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Comparing Parking Strategies of Autonomous Transit On Demand with Varying Transport Demand

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Abstract

Autonomous transit on demand are increasingly considered to become a viable substitute for taxi services. AVs can be managed through a centralized controlling system, targeting system optimization rather than user optimality. This centralized control can enable a more efficient, strictly-adhered-to parking strategy to reduce inefficient empty traveling. In this project, four different parking strategies are implemented in the AV extension of MATSim (Multi-agent transport simulation), namely demand-based roaming, parking on the street, parking in depots and a mixed strategy of parking on the street and in depots. The influence of different PT demand levels on the different parking strategies was explored, showing that the shared system is robust to varying levels of demand, and that the different parking strategies trade off user convenience for operational cost. The road parking strategy appears to be the best for consolidating rides into larger vehicles, especially for the increased demand scenario.

Keywords: Agent-based Modeling; MATSim; Parking; Autonomous Vehicle

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1. Introduction

Autonomous transit-on-demand (ATOD) is a possible new public transit mode where AVs are essentially autonomous buses. It is conceived as a stop-to-stop bus service with dynamic routing among dedicated stops, which can combine the advantages of both taxi and bus[1]. Ride-sharing companies (essentially, companies offering a platform for informal taxi services), such as Uber, have been offering dynamic ride-sharing services for a number of years, but the number of passengers sharing rides cannot be compared to those using ordinary transit services. However, dynamic ride-sharing with autonomous vehicles can be very different from that with human drivers. For the policymaker, the proposed ATOD service can be deployed and managed for the system optimum (assuming it is under centralized control, e.g. a transport authority or transit operator). ATOD could offer more flexible and on-demand service than buses, while being more precisely controlled and coordinated than taxis. Operating flexibly as a stop-to-stop, door-

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to-door or first/last mile rail connection, the flexibility of precise, centralized control could radically transform transit into a mode of choice, rather than necessity.

The new ATOD system will definitely challenge planning authorities and have a significant influence on future urban form. Zhang et al. [2] found that autonomous vehicles can release parking occupied urban space; Maciejewski et al.[3] argued that the shared autonomous vehicle (SAV) may have a positive effect on traffic congestion; Fagnant et al. [4] pointed out that each SAV can replace around eleven conventional vehicles; [7] explored a automated parking lot management system with good performance for autonomous vehicles. This implies that urban and transport planners do not have to focus on how to allocate urban space to satisfy increasing transport demand anymore. Network capacity can be much less compared to the current situation and parking can be relocated outside the urban area on cheaper land.

This paper focuses on the implementation and the evaluation of different parking strategies for a mix of autonomous vehicle sizes, operating as a centrally controlled ATOD system. Four different parking strategies are discussed, namely demand-based roaming (i.e., no parking, ever), parking on the street, in depots and a mixed strategy, with varying levels of PT demand. In the rest of the paper, the abbreviations of roaming, road, depot and mix are used to refer to each strategy respectively. The demand levels are categorized as high demand, normal demand and low demand.

2. Methodology

Simulations are executed using the Multi-Agent Transport Simulation (MATSim), with implementation and modification of the Demand Responsive Transit (DRT) extension [5]. MATSim is an activity-based, extensible, open-source multi-agent simulation framework implemented in Java [6]. To emulate user equilibrium, the same day is simulated several times while agents optimize their own travel experience in a process of co-evolution.

The MATSim DRT extension can simulate autonomous transit with dynamic routing and ride-sharing. AVs are dynamically routed in response to passenger requests. A central dispatcher assigns passengers to vehicles, adding modifications to a vehicle's task schedule. When a new request is received, it is converted to drive and stop tasks in the schedule, followed by a stay task. The above-mentioned four parking strategies are implemented when the vehicle starts to execute a stay task and the vehicle departs when the stay task is finished, triggered by incoming pickup requests. The dispatcher in the DRT extension attempts to maintain a realistic level of service by allowing reasonable detours, defined by a maximum waiting time constraint for new passengers and maximum in-vehicle travel time detour factor for passengers to be dropped off. As long as the maximum waiting time and in-vehicle time of one passenger is violated, the request will be rejected by the vehicle. This rule only applies for request dispatching and sometimes passengers wait longer than the maximum waiting time due to unpredictable traffic situations, such as traffic congestion. The vehicle with the least detour cost (including both pick up and drop off detour) among all types of vehicles will be selected for the passenger. For all strategies, the vehicles are still available for dispatching on the way to parking. Only the parking behavior of autonomous vehicles is simulated in the system.

Demand-based roaming is similar to the cruising behaviour of taxis, which keep moving and tend to drive to anticipated high demand areas when idle. The strategy works by recording demand from previous iterations at a zonal level, where the study area is divided into grid according to a predefined cell size (1km in the study). In each iteration of the MATSim mobility simulation, the number of departures in each zone are counted every 30 minutes and saved as a demand estimate for the next iteration. During the simulation, once a vehicle is idle, it will choose an adjacent destination zone through a weighted sampling of anticipated demand. Within the destination zone, the vehicle performs a random walk and repeats the above process until it is assigned a passenger. To simplify and characterize each strategy, vehicles in this strategy will never stop, even if the expected demand of all zones is zero, in which case vehicles will randomly choose a zone to roam. The strategy increases the probability for vehicles to be matched with passengers as well as dynamically relocating vehicles depending on demand, but, at the same time, it increases empty mileage.

Parking on the street is similar to the existing parking strategy of private vehicles in many cities. Vehicles park in the nearest available road space to the trip destination waiting for the next request. Parking on the street will block one lane (or half lane one-lane road) and the capacity of the street will be reduced accordingly once it is occupied for parking by at least one vehicle. Later, if all parking vehicles leave the link, the number of lanes and the capacity of the link will recover. The number of parking spaces along the street depends on the length of the street and the size of the vehicle, thus offering more spaces for smaller vehicles. If the current link is not allowed for parking, the vehicle will randomly choose one link among all next links to cruise for parking till it reaches an available space. Parking on the street saves space of parking depots, but may cause congestion, which is why it is discouraged in many urban areas. However, as the SAV fleet is significantly smaller than that of a private vehicle fleet, it is expected that it will not produce a significant reduction in capacity relative to the fleet size.

Parking in depots means that the vehicle always drives back to a depot once it is empty but can still accept a new request either on the way or in the depot. There are several depots in the system, once the nearest depot is full, the vehicle has to drive to the second nearest depot and so on. After choosing the nearest available depot, the parking place in the depot will be reserved for the vehicle, and once the vehicle accepts a new request, the reserved parking place will be released. This strategy is similar to existing public transit parking strategies, which relocates vehicles away from the dense downtown area with high parking cost and limited supply. Depots can be located in peripheral areas and the strategy can totally free up dense urban space from parking. Its disadvantage is extra empty travel time and distance from depots to the origin of the traveler and from the destination of the traveler to the depots, as well as the cost of purpose-built parking space.

Mixed parking strategy represents an approach to use existing residential parking infrastructure rather than purpose-built infrastructure outside the urban area. In the mixed parking strategy, AVs will stay on the street for overnight parking (20:00 - 07:00) but will switch to the depot strategy during the daytime (07:00 - 20:00). Residential parking lots are always empty during daytime as people drive their car to work and the roads are usually empty during night because of fewer traffic. Therefore, the mix strategy may combine the advantage of parking on the road and in deports with fewer space consumption. At 7:00 in the morning, all idle vehicles will move to the nearest available residential parking lot; while at 20:00 in the evening, all idle vehicles will move to the nearest available street. Slightly different from the two strategies in previous sections, only 4-seater AV bus are allowed to park on the street. Furthermore, the 4-seater AV bus can park in small depots in residential areas during daytime. Big AV buses can only park in the peripheral depot throughout the day in the mixed parking strategy. The mixed parking strategy tries to take advantage of both road and depot strategies with dynamic traffic management. It is expected that the strategy has less operational cost than the depot strategy but will produce a better user experience than the road strategy, as less congestion may result.

3. Scenario

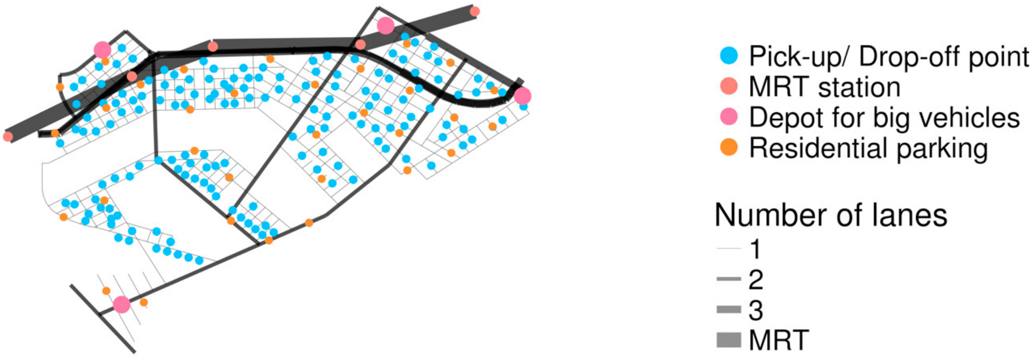


Fig. 1. The planned network of the new urban development area, Tanjong Pagar.

For this study, a scenario for a future development in Singapore is produced, titled Waterfront Tanjong Pagar. The Waterfront Tanjong Pagar project represents a Future Cities Laboratory (FCL) synergy project including eight FCL research modules led by Dietmar Leyk. The planned Tanjong Pagar network (fig. 1) consists of 1728 links, 578 nodes, 330 pick-up/drop-off points and 1 MRT (Mass Rail Transit) line with 5 stops. Most links in the network are one lane per direction, the expressway is two lanes per direction and the tunnel is three lanes per direction. AVs are only allowed to park, pick up or drop off on the one-lane-per-direction streets (two lanes in total), as the expressway and tunnel are only designed for high-speed traffic. Whenever there are parking or dwelling vehicles, the capacity of a link is reduced by half.

In the scenario, only MRT and ATOD are available public transit (PT) choices. Besides these, the scenario also contains car, walking and normal taxi modes in proportions representing a realistic Singapore traffic demand. No mode shift is allowed between public transport, car and normal taxis, but after each iteration public transport travelers can change their route to use only AV buses, MRT or a combination of the two. Effectively then, the ATOD system is simulated either as an individual transport mode or as a first/last-mile solution to the existing MRT system. Parameters used in the utility function of each PT mode are calibrated according to Singapore PT pricing system. In the simulation, the number of trips by taxi and private vehicle is fixed for all scenarios, which is 29945 for taxi and 156983 for private vehicle, only PT demand varies, which is 398324 for high demand (30% more than normal demand), 299050 for normal demand and 199245 for low demand (30% less than normal demand). 40 iterations are simulated to reach a stable system score.

In order to capture the effects of overnight trips, the simulation runs from 00:00 to 28:00. The vehicle mix is the same for all scenarios, 280 4-seater vehicles, 230 10-seater vehicles, and 90 20-seater vehicles. The fleet size was determined after a number of test simulations, which revealed this vehicle mix to be adequate to serve the demand, but it does not necessarily mean that this vehicle mix is optimal. The study does not consider cost implications of the fleet mix, assuming this to be application-specific in practice. In the study, no time is spent on justifying costs, as it is expected that sensitivity analysis of relative costs for future scenarios and transport modes should be the default approach to test for robustness, and any specific relative cost allocation is likely to be wrong. That said, time constraints have prevented us from doing such a sensitivity analysis at this stage.

4. Results

4.1. Summary

Table 1. Overall result of different strategies of different demand for ATOD (Only AV is included in the key performance indicators)

Strategy	Demand	Mode share		Avg. occupancy	Avg. travel time[s]	Avg. walk distance[m]	Travel distance[kkm]	
		AV bus	MRT				Total VKT	Empty VKT
Roam	Low	41.81%	58.19%	0.27	696.41	438.26	571.26	516.28
	Normal	42.62%	57.38%	0.41	707.94	435.03	581.44	501.57
	High	42.15%	57.85%	0.55	712.39	440.42	572.99	474.59
Road	Low	41.85%	58.15%	0.29	704.57	438.89	52.35	2.38
	Normal	42.63%	57.37%	0.49	714.71	435.37	74.60	3.55
	High	41.96%	58.04%	0.65	731.92	441.15	92.85	3.96
Depot	Low	41.67%	58.33%	0.26	736.39	440.10	59.31	5.13
	Normal	42.38%	57.62%	0.44	728.11	438.60	79.20	6.58
	High	42.01%	57.99%	0.59	738.18	441.76	100.48	8.03
Mix	Low	41.85%	58.15%	0.28	726.02	439.02	57.36	3.97
	Normal	42.54%	57.46%	0.46	734.15	433.96	80.88	5.67
	High	42.15%	57.85%	0.61	744.45	440.38	99.37	5.91

According to table 1, among all four strategies, the mode share of AV bus increases first and slightly drops in high demand scenario with increasing demand. It is not clear whether this fluctuation is due to the various number of transfers of each passenger or because passengers prefer AV bus in normal demand scenarios. For the average occupancy, it is expected that the average occupancy increases with the increasing demand, however, the increment is different among different strategies. The increment of the depot strategy is the most visible, with 127% more occupancy in high demand compared to the low demand, followed by road strategy with 124%, mix strategy with

118% and roaming strategy with only 104% more occupancy in high demand scenario. For the travel time, including the waiting time and the in-vehicle time, as expected, the roaming strategy has the shortest travel time as there are always vehicles around demand; while depot strategy has the longest travel time because vehicles have to travel from the suburb depots to the downtown area. The travel time increases with the increasing demand, but the increment is not very noticeable, which may be compensated by the increasing vehicle occupancy. A further reason is that in the ATOD system travel time is restricted by the request accepting conditions, which will reject the coming requests resulting in long wait or in-vehicle time of the accepted requests. For walk distance, there is no significant difference among all scenarios. For travel distance, it is not surprising that the total and the empty VKT (Vehicle kilometers traveled) for the roaming strategy is extremely high because they never stop in the system. It is also expected that the road strategy has the least total and empty VKT because vehicles park on the nearby street. Finally, mix strategy is in the middle and the total and empty VKT of the depot strategy is higher than the road and mix strategy.

4.2. Occupancy

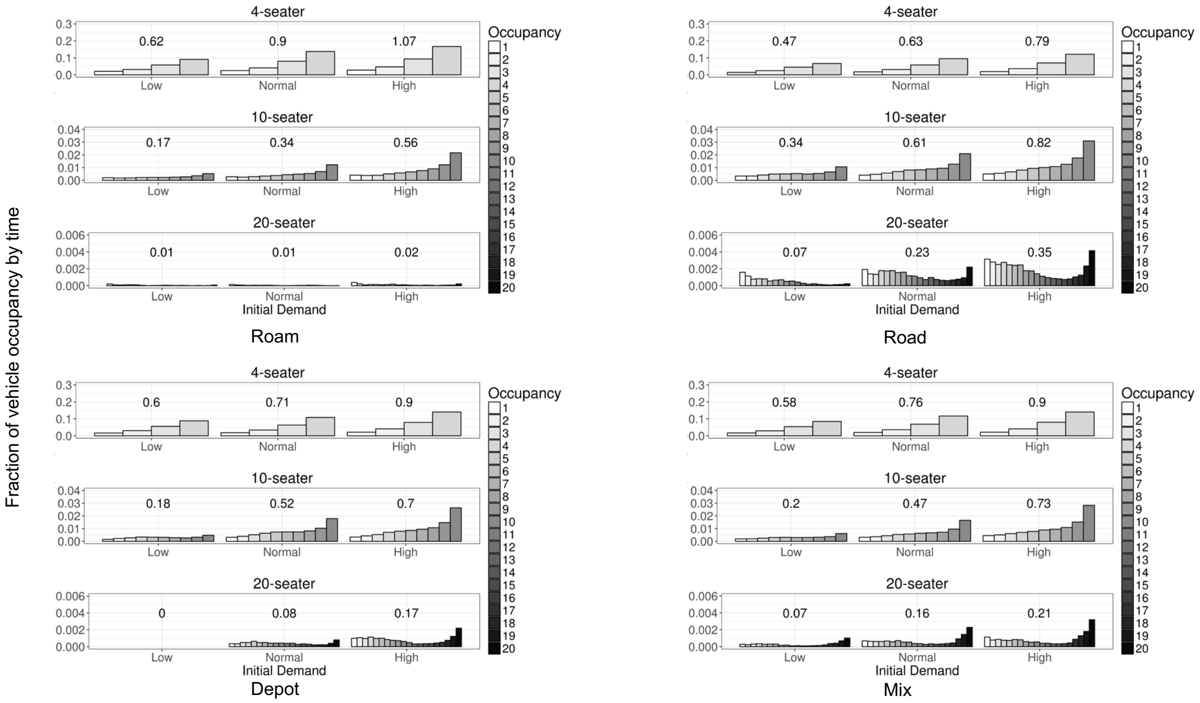
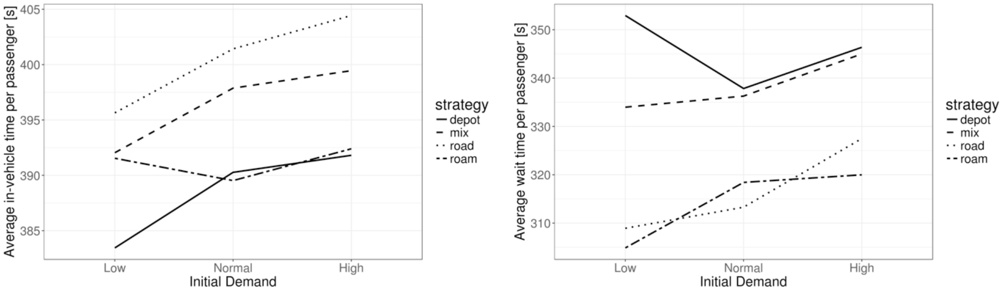


Fig. 2. Vehicle occupancy (The number above each bar chart shows the average occupancy).

Further examination of average vehicle occupancy by different vehicle types reveals a marked degree of variation among different strategies. From fig. 2, the road strategy has a higher vehicle occupancy of larger vehicles while roaming strategy has fewer passengers sharing the ride in big vehicles. This can be due to the high availability of small vehicles in the roaming scenario. Small vehicles are more agile and flexible than big vehicles. 4-seater small vehicles can be idle quickly and in the roaming strategy, there will be more small vehicles around the demand, hence 4-seater vehicles are probably more used compared to bigger vehicles. On the other hand, for the road strategy, all vehicles including 4-seaters, stop around the destination, which can be far away from the demand. With the increasing demand, the occupancy increases accordingly but not linearly among different vehicle types. Another assumption for the supremacy of 4-seater vehicles is the scale effect, which means that the larger number of vehicles of one type makes it more likely to encounter and use the type. Unfortunately, the current simulations cannot support or deny any of these assumptions and further analysis is needed, to tease apart their relative contributions to the observed effects.

4.3. Travel time

The in-vehicle travel time of most strategies increases with more demand, which is expected and reasonable. The increment of high demand scenarios is within 10s, which is quite tolerable for a 10-minute trip. With the road strategy, agents travel longer due to more congestion caused by the reductions of capacity. This also explains why agents spend less in-vehicle time when vehicles park inside depots. Waiting time of most strategies also increases with more demand with more noticeable differences around 15-20 seconds. In the opposite manner of in-vehicle times, the depot strategy generates the longest waiting time. Agents have to wait longer because vehicles are not easily available compared to the roaming or road strategy.



(a) In-vehicle time (b) Wait time

Fig. 3. Travel time comparison of the 4 parking strategies with demand variation.

5. Conclusion

The paper simulates ATOD system with four different parking strategies and three different initial PT demand levels were analyzed. The modeled ATOD system with a fixed fleet size, was flexible and robust enough to serve from 70% to 130% of a normal demand with an acceptable level of service. By adjusting the vehicle occupancy and the vehicle kilometers traveled, the ATOD system can guarantee the experience of passengers in terms of walking distance, waiting time and traveling time. From the perspective of passengers, based on the simulation results, the roaming strategy is the most attractive with shorter travel times, but from the perspective of operation, it is the worst. To save the 10-30s travel time is remarkably expensive, with empty travel distances 100 times longer than other strategies. The vehicle occupancy of the ATOD system is higher than conventional ride-sharing services, and big vehicles are frequently used in the road, depot and mix strategy. It will be interesting to confirm whether the higher occupancy of small vehicles is due to its flexibility and availability or due to the higher number of small vehicles. Probably a clearer relationship between the vehicle mix and the vehicle occupancy will be observed in the future studies.

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