Who will be served by the Shared-Automated-Vehicle?

Golan Ben-Dor
Tel-Aviv University
PO Box 39040, 69978
Tel-Aviv, Israel
golanben@mail.tau.ac.il

Eran Ben-Elia
Ben-Gurion University
PO Box 653, 8410501
Beer-Sheva, Israel
benelia@bgu.ac.il

Itzhak Benenson
Tel-Aviv University
PO Box 39040, 69978
Tel-Aviv, Israel
bennya@tauex.tau.ac.il

Abstract

Shared Automated Vehicles (SAVs) could change the urban transport landscape by reducing congestions, air pollution, and traffic accidents. To establish SAVs service, providers need to supply a high level-of-service while maintaining an economically justified and limited fleet size. Inability to serve requests on time due to fleet size limitations could well jeopardize the future adoption of SAVs. We estimate the trade-off between the fleet size and level-of-service using an Agent-Based simulation of SAV services in the Tel-Aviv Metropolitan Area, Israel. We demonstrate that a SAV fleet larger than 50k vehicles could serve the entire intra-metropolitan travel demand and decrease congestion by 20%. However, the rejection rate for 50k fleet remains very high - 6%. To decrease rejections to a reasonable 1- 2% level, the fleet should be increased to at least 100K. Even for this large fleet, the rejection rate for the trips between the metropolitan core and its outskirts remains above 20%. We thus conclude that future SAV services cannot fully substitute other transportation modes and future transportation will remain essentially multimodal.

Keywords: Agent-Based simulation; MATSim; Shared Automated Vehicles; Service Rejections, Ridesharing.

1 Introduction

Experts estimate that in the future, automated vehicles will govern the urban landscape (Litman, 2017). It is also believed that these future vehicles will be shared by travelers similar to the ridesharing services like Via and Uber (Fleischer, Schippl, & Givoni, 2018). With the advancement of technology and proper regulation, Shared Automated Vehicles (SAVs) may become a public domain with the potential to reduce air pollution, accidents, etc. (Fagnant & Kockelman, 2014).

It is difficult to imagine how urban transportation will adapt to SAV introduction. Large-scale spatially-explicit simulations of future transport in a city or metropolitan region are one of the available methods nowadays for understanding and planning future SAV traffic and their interactions with other transportation modes.

By economic reasoning, the future SAV fleet should be as small as possible and could well need to reject some pickup requests. However, the high rejection rate could put at risk the acceptance of SAVs as a substitute for conventional modes (Leich & Bischoff, 2018). We thus investigate the emerging temporal and spatial patterns of future SAV service. We perform large-scale simulations for the Tel-Aviv Metropolitan area (TAMA) in Israel, where all vehicular modes are replaced with SAVs. The simulations are performed with the MATSim (Multi-Agent Transport Simulation), an open-source framework for implementing large-scale agent-based transport simulations (Horni, Nagel, & Axhausen, 2016), MATSim operates at the spatial resolution of individual travelers who follow their daily travel plans and can modify them (e.g., depart earlier, re-route, change mode) in order to minimize their total daily utility. To simulate AV-based ridesharing services we employ the demand-responsive transport (DRT) algorithm of (Bischoff, Maciejewsk, & Nagel, 2017).

Few studies have investigated the consequences of replacing some or even all urban transportation modes with automated vehicles. In Singapore, it is demonstrated that the entire population could be served by shared AV (Automated Vehicle) fleet (car-sharing only, no ridesharing) one-third the size of the current private vehicle pool (Spieser et al., 2014). In a MATSim-based study for Berlin, replacing all private vehicles by a fleet of 100k shared AV was sufficient to serve 1.1 million existing car users (Bischoff & Maciejewski, 2016). To the best of our knowledge, large-scale ridesharing simulations are not yet investigated.

2 The TAMA MATSim scenario

TAMA comprises 45% of Israel's 8M population (The Central Bureau of Statistics, 2016) and includes the city of Tel-Aviv as its core and three additional concentric rings, Figure. 1.

We investigate MATSim SAV scenarios that simulate daily activities of 330,174 agents, 10% of the TAMA population, sufficient for adequate representation of the TAMA dynamics (Bekhor, Dobler, & Axhausen, 2010). Reflecting TAMA transportation dynamics, 66% of the MATSim travelers perform trips within TAMA and 34% travel from/to outside. The road network (Figure 1a) was supplied by “Ayalon Highways Co.” and includes ~20k links, while the Public Transit (PT) network was established according to the GTFS (General Transit Feed Specification) database. During the simulation, only agents residing inside the TAMA are allowed to adapt to the changing conditions and change their routes, departure times and mode trips. External trips remained constant as background traffic. The MATSim simulation converges towards the steady state of user equilibrium where none of the agents can improve its daily utility by changing behavior. All results below are based on this assumption and reflect a model steady state for a working day.

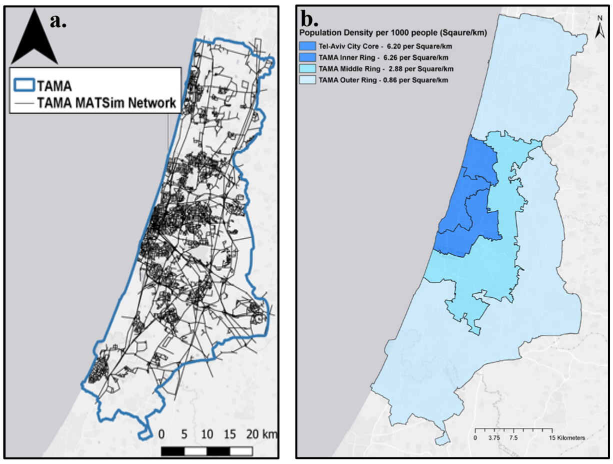

Figure 1. Map of the TAMA road network (a) and population densities in the metropolitan concentric rings (b).

The current TAMA transportation scenario was verified based on 187 long-term traffic count locations within the metropolitan area obtained for week days (Sun-Thu), between 07:00-20:00 and calibrated according to the Cadyts approach (Flötteröd, 2009). After calibration, the correlation between the model and real traffic counts was $R^2 = 0.932$. The Mean Relative Error (MRE) between simulated and real traffic counts was calculated for relevant links as $MRE = \frac{|sim_{volume} - Counts_{volume}|}{Counts_{volume}}$. The obtained MRE (Figure 2), with the daily average ~17%, is similar to those presented for MATSim simulations in Berlin and Zurich (Flötteröd, Chen, & Nagel, 2012; Ziemke, Nagel, & Bhat, 2015).

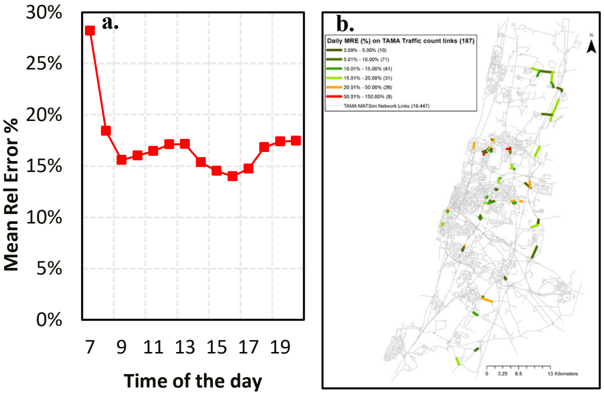

Figure 2. (a) Average hourly MRE between traffic counts stations and simulation volumes for the calibrated TAMA model (b) Map of the MRE daily averages.

To investigate the effects of introducing SAVs in the TAMA, all vehicular modes were replaced with SAVs. External trips (trucks, commercial vehicles, and cars) from/to the TAMA were included as background traffic.

SAVs trips in all investigated scenarios follow the "door-2-door" service scheme. The following scenarios were investigated:

- Fleet size – 50,000-150,000 of 4-seat vehicles, initially randomly located on the network.
- When not in use, vehicles remain parked at the destination of the previous journey.

Each scenario is examined with and without the possibility to reject an agent's service request.

SAVs service was simulated according to the MATSim Demand-Responsive dispatching algorithm (Bischoff, Maciejewsk, & Nagel, 2017). Roughly, the algorithm steps are the following: Consider all vehicles that satisfy the following conditions: (1) Can arrive at the pickup point earlier than the maximum possible waiting time; (2) Have a vacant seat for a traveler; (3) Guarantee acceptable delay to the other passengers who already share the ride. If no SAV can satisfy all three conditions, the traveler's request is rejected. In the simulations, we assume that the travel time of a ridesharing passenger cannot exceed 1.5 times of the travel time of a direct trip between the given origin and destination and that the maximum waiting time cannot exceed 12 minutes. No-rejection simulations ignore the limitation of the waiting time.

3 Simulation Results

The daily average rejection rate and 95th percentile of the travelers' waiting time with and without rejections, as dependent on the SAV fleet size are presented in Figure 3. Without request rejections, the service is substantially improved with the growth of the fleet from 50 to 100K vehicles. However, any further increase in the fleet is almost insignificant. Nevertheless, the rejection rate for the minimal possible fleet size of 50k vehicles is relatively very high - 6%.

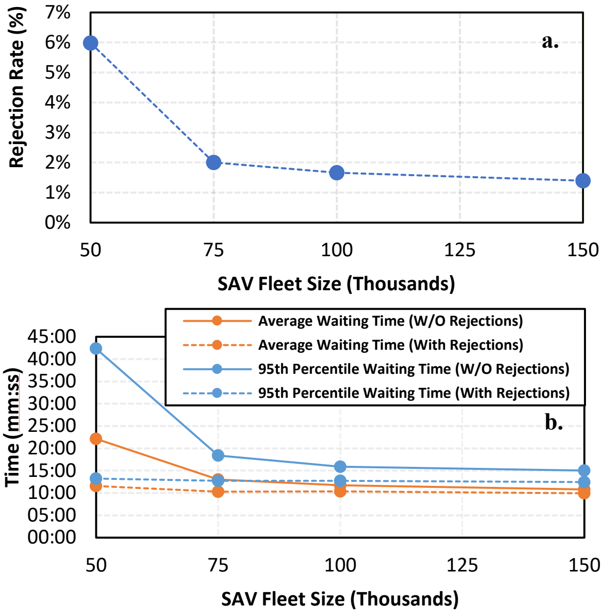

Figure 3. (a) Daily rejection rate; (b) Daily average and 95th percentile of the waiting time with/without rejections, as dependent on the SAV fleet size

Figure 4 presents the number of daily trips by vehicle occupancy for different SAV fleet size (50,000-150,000). Evidently, the major effect of a larger fleet is a reduction in the waiting time.

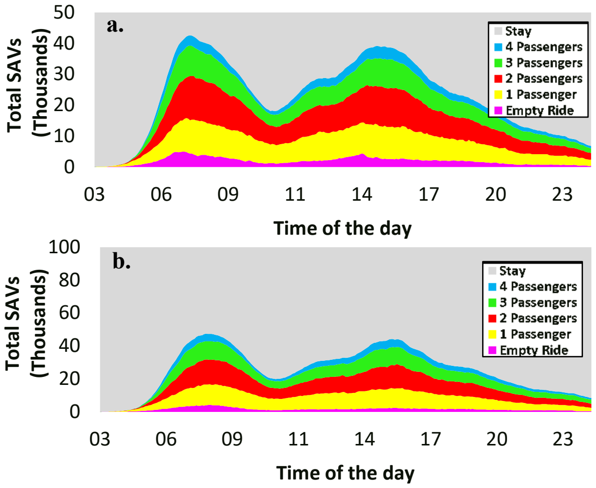

Figure 4. SAV occupancy and number of trips with rejections: (a) 50k SAVs; (b) 100k SAVs

Evidently, the Level-of-Service (LOS) provided by a 50K SAV fleet is relatively low - daily rejection rate is 6% and 95th percentile of the waiting time is 25 minutes in case of rejections and 45 without rejections. A 100K fleet guarantees inherently higher LOS. If rejections are possible, their daily rate decreases to 1.66% and the 95th percentile of waiting time is 12 minutes, Figure 3(b). Without rejections, the 95th percentile and average waiting time are only 2 minutes higher.

3.1 Spatial distribution of rejections

We investigate the spatial distribution of rejections during the morning peak, 06:00-10:00, when 32% of the total daily trips are performed. The OD matrix of peak period SAV trips is presented in Table 1 with 926,480 SAVs trips operating during this period. Table 2 presents the OD matrix of rejected trips and Table 3 the rejection rate. The rejection rates presented in Table 3 are very low, 0.34%, for all trips starting/ending in the Tel-Aviv Core/Inner Ring/Middle ring whereas the share of rejections is high for trips between the Tel-Aviv core to the Outer ring (25.19%) and between the outer ring to the Tel-Aviv core (22.70%).

Table 1, OD matrix of SAV trips aggregated for 06:00-10:00 (100,000 SAV fleet, four seats)

Destination Origin	Tel-Aviv Core	Inner Ring	Middle Ring	Outer Ring	Total
Tel-Aviv Core	109,190	27,830	11,710	1,990	150,720
Inner Ring	115,630	108,170	50,430	5,350	279,580
Middle Ring	51,070	47,230	179,630	21,350	299,280
Outer Ring	19,850	12,940	39,820	124,290	196,900
Total	295,740	196,170	281,590	152,980	926,480

Table 2, OD matrix of rejected SAV trips aggregated for 06:00-10:00 (100,000 SAV fleet, four seats)

Destination Origin	Tel-Aviv Core	Inner Ring	Middle Ring	Outer Ring	Total
Tel-Aviv Core	0	0	0	670	670
Inner Ring	120	160	170	1,570	2,020
Middle Ring	30	110	420	1,130	1,690
Outer Ring	5,830	3,770	4,130	3,810	17,540

Table 3, Rejection rate [Rejections/(Rejections + Trips)] by OD Matrix of SAVs (100,000 SAV fleet, four seats)

Destination Origin	Tel-Aviv Core	Inner Ring	Middle Ring	Outer Ring
Tel-Aviv Core	0.00%	0.00%	0.00%	25.19%
Inner Ring	0.10%	0.15%	0.34%	22.69%
Middle Ring	0.06%	0.23%	0.23%	5.03%
Outer Ring	22.70%	22.56%	9.40%	2.97%

To assess the potential benefits of a future SAV fleet, we compared traffic counts from the current TAMA road network to those obtained in the simulation of 100K SAV fleet (without rejections). The average daily change in traffic between the current counts and the SAV simulation (given the fixed background outer traffic) is -21%. That is, a shift to SAVs will essentially decrease congestion. On inter-urban roads, the congestion decreases by 25%, whereas on urban roads the decrease is smaller, 14%.

Transition to SAV results in the 5 - 10 km/h increase of the average speed on the majority of the street segments, including all main TAMA highways. The remaining traffic jams during the morning peak are observed mainly on internal road links of the Tel-Aviv city core where many travelers either start or end their trips (Figure 5).

4 Discussion

Based on our analysis, a four-person SAV fleet larger than 50K vehicles will reduce traffic volumes in SAV scenarios and eliminate congestion almost entirely. However, to reach sufficient LOS in regards to the waiting time and rejection rate, the minimally necessary SAV fleet should be, at least, doubled to 100K. Even with this excessive and economically unjustified fleet size half of which is waiting for being requested during the day, the residents of the outer metropolitan ring cannot be appropriately served: To reach reasonable waiting times of 10 or less minutes (Fagnant & Kockelman, 2014), more than 20% of outer ring requests must be rejected. This trade-off between the SAV LOS and SAV fleet size (Figure 3), is an inherent property of SAV as an on-demand service. We thus assert that SAV fleet will never be sufficient to guarantee an available vehicle at reasonable distances from any potential request in

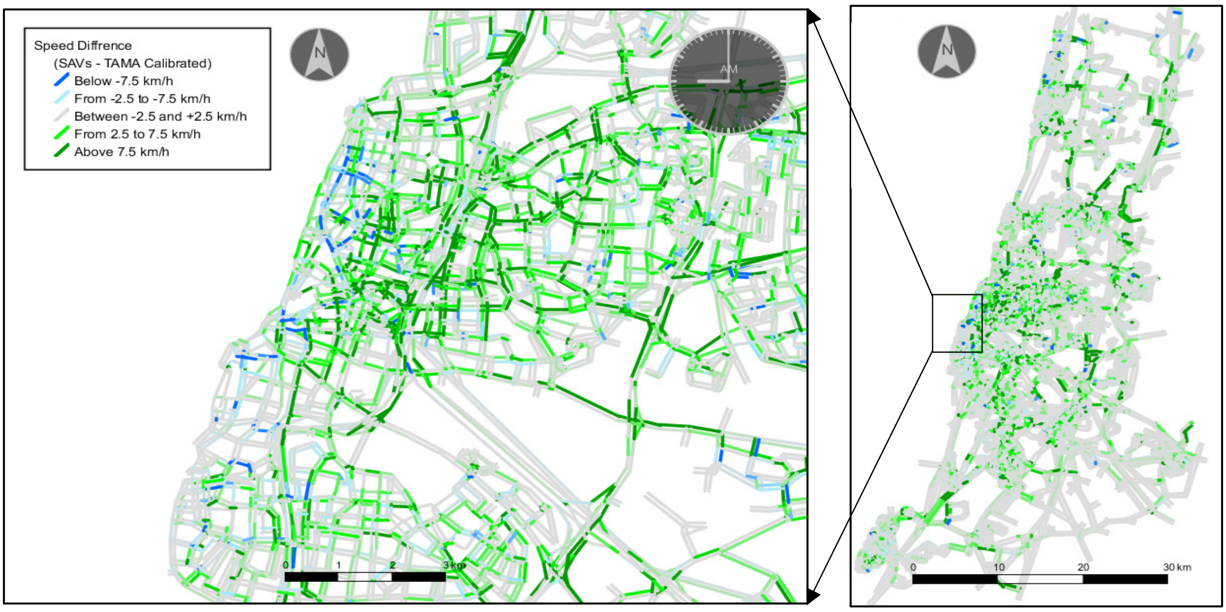

Figure 5. Average Speed Difference between 100K SAVs with 4 seats and calibrated TAMA simulation (08:00-09:00)

low-demand areas. The above inherent trade-off seems critical for travelers' adoption of SAV. Introduction of SAV will be inevitably gradual and start from trips between highly demanded OD pairs. Steady and effective SAV service that is limited to a subset of origins and destination with high demand seems to be the most probable scenario of SAV penetration into a future multimodal urban transportation system and its eventual societal adoption.

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