Simulations of different scenarios of the use of autonomous vehicles with a multi-agent model

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1 INTRODUCTION

The arrival of autonomous vehicles on the roads is becoming reality. Being able to predict the impacts that driverless technology will have, is therefore a burning question (Fagnant & Kockelman, 2015). However, the impacts generated by these vehicles depend on the type of use that will be made of them. This work proposes and compares different simulation scenarios for different uses of autonomous vehicles.

The existing literature focuses mainly on shared autonomous modes, for exemple the impacts of robotaxis or the parameters of such a service, for example the size of the vehicle fleet. Private use of AVs, has been addressed much more sparsely. A common implicit assumption seems that private use is inherently bad for the environment and not worth investigating. Here, both are considered and impacts are compared. The shared mode, robotaxis, is addressed under two scenarios, solo use, and ride-sharing.

2 MATERIALS AND METHODS

Simulations are performed using the open-source multi-agent software MATSim (Axhausen *et al.*, 2016). The disaggregation level allows the explicit modeling of autonomous vehicles. Dedicated extensions of the toool, DVPR (Maciejewski, 2016) and DRT (Bischoff *et al.*, 2019), have been developed and used to model the behavior of autonomous vehicles. The extension, which models MaaS modes, relies on a centralized system that receives requests as soon as an agent wants to use this mode. It will then, according to a different algorithm for each case, order a vehicle to take care of the request by trying to be the most efficient.

In total three scenarios are simulated. For the first scenario, which corresponds to private use, the code has been modified so that the vehicle can only be assigned to the household that owns it. This mode is called private autonomous vehicle (PAV). For the second scenario, when an agent makes a request, the closest available vehicle is affected to it, if any is available. Otherwise, as soon as a vehicle becomes available it will respond to the closest request. This mode is called shared autonomous vehicle (SAV). For the third scenario, when an agent makes a request, it is the vehicle whose insertion of this request in its planned route will generate the least increase in operation time that will be sent. This mode is called pooled shared autonomous vehicle (PSAV).

The scenarios are modeled for the city of Montreal, where these modes are added to a transportation system that includes already public transport, walking and cycling Manout & Ciari (2021), but removing conventional cars, to best measure the impact. For reasons of computation time, the simulations were done on a sample of 5 % of the Montreal population, which produces reliable results (Llorca & Moeckel, 2019).

3 RESULTS

The results of the simulations and the comparison between the different uses of autonomous vehicles are seen from different perspectives : impacts of the use of others modes, impacts on the environment because of the total distance increase with empty trips and also a measure of equity through comparison of agent's score by income.

3.1 Modal share

One of the questions raised by the introduction of modes as convenient as a conventional car but without the burden of driving is: will autonomous vehicles replace public transport? The analysis of modal share and modal shift shows that the modal share of the motorized modes (car and car-passenger for the baseline scenario, and PAV, SAV, and PSAV for scenarios 1, 2, and 3, respectively) is fairly stable. Active modes and public transport even gain some share, although by small margins.

3.2 Distance travelled

Table 1 shows the total average VKT and distance per trip or per vehicle on the road network. Scenarios 1 and 2 show a very large increase in VKT (71 % and 85 % respectively). For scenario 1, of the additional km produced compared to the baseline scenario, $0{,}52 \cdot 10^6$ km (24 %) come from the demand induced by the modal shift and $1{,}61 \cdot 10^6$ km from the empty trips generated between requests to pick up different agents. For scenario 3, the increase is less important, as ride-sharing is allowed. Moreover, the dispatcher of the requests minimizes the distances traveled by the vehicles. In scenario 3, it takes into account where an occupied vehicle will go, while in scenario 2, it will simply send a new vehicle, even if in the meantime one becomes available closer, it will not be considered. The share of empty kilometers is also lower for the PSAVs. In terms of average distances per trip, the effect of empty trips can be observed, since the distances with passengers for autonomous modes are approximately equal to those for *car* in the baseline scenario. In contrast, for the PSAVs in Scenario 3, the average vehicle distance is less than the passenger distance because passengers can be grouped together. The average distance per vehicle, shows also that shared vehicles are used much more.

Scénario Modes	Base car	Sce1 PAV	Sce2 SAV	Sce3 PSAV
VKT (10^6 km)	2,98	5,11	5,12	4,14
Extra VKT (10^6 km)		2,13	2,54	1,16
Avg distance /trip (km)	14,55	20,96	21,06	16,12
Empty share		31 %	31 %	21 %

Table 1 – *Distances traveled*

3.3 Environmental impacts

Using Canadian vehicle sales data for the proportion of each class of vehicle in the fleet, are calculated total energy consumption and GHG emissions are claculated.

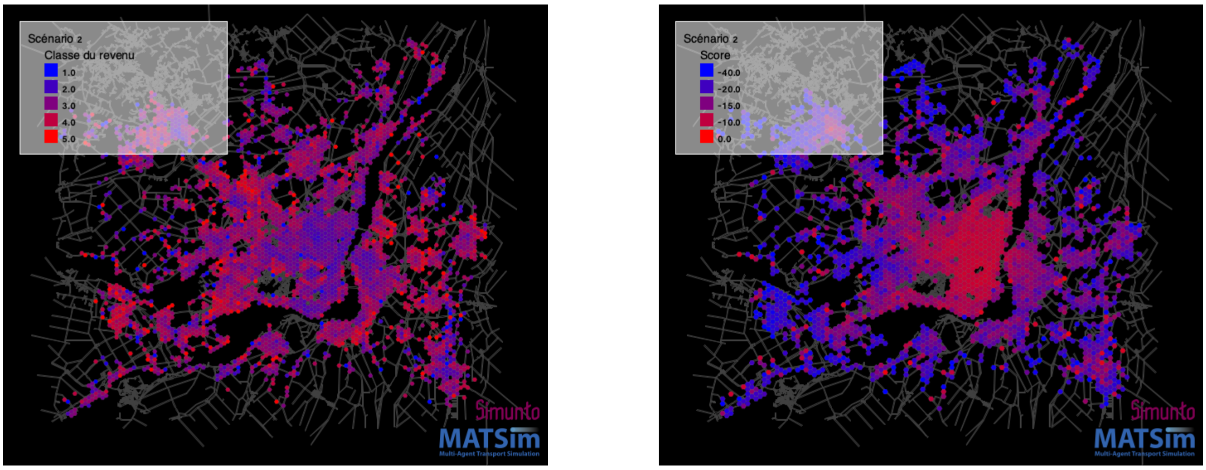
As expected by such a large increase in VKT, there is an increase in total energy consumed and GHGs emitted. The only scenario that meets the objective of reducing pollution is scenario 3. By limiting empty miles for the PSAV mode, smoothing automated driving, and changing the vehicle model, a decrease in energy consumption is observed.

	base	sce1 (hyp.A)	sce1 (hyp.B)	sce2	sce3
Energy consumption. (10^6 MJ)	35,5	54,7	35,3	38,1	28,6
Evolution cons.		+ 54 %	0 %	+8 %	-19 %
GHG emissions (10^9 g GEG)	2,36	3,64	2,72	2,94	2,21
Evolution emis.		+54 %	+15 %	+25 %	-6 %

Table 2 – *Energy consumption and GHG emissions*

However, if instead of considering the same fleet composition as today for the private ownership scenario (hyp.A) we consider a fleet entirely composed of medium sized cars instead (hyp.B), increase in GHG emissions goes from a 54% to a 15%. Overall, improvements in driving through automation do not compensate for the energy impacts of driving empty, but fleet adjustments could help limit the impact.

3.4 Equity analysis



(a) *Income class of the household* (b) *Scoring of the agent*

Figure 1 – *Comparison between the scoring and the revenue*

MATSim allows us to compare the socio-economic characteristics of the agents with the score they obtain for the realization of their activity plan during the simulation. Surprisingly, we notice that households with a higher income have a lower score (see figure 1). This can be explained by the fact that they live in lower density areas. The level of service of autonomous vehicles is therefore not as good, so they have more waiting time and a penalized score.

4 DISCUSSION

This work allows for comparing, at different levels, three different uses of autonomous vehicles. The comparison between the impacts of private use and on-demand shared services, to the authors' knowledge, was not done before.

The results produced through multi-agent modeling confirm previous findings, but with some significant differences. As expected, in comparison to private use, the pooled shared service has a better environmental performance and differences are not small, but they can be reduced with appropriate policies, for example varying vehicles types. In general, results suggest a more nuanced reality than the heaven or hell dichotomy (where private ownership would be "hell" and a shared use "heaven") as it has been sometimes mentioned in the public discourse.

For this work, modeling parameters have been set based on the literature. The calibration may not be adapted and to the Montreal case. This is an avenue to be explored in order to obtain more reliable results. The model used also has limitations in terms of the likelihood of using autonomous vehicles for private use. Currently, informal, intra-household carpooling is not allowed.

Finally, although the extreme scenarios presented here, almost exclusively either private or shared vehicles, are useful for analysis, more complex scenarios in which several different uses would coexist may be more realistic, and will be explored in the future.

References

Axhausen, Kay W., Horni, Andreas, & Nagel, Kai (eds). 2016. *The Multi-Agent Transport Simulation MATSim*. London: Ubiquity Press.

Bischoff, Joschka, Führer, Karoline, & Maciejewski, Michal. 2019. Impact assessment of autonomous DRT systems. *Transportation Research Procedia*, **41**, 440–446. Urban Mobility - Shaping the Future Together mobil.TUM 2018 - International Scientific Conference on Mobility and Transport Conference Proceedings, https://doi.org/10.1016/j.trpro.2019.09.074.

Fagnant, Daniel J., & Kockelman, Kara. 2015. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice*, **77**, 167–181. https://doi.org/10.1016/j.tra.2015.04.003.

Llorca, Carlos, & Moeckel, Rolf. 2019. Effects of scaling down the population for agent-based traffic simulations. *Procedia Computer Science*, **151**, 782–787. https://doi.org/10.1016/j.procs.2019.04.106.

Maciejewski, M. 2016. Dynamic Transport Services. *Pages 145–152 of: The Multi-Agent Transport Simulation MATSim*. Axhausen, Kay W. and Horni, Andreas and Nagel, Kai.

Manout, Ouassim, & Ciari, Francesco. 2021. Assessing the Role of Daily Activities and Mobility in the Spread of COVID-19 in Montreal With an Agent-Based Approach. *Frontiers in Built Environment*, **7**.