	0.46
0.6	195	110	105	5	317 164	312 695	0.50
0.7	203	109	112	4	351 497	383 338	0.52
0.8	208	107	116	2	386 932	452 880	0.54
0.9	213	107	121	2	420 340	524 448	0.56
1.0	218	106	125	1	450 836	598 929	0.57

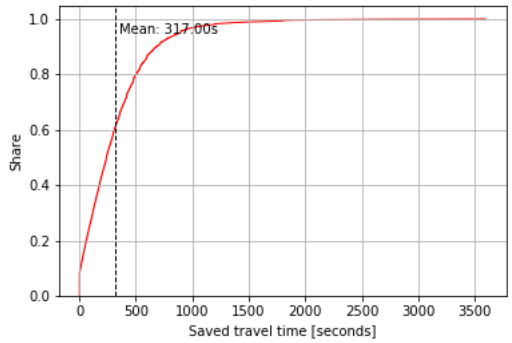

Fig. 3. Cumulative density function potential intermodal travel time savings compared to current transit travel times.

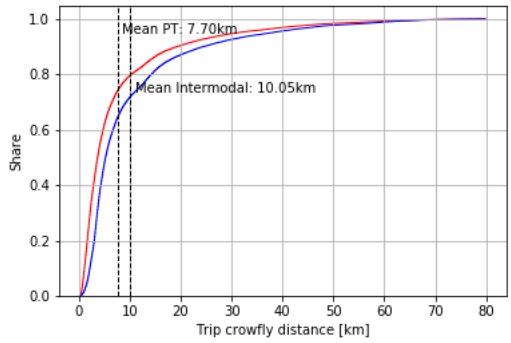

Fig. 4. Cumulative density function of all trips (red) versus intermodal transit trips (blue) distances.

V. DISCUSSION

While we focused on docked bike-sharing systems, it would be straightforward to repeat the studies with the dockless bike- and scooter-sharing services. Finally, the joint simulation of all available services would allow us to obtain a complete picture of the current potential of shared services in the San Francisco Bay Area to serve as a first/last mile solution. Nevertheless, the current results indicate that the docked bike-sharing service analyzed can reduce the travel times for public transit. However, the potential benefits depend on the adoption rate and are then balanced with service quality. Further increasing the supply of bicycles improves the accessibility of the service but at the cost of slightly higher egress time from stations to the final destination. The analyzes only focused on the potential to save travel time. However, the individuals do not only consider travel time when making mode-choices but also transfer burden, cost, comfort, and reliability. Better integration of shared services with public transit would potentially reduce the transferring burden and cost. Comfort could be increased by providing electric bicycles and better and safer cycling infrastructure. Reliability of the service (i.e., certainty that the bicycle can

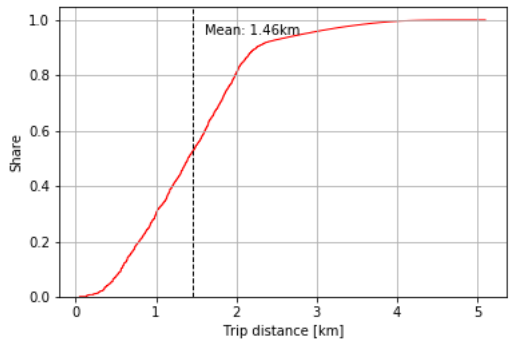

Fig. 5. Cumulative density function of distance traveled with a bicycle for intermodal transit trips.

be found close to the origin) is essential as it ensures that individuals can better plan their journeys. Here a balance between adoption and the number of bicycles needs to be investigated.

The proposed module and eqasim framework also allow investigating mode-decisions of individuals [18]. Currently, an estimated mode-choice model included in the agent-based model for San Francisco[5] does not include micromobility services as they were not present when the California Household Travel Survey (CHTS) was conducted back in 2012. Other studies focusing on micromobility or future instances of CHTS would bring valuable insights into how individuals trade off different alternatives and their parts. This would allow for more in-depth analyses of the potential of micromobility services to contribute to the more sustainable way of moving in San Francisco.

VI. Conclusion

This paper presented an open-source generic shared mobility simulator based on MATSim. The simulator opens possibilities to simulate any combination of shared mobility services, be it human or engine powered, two or four-wheeler, docked, or dockless.

The case study presented analyzed the potential of Bay-Wheels bike-sharing system to reduce transit travel times through first/last mile integration. Critical tradeoffs between adoption rate, quality of service, and supply size are presented. Given its small supply size, the service could reduce transit travel time for up to 1.4% of trips, given supply and infrastructure capacity constraints, but acknowledging that with certain re-balancing this could be even increased. Expansion of the service could further increase the number of trips that can reap this benefit. However, the marginal increase in the number of served trips does not scale with the increase in the number of bicycles.

Finally, better integration of shared services with public transit (i.e., visibility, trip planning, unified cost) would ensure that the travel time improvements can overcome the additional cost and transfer burdens. This would allow public transit to increase its competitiveness with private car usage, which would bring us closer to the sustainability goals.

[5]https://github.com/eqasim-org/eqasim-java/

References

[1] A. Horni, K. Nagel, and K. W. Axhausen, *The multi-agent transport simulation MATSim*. Ubiquity Press, 2016.

[2] S. Shaheen, A. Cohen, N. Chan, and A. Bansal, "Sharing strategies: carsharing, shared micromobility (bikesharing and scooter sharing), transportation network companies, microtransit, and other innovative mobility modes," in *Transportation, Land Use, and Environmental Planning*, E. Deakin, Ed. Elsevier, 2020, pp. 237–262.

[3] S. Shaheen and A. Cohen, "Shared micromoblity policy toolkit: Docked and dockless bike and scooter sharing," UC Berkeley Transportation Sustainability Research Center, 2019.

[4] J. Lazarus, J. C. Pourquier, F. Feng, H. Hammel, and S. Shaheen, "Micromobility evolution and expansion: Understanding how docked and dockless bikesharing models complement and compete – A case study of San Francisco," *Journal of Transport Geography*, vol. 84, p. 102620, 2020.

[5] F. Barnes, "A Scoot, Skip, and a JUMP Away: Learning from Shared Micromobility Systems in San Francisco," 2019.

[6] G. Oeschger, P. Carroll, and B. Caulfield, "Micromobility and public transport integration: The current state of knowledge," *Transportation Research Part D: Transport and Environment*, vol. 89, p. 102628, 2020.

[7] S. Ji, C. R. Cherry, L. D. Han, and D. A. Jordan, "Electric bike sharing: simulation of user demand and system availability," *Journal of Cleaner Production*, vol. 85, pp. 250–257, 2014.

[8] J. P. Romero, A. Ibeas, J. L. Moura, J. Benavente, and B. Alonso, "A simulation-optimization approach to design efficient systems of bike-sharing," *Procedia-Social and Behavioral Sciences*, vol. 54, pp. 646–655, 2012.

[9] M. Lu, S.-C. Hsu, P.-C. Chen, and W.-Y. Lee, "Improving the sustainability of integrated transportation system with bike-sharing: A spatial agent-based approach," *Sustainable Cities and Society*, vol. 41, pp. 44–51, 2018.

[10] C. Hebenstreita and M. Fellendorfa, "Dynamic, multi-and intermodal bike sharing in agent-based modelling," *Journal of Traffic and Transportation Management*, vol. 1, no. 1, pp. 09–17, 2019.

[11] H. Becker, M. Balac, F. Ciari, and K. W. Axhausen, "Assessing the welfare impacts of shared mobility and mobility as a service (maas)," *Transportation Research Part A: Policy and Practice*, vol. 131, pp. 228–243, 2020, developments in Mobility as a Service (MaaS) and Intelligent Mobility.

[12] M. Balac, F. Ciari, and K. W. Axhausen, "Carsharing demand estimation: Case study of Zurich area," *Transportation Research Record*, vol. 2536, no. 1, pp. 10–18, 2015.

[13] J. Bischoff and M. Maciejewski, "Agent-based simulation of electric taxicab fleets," *Transportation Research Procedia*, vol. 4, pp. 191–198, 2014.

[14] M. Balac and S. Hörl, "Synthetic population for the state of California based on open-data: examples of San Francisco Bay area and San Diego County," in *100th Annual Meeting of the Transportation Research Board*, Washington, D.C., 2021.

[15] S. Hörl and M. Balac, "Introducing the eqasim pipeline: From raw data to agent-based transport simulation," *presented at ABMTRANS*, 2021.

[16] D. Delling, T. Pajor, and R. F. Werneck, "Round-based public transit routing," *Transportation Science*, vol. 49, no. 3, pp. 591–604, 2015.

[17] A. Kabra, E. Belavina, and K. Girotra, "Bike-share systems: Accessibility and availability," *Management Science*, vol. 66, no. 9, pp. 3803–3824, 2020.

[18] S. Hörl, M. Balac, and K. W. Axhausen, "Pairing discrete mode choice models and agent-based transport simulation with MATSim," in *98th Annual Meeting of the Transportation Research Board*, Washington, D.C., 2019.