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Determining an Optimal Fleet Size for a Reliable Shared Automated Vehicle Ride-Sharing Service

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Abstract

Shared Automated Vehicles (SAVs) have the potential to revolutionize the urban transport landscape by reducing congestions, air pollution, and traffic accidents. However, the rejection rate for the travelers' requests can jeopardize the potential adoption of SAVs as a new sustainable mode. We present MATSim simulations of SAVs service requests and rejections in the Tel-Aviv Metropolitan Area (TAMA) in Israel and demonstrate that fleets of 50-150K vehicles could well serve the entire intra-metropolitan travel demand, with an average occupancy of ~2 compared to 1.1 passengers per vehicle today. Minimal fleet size of 50K SAVs is sufficient for serving TAMA users' activities but carries a high level of daily rejections 6%. An increase to 100K vehicles reduces the overall rejection rate to 1.66% with the rejection rate for trips between the TAMA core and outskirts remaining higher than 20%. A larger fleet size does not seem to improve the level of service significantly. The operational implications for optimal fleet size determination are further discussed.

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

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1. Introduction

The popular belief that future urban transportation will be taken over by Shared Automated (driverless) Vehicles (SAV) [1] is based on the success of Transportation Network Companies (TNC) like, Lyft, and Uber [2] and clear understanding that a modal shift to SAVs will bring dramatic improvements in road congestion, air pollution, and traffic safety [3]. Large-scale simulations are probably the only practical method available nowadays for studying whether travelers will adopt the SAV as the main mode and bring an end to traffic congestion.

Several studies have investigated the consequences of replacing some or even all transportation modes with SAVs. In Singapore [4] the entire population could be served by an SAV fleet (car-sharing only, no ride-sharing) of one-third of the current private vehicle pool. In a MATSim-based study for Berlin, replacing all the private vehicles by a fleet of 100,000 SAVs without ride-sharing [5], was sufficient to serve 1.1 million existing car users. To the best of our knowledge ride-sharing simulation studies are somewhat limited in scope to small study areas [6,7].

We examine the potential effectiveness of ride-sharing with SAVs, in a large-scale MATSim [8] scenario of the Tel-Aviv Metropolitan Area (TAMA) focusing on the waiting time and rejection of service for some of the users of a shared ride service. For this purpose, we estimate the interdependence between the fleet size and fraction of non-served users assessing the spatial and temporal implications of SAVs requests rejections on the passenger's level of service. We investigate the extreme scenarios where SAVs replace all other vehicular modes. To simulate SAV-based ridesharing services, we employ the demand-responsive transport (DRT) algorithm of Bischoff et al., which optimizes the SAV dispatching [7,9], DRT is tested with and without service request rejections.

2. Methodology

2.1. The MATSim scenario for the TAMA

The TAMA comprises 45% of Israel's population [10] and includes the city of Tel-Aviv at its core and three additional concentric rings, Fig. 1.

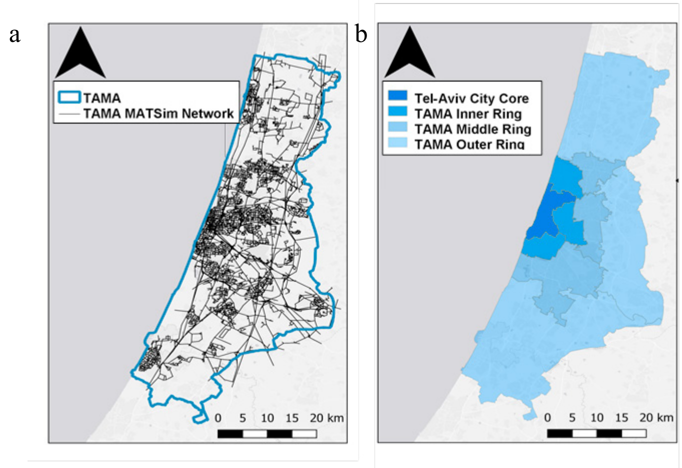

Fig. 1. Map of the TAMA road network (a) and the metropolitan concentric rings (b)

We investigate MATSim scenarios that simulate daily activities of 330,174 agents (10% of the population) [11,12] with 66% of the travelers performing trips within TAMA whereas the rest of the travelers arrive from the outside. Our MATSim simulations include all existing PT modes - rail lines and bus lines. The road network (Fig. 1a) was supplied by "Ayalon Highways Co", while the PT network was built based on the General Transit Feed Specification (GTFS) database. MATSim implementation for TAMA was calibrated and verified against 187 locations of long-term traffic counts using the Cadyts approach [13]. The correlation between the model and the real counts was $R^2 = 0.592$ for the non-calibrated and $R^2 = 0.932$ for the calibrated model versions.

In our simulations, all vehicular modes inside the TAMA were replaced with SAVs. External trips (trucks, commercial, cars - 33% of all trips) from/to TAMA were added as background traffic. SAVs trips in investigated scenarios follow the "door-2-door" service scheme. The following scenarios were investigated:

- SAV fleet size – 50,000-150,000 of 4-seat vehicles, initially randomly positioned on the network.
- SAV when not in use – park near the end of the previous journey.
- Each scenario is examined with and without the possibility to reject an agent's request.

To simulate SAVs service, we employed the DRT MATSim dispatching extension [7,9] that, roughly, implements the following algorithm: Consider all vehicles that (1) Can arrive at the pickup point earlier than the maximum permitted waiting time; (2) Have a vacant seat to pick up a traveler; (3) Guarantee acceptable delay to the other passengers sharing this ride. If none of the SAVs satisfy these conditions, the traveler's request is rejected. We also assume that the travel time of the marginal passenger cannot be 1.5 times longer than the travel time of a direct OD car trip and that maximum waiting time cannot exceed 12 minutes. No-rejection simulations ignore the limitation of the waiting times.

3. Simulation results

The daily average and 95th percentile of the travelers' waiting time and the rejection rate, as dependent on the SAV fleet size are presented in Fig. 2. Evidently, without rejections, the service is substantially improved with the growth of the fleet from 50 to 100K vehicles. However, any further increase is insignificant. In Fig. 2(b), with rejections the waiting times are almost identical across all fleet sizes (dashed lines). Nevertheless, the rejection rate for 50k vehicles is very high (6%) compared to larger fleets.

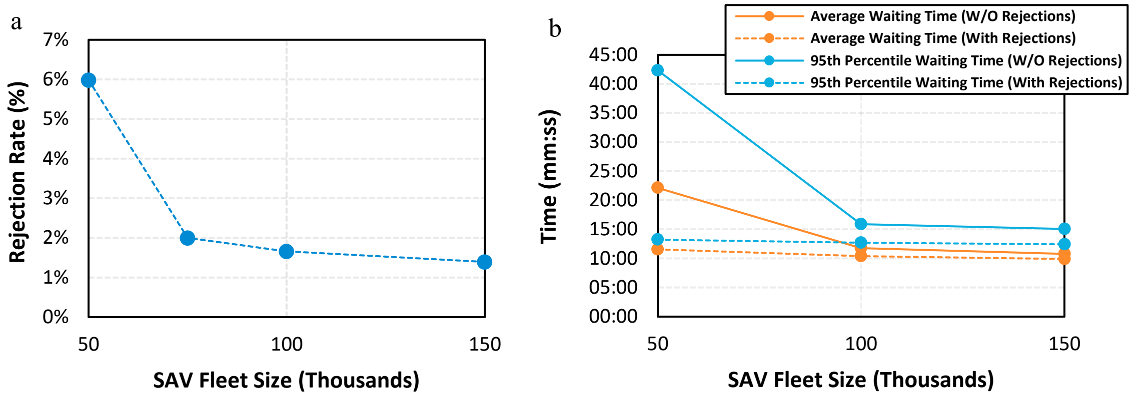

Fig. 2 (a) Daily rejection rate; (b) Waiting time - daily average and 95th percentile with/without rejections as dependent on the SAV fleet size

Fig. 3 presents the number of daily trips and vehicle occupancy for SAV fleets of the same sizes as in Fig. 2 – 50K and 100K with rejections. The 50K fleet is almost fully utilized during the peak hours; the 100K fleet essentially reduces waiting time and the rejection rate while the number of serving vehicles increases only slightly, compared to the case of the 50K fleet, e.g., 9.7% during the morning peak. In both cases, the number of utilized SAVs declines to 30K during the midday. That is, we need about 50K to supply the vast majority of the travel demand in the TAMA, and a further increase in the fleet size positively affects the Level-of-Service.

We consider a Level-of-Service characteristic of the 50K fleet with daily rejection rate of 6% and very high 95th percentile of the waiting time as unacceptable and continue with the scenarios of 100K that guarantee a daily rejection rate below 2% and 95th percentile of 12 minutes, when rejection policy is applied (Fig. 2).

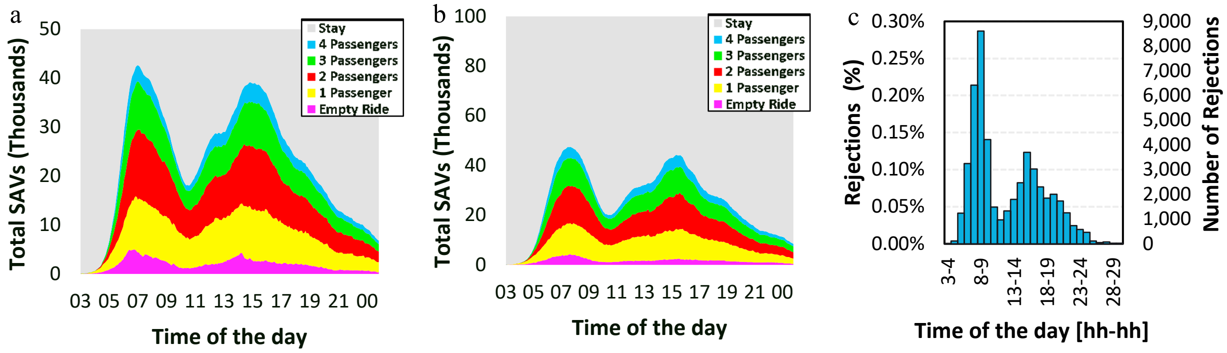

Fig. 3. SAV occupancy and number of trips with rejections: (a) 50,000 SAVs; (b) 100,000 SAVs and (c) daily rejections dynamics of 100k SAVs

3.1. Comparing Level-of-Service of the 100,000 SAV fleet in scenarios with/without rejections

For the 100K fleet size, the daily rejection rate is 1.66% (Table 1) with a total of 48,610 rejections. Statistics of the SAV fleets are presented in Table 1, and we can observe that a rejection policy slightly (4%) improves travel time, significantly (25%) improves 95th percentile of the waiting time and reduces operator losses - empty vehicle trips and total km of vehicle traveled ~15-16%.

Table 1. Passengers/Fleet Performance comparison for 100,00 SAV (four seats) with/without rejections

	Passenger Parameters							*SAV Fleet Parameters*	
	Average Waiting Time [mm:ss]	Median Waiting Time [mm:ss]	Waiting Time (95th Percentile) [mm:ss]	Average Travel Time [mm:ss]	Average Direct Distance [km]	Average Detour Distance [km]	Rejections [%]	Total Empty Vehicle km Traveled [1000 km]	Total Vehicle km Traveled [1000 km]
Without Rejections	11:46	07:19	15:53	23:16	9.81	3.16	-	55.7	2,013
With Rejections	10:24	06:14	12:42	22:20	9.02	2.97	1.66%	48.2	1,728
Relative Change* [%]	-13.14%	-17.38%	-25.07%	-4.18%	-8.76%	-6.40%	-	-15.56%	-16.49%

*Relative change is calculated as (With Rejections - Without Rejections) / With Rejections

Fig. 4 presents hourly dynamics of the average and 95th percentile of passengers' waiting times with/without rejections. The demand to serve all travelers hardly influences the average values while influencing the tails of the distribution.

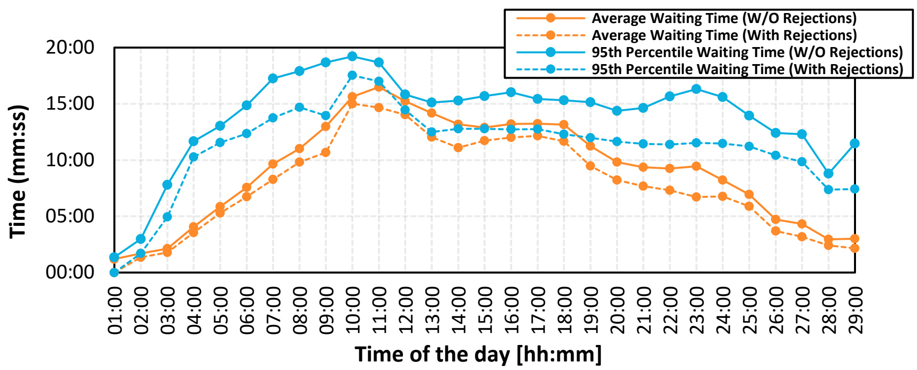

Fig. 4. Hourly average and 95th percentile of waiting time for 100,000 SAVs with four seats with/without rejections

3.2. Spatial distribution of rejections

We investigate the spatial distribution of rejections during the morning peak (06:00-10:00). The number of rejections during this period is about 21K, i.e., 50% of the daily total of 48K. Table 2, presents an OD matrix of the served and rejected SAV trips and the fraction of rejections among all morning peak trips. Most of the rejections occur where origin or destination fall in the outer metropolitan ring.

Table 2. Origin/Destination matrix of Served, Rejected and Rejection rate* of SAVs trips, 06:00-10:00, 100,000 SAVs, four seats

Destination / Origin	Core			Inner Ring			Middle Ring			Outer Ring			Total		
	Served	Rej	Rate	Served	Rej	Rate	Served	Rej	Rate	Served	Rej	Rate	Served	Rej	Rate
Core	109,190	0	0.00%	27,830	0	0.00%	11,710	0	0.00%	1,990	670	25.19%	150,720	670	0.44%
Inner Ring	115,630	120	0.10%	108,170	160	0.15%	50,430	170	0.34%	5,350	1,570	22.69%	279,580	2,020	0.72%
Middle Ring	51,070	30	0.06%	47,230	110	0.23%	179,630	420	0.23%	21,350	1,130	5.03%	299,280	1,690	0.56%
Outer Ring	19,850	5,830	22.70%	12,940	3,770	22.56%	39,820	4,130	9.40%	124,290	3,810	2.97%	196,900	17,540	8.18%
Total	295,740	5,980	1.98%	196,170	4,040	2.02%	281,590	4,720	1.65%	152,980	7,180	4.48%	926,480	21,920	2.31%

*Rejection rate is calculated as: Rejected / (Served + Rejected)

3.3. Benefits of SAV mode

To assess the potential benefits of the future SAV, we compared traffic counts for the current state of the TAMA to the model counts obtained in the scenarios with the 100K SAV fleet, without rejections (Fig. 6). The average daily decrease in traffic congestion associated with SAVs is ~21%. On inter-urban roads, the difference is 25% whereas on urban roads it is 14% only. If rejections are allowed, the decrease in congestion is 28% on urban roads and 19% on inter-urban roads.

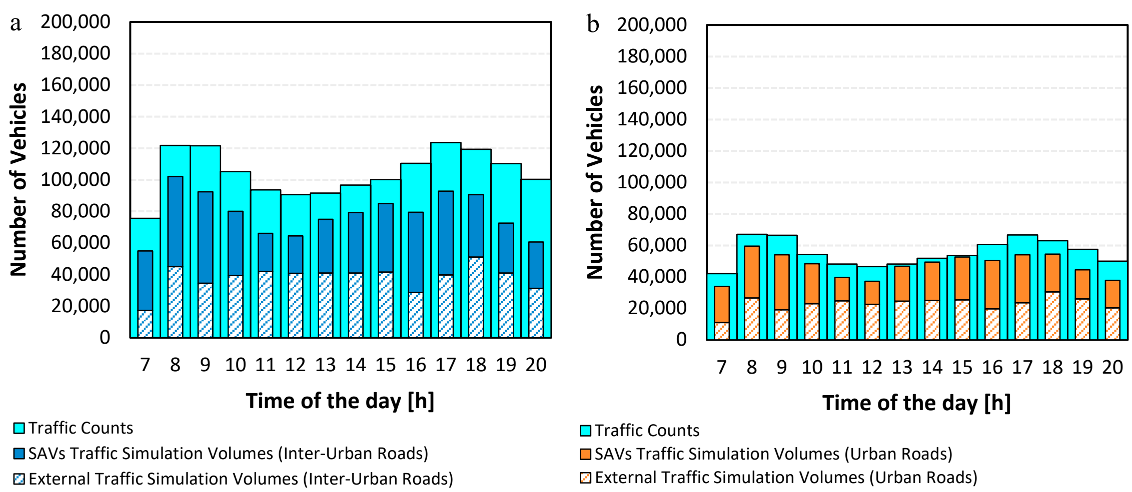

Fig. 5. Traffic counts for the current model split in TAMA compared to counts for the scenario of 100K SAVs, 4 seats, without rejections, (a) traffic volumes on inter-urban roads; (b) traffic volumes on urban-roads

Spatially, the transition to SAVs reduces traffic congestion. Traffic jams are only observable (in SAV 100K fleet scenario) on the internal roads of the Tel-Aviv city core during the morning hours, when many travelers start their trips simultaneously. Similarly, even in the peak hours, a 100K SAV fleet does not produce congestion on the main TAMA highways.

4. Discussion

The average car occupancy in SAV scenarios is 2.1, twice higher than 1.1 - the average occupancy of private car in the TAMA today [14]. The higher average car occupancy results in a 20% decrease to traffic volumes in SAV scenarios and is sufficient to reduce congestion almost entirely. With a rejection policy enabled, the majority of the travelers will not wait for too long; however, the rejections are not distributed evenly in space and travelers residing in the outer ring of the TAMA will suffer essential service disruptions. In order to guarantee appropriate waiting time for everybody, the required fleet size should be essentially larger. The tradeoff between passengers' waiting time and operational efficiency seems to be an inherent property of the SAV mode. It will always be valid, and we thus assert that the balance between the economic cost of the SAV for the operator, and acceptance of the SAV trip price by the users will define the future share of the SAV.

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