Modelling electric vehicles usage in a carsharing fleet using MATSim

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SHORT SUMMARY

In many countries, urban transportation systems strive to serve travel demand. With increasing mobility needs and climate change concerns, carsharing, among other solutions, can be a serious alternative to private car. With current environmental concerns, carsharing operators have started to introduce electric vehicles into their fleet. The electrification of carsharing is challenging, for operators and users. In this paper, we examine the impact of weather conditions (temperature) and range anxiety on the adoption and use of electric shared cars in comparison with conventional cars.

The adoption of electric vehicles in the context of carsharing is simulated using the multi-agent system MATSim. Results show that, in the case of Montreal, the potential negative impact of temperature and range anxiety on carsharing demand and use is very limited. Findings of this research can be of interest to carsharing operators.

Keywords: Carsharing, Electric vehicles, Agent-based modelling, Range anxiety, Temperature, Battery.

1. INTRODUCTION

With increasing urban population (United Nations, 2019), urban transportation systems strive to serve travel demand. In various metropolitan areas around the world, transportation networks are congested (Tomtom, 2021). In order to meet the growing need for mobility, new and renewed travel modes have emerged. One of these solutions is carsharing which is based on shared cars that can be rented, often for short periods of time. By offering a cheaper alternative to the private car, carsharing meets the need for flexible and personalized possibilities for automobility, without the burden incurred by the private car (capital and operating costs, parking, maintenance, etc.). Thanks to these benefits, various cities have engaged in promoting and adopting carsharing (Shaheen & Cohen, 2007, 2012).

First carsharing systems, were mostly based on the internal combustion engine technology (ICEV). However, with the technological progress made in alternative-fuel engines and rising concerns about pollution and climate change, various carsharing operators opted for mixed fleets. In this context, battery-electric vehicles (BEVs or simply EVs) were gradually offered for rent in these systems. The introduction of EVs poses unprecedented challenges to carsharing operators and their clients. In comparison with ICEVs, EVs have a limited driving range and higher capital costs (Pavlenko, Slowik, & Lutsey, 2019). The charging time of EV batteries often takes several hours during which the EV is out of service. The efficiency of EVs is also sensitive to ambient temperature conditions. Low or high temperatures can drastically reduce the range of batteries and their lifetime (Yuksel & Michalek, 2015). From a client perspective, the use of EVs can, in some cases and for some users, be a source of range anxiety, that is *the fear of becoming stranded* (Tate, Harpster, & Savagian, 2008) due to battery depletion. On the other hand, EVs require less maintenance costs than ICEVs (Pavlenko et al., 2019), emit less noise and pollutants in the air and offer a new eco-friendly driving experience.

Given the opportunities and the challenges to introduce EVs in carsharing, it is critical to understand and to assess the opportunity of carsharing electrification. In this research, we evaluate the opportunity of introducing EVs in the carsharing system of Montreal, Canada and the impacts of shared EVs on the adoption and use of carsharing under different scenarios regarding range anxiety of clients and weather conditions.

2. METHODOLOGY

MATSim

MATSim is an open-source multi-agent transportation simulation framework (Horni, Nagel, & Axhausen, 2016). It has been under constant development by TU Berlin and ETH Zurich for more than 15 years. Currently, MATSim is used and supported by an growing transportation community and it is one of the most leading and used transportation agent based model. Electric carsharing (e-carsharing) is one of the various travel modes that can be simulated by MATSim. The simulation of e-carsharing requires the inclusion and the management, in space and time, of shared EVs and dynamic rental requests. In Matsim, the carsharing extension allows the simulation of this system as a travel mode that necessitates dynamic management of the interaction between travel demand (incoming requests) and supply (availability of cars in space and time). EVs simulation as part of carsharing vehicle fleet comes with two main challenges : (1) the use of electric cars that require the management of their charging and discharging in relation with network conditions (congestion) and charging infrastructure (availability); (2) the competition between carsharing and conventional travel modes. In this context, the agent-based approach of MATSim is appropriate as it allows to track, in space and time, individual agents and vehicles, the availability of shared cars and the state of charge (SOC) of EVs. The possibility to simulate the competition of carsharing with other travel modes (endogenous travel demand) is also another noteworthy contribution of this framework.

Electric carsharing

The use of shared cars requires the possession of a carsharing membership. Among the vehicles used in carsharing service, there are station-based shared vehicles. These vehicles can be of two types: ICEV or EV. The model assume that both types have equal chances be rented, everything else being equal. When an agent chooses to rent an EV, it requests the one with most charged battery. Moreover, prior to the reservation of an EV, agents check the available SOC of the battery and compare it with their projected travel needs. The EV is rented only if its SOC covers the a priori required energy.

We assume that carsharing operates on the basis of a membership business plan where members pay a monthly fee regardless of their use of the service to benefit from advantageous rental fees. The membership business plan is commonly adopted by the carsharing industry (Brook, 2004). For the a carsharing member, the marginal cost of a carsharing trip is often proportional to rental time or to trip distance or both.

Shared EVs are subject to discharging and recharging constraints. EVs incur discharging while driving due to: (1) energy consumption of the engine and (2) auxiliary energy consumption by on-board gadgets (air heating and cooling, lights, etc.) (Waraich & Bischoff, 2016; Bartlomiej, Slaski, & Maciejewski, 2016). The driving energy depends primarily on the characteristics of the vehicle: its mass, aerodynamic shape, and engine efficiency. Auxiliary energy consumption depends mainly on temperature. With low or high temperatures, the range of the EV battery can significantly be reduced, especially due to air heating and cooling. In these situations, the driving range of shared EVs decreases while their number of charging cycles and out-of-service duration increase.

In this research, we assume that shared EVs are only allowed to be charged at carsharing stations. After each rental, clients are required to plug in the rented EV to the charging station. Each parking lot is equipped with a second generation charging station delivering a power of 7.5 kW (level 2 chargers). We also assume that shared EVs are not open for reservation when their battery state of charge (SOC) is below a minimum SOC threshold of 5%. This minimum threshold is required for routine operations, like relocation or maintenance, and to reduce the risk of empty battery.

Range Anxiety

Range anxiety is defined here as the fear and the stress of being stranded due to a completely depleted EV battery (Tate et al., 2008; Franke, Neumann, Bühler, Cocron, & Krems, 2011). From a modelling perspective, this negative affect is translated into two parameters:

- Preference for a safety or a comfort buffer when renting a car, i.e. more energy than requiered (Franke et al., 2011; Kurani, Turrentine, & Sperling, 1994; Franke & Krems, 2013)
- Experience of stress when the SOC is very low (Adenaw & Lienkamp, 2021)

For a car trip that requires a minimum state of charge of the battery SOC_{min}, research suggests that car drivers have a preference battery range SOC_{pref} that is greater than the minimum range. This is also true for ICEVs, but the safety buffer is even more significant for EVs as recharging requires time and special infrastructure. Research also suggests that preference for a safety buffer is especially dominant among inexperienced EV users (Rauh, Franke, & Krems, 2014; Franke et al., 2011). The comfort or safety buffer is the relative energy surplus ($\frac{SOC_{pref}}{SOC_{min}} - 1$) needed by EV users to avoid stressful situations or adaptation strategies of their mobility or activity plans. We assume that carsharing members have a constant comfort buffer of 25% as shown by (Franke et al., 2011) in the more general case of EV drivers. The second implication of range anxiety relates to the negative affect drivers can experience when the SOC drops below a reference threshold SOC_{stress} while driving. This negative experience is translated into a penalty of the agent's utility. The duration spent driving the shared EV with a SOC less than SOC_{stress} is assumed more stressful than driving under normal conditions. Consequently, this duration has a higher opportunity cost of time than the rest of driving time.

Scenarios

Montreal has a continental weather with very cold winters. The minimum daily average temperature of January is $-10°$C and the average minimum is $-14°$C, whereas the ideal temperature range of EV batteries is 15°C to 25°C (CAA, 2021). Montreal winter conditions can be challenging to the operation of EVs as batteries are sensitive towards ambient temperatures and their driving range can drastically be reduced, especially when air heating is activated (Iora & Tribioli, 2019). The impact of this reduction can magnified by range anxiety. In this context, our case study evaluates the joint impact of range anxiety and ambient temperature on the adoption and use of carsharing in general and shared EVs in particular. To show the impact of the temperature and the range anxiety generated by the fear of running out of battery, we propose to run 4 simulations based on the scenarios described in table 1. We assume that the values for the temperature are close to the average minimum temperature in Montreal ($-15°C$ is the temperature used in scenarios 1 and 2) and one ideal temperature for EV batteries ($+15°C$ is the temperature used in scenarios 3 and 4). For range anxiety, we assume a range anxiety below 30% of battery capacity (with vehicles having 30kWh battery capacity).

Table 1: Electric carsharing scenarios

	No Range Anxiety	Range Anxiety 30%
Temperature $-15°C$	Scenario 1	Scenario 2
Temperature $+15°C$	Scenario 3	Scenario 4

These parameters are included in the synthetic population of Montreal. This population is adapted from (Manout & Ciari, 2021).

3. RESULTS AND DISCUSSION

Simulation results of the above scenarios are presented in three figures 1, 2 and 3.

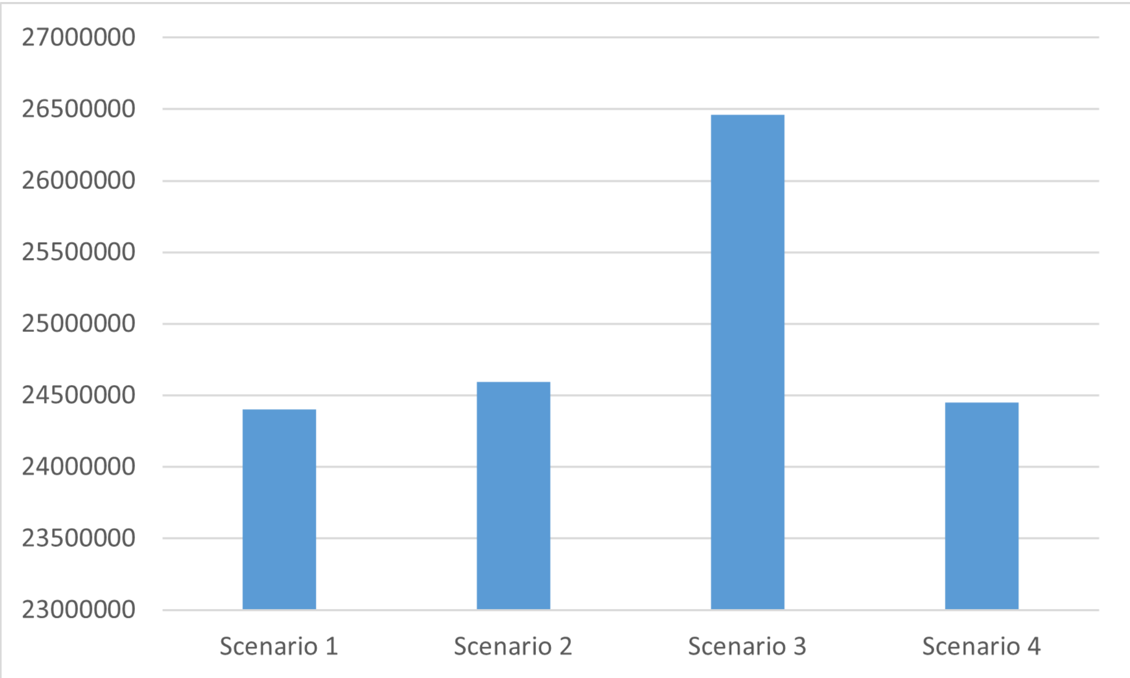

Figure 1: Trip distance of shared cars in the four scenarios

The distances of the trips performed in the 4 scenarios are presented in Figure 1. We note that the distances made in scenario 3 where the temperature is average (+15 degrees) and the range anxiety is not used. These conditions push users to use EVs a lot more since the battery does not discharge as quickly as when the temperature is low. Also the non-existence of range anxiety encourages users to choose EVs since they do not take into consideration the impact of the level of the battery available to perform the desired trip. Conversely, the number of locations of Evs in the other three scenarios, having low temperature with two levels of range anxiety and the scenario having a medium temperature with 30% in range anxiety, is less important. This can be explained by the low temperature affecting the autonomy of EVs and by the presence of range anxiety that pushes users to take into consideration the capacity of the battery level available to perform the trip without having to recharge the battery during the trip. Finally, the distances traveled during the scenarios with an average temperature (with rnage anxiety at 30% and without range anxiety) are

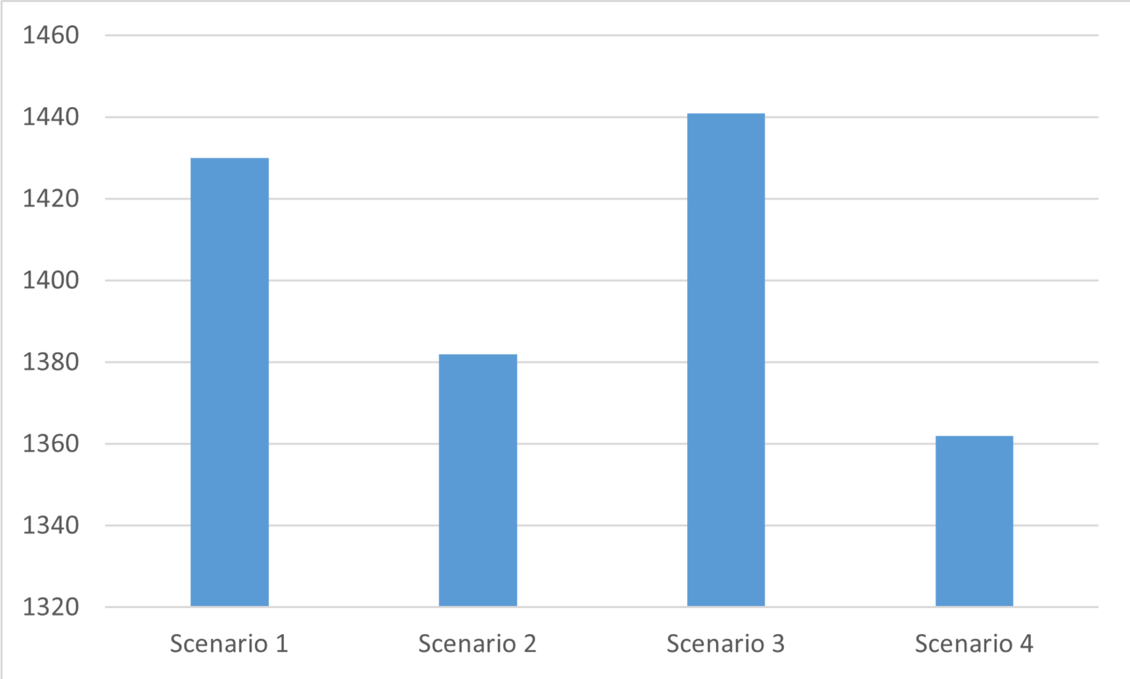

Figure 2: Number of trips of shared cars in the four scenarios

greater than those traveled during rental in low temperature. This result shows that the temperature impacts the distances for which Evs are chosen to perform various trips.

In the same way as distances, duration of EVs rentals, presented in Figure 3 where we see that in the scenario 3 having a temperature +15 and without using range anxiety, are greater compared to rental duration in the other scenarios.

As for the number of journeys made per scenario, presented in Figure 2, the number of trips is greater when there is no range anxiety, regardless of the temperature (scenarios 1 and 3 compared to scenarios 2 and 4). These results show that users take into consideration the ability of the Ev battery to perform the trip without needing to recharge it.

4. CONCLUSION

On the one hand, the results presented above show that there is an impact of temperature on the number of trips performed using EVs. On the other hand, these results show the impact of temperature combined with range anxiety on duration and distances of rentals performed with EVs. MATSim, used to simulate the use of carsharing, considers the activities carried out during a weekday to perform simulations. These findings can help carsharing operators estimate the impact of temperature and the range anxiety on the choice of vehicles (EVs or ICEVs) in carsharing stations. Also, these results allow the carsharing operator to predict and plan the use of the EVs in its fleet depending on the temperature and the apprehension of the drivers regarding the battery capacity.

Thus, the methodology proposed here can be used by operators to design the efficient strategies to introduce EVs in carsharing systems. In the short term, the integration of EVs into the carsharing fleet will be carried out by taking into consideration the information related to temperature of the town where it is located and the number of vehicles to be used according to the temperatures and users' perception of the level of the battery needed (range anxiety) to complete the trip, on one hand. In long term planning, on the other hand, these results would allow operators to under-

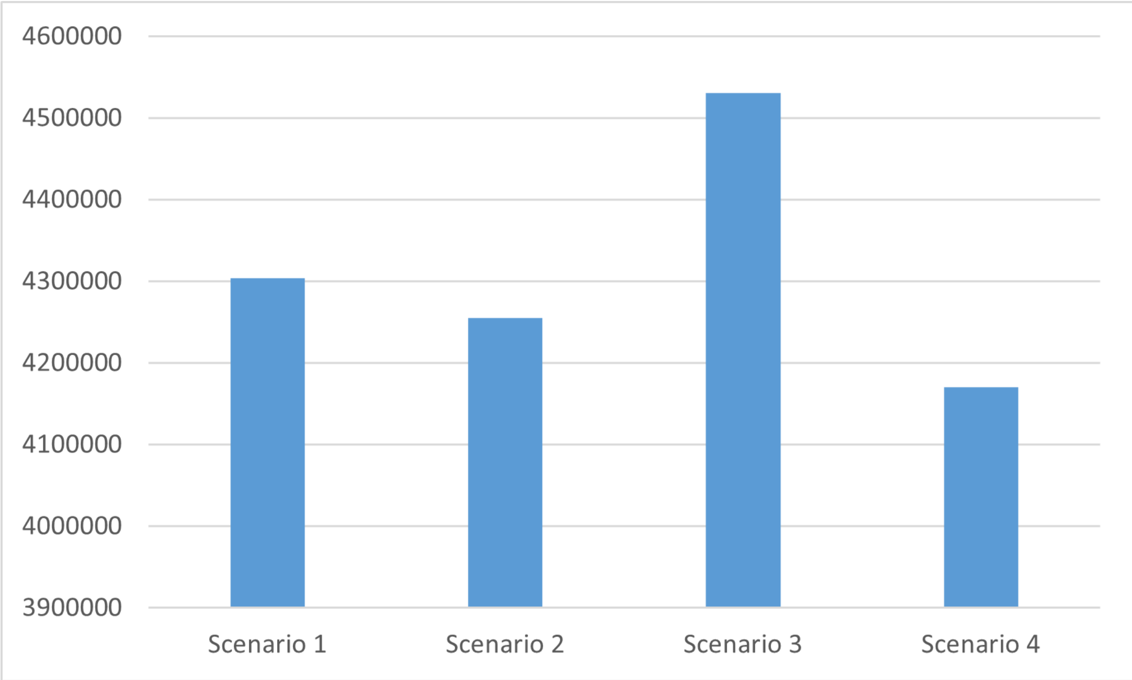

Figure 3: Rental duration of shared cars in the four scenarios

stand how battery technology evolution impacts how quick they can move from ICEVs and EVs. Eventually, from a certain point on (i.e. a certain battery range) they could use ICEV and EV interchangeably. The results we will present are specific to the case of Montreal since they are related to the way carsharing is used in the city and the type of trips members are using carsharing for. However, even if results themselves are not necessarily transferable to other cities, the methodology is applicable in other contexts.

However, Our future work will focus on the limitations resulting from the assumptions that we have put in place to perform our simulations. Indeed, we had to choose a zero cost for carsharing in order to notice the use of this mode of transport among the existing modes in the simulations. The future work that must be done to have a real cost affected to carsharing is to calibrate the mode. Another limitation that could be noted is related to the distribution of carsharing stations and vehicles in the geographical region studied. We placed carsharing stations and the vehicle fleet proportionally to departures using cars based on Origin-Destination matrix. Next step will be to reproduce the existing distribution of carsharing station and their vehicles in the city of Montreal in order to have a more realistic situation regarding the usage of carsharing service. As for the normal distribution that we used to assign the level of batteries to EVs used in carsharing fleet, it induces an impact on the choice of EVs in carsharing stations. This distribution could influence the time and duration of usage of EVs in the case where one of these vehicles are chosen in the station.

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