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Agent-based simulation of electric taxicab fleets

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Abstract

Battery operated electric vehicles offer the opportunity to manage zero-emission car traffic at low operational costs. Due to their current range constraints, electric vehicle operations are mainly attractive for inner-city transport, with taxicabs being one possible field of application. In this paper, a battery operated electric taxicab fleet is simulated in a small city scenario using the agent-based transport simulation MATSim. The simulation results indicate no negative impact on the level of service provided by taxis in everyday operations when using electric cars. However, facing increased demand, conventionally operated taxi fleets may provide a better service.
The simulation also demonstrates that every taxi rank only needs to be equipped with a small number of charging outlets. Under these circumstances, it may be useful from the passengers' perspective to dispatch those taxis with the highest battery charge level first.

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Keywords: battery electric vehicles; e-mobility; electric taxis; taxi dispatch; multi-agent simulation; MATSim

1. Introduction

Battery electric vehicles (BEV) are on the top list of currently discussed topics concerning private transport. Research in BEVs is driven both privately and by the public with huge investments. At the same time, however, the general public looks rather skeptical at electric cars. Especially, the short range is a restraint that prevents people from switching to BEVs.

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Nomenclature

BEV	battery electric vehicle
SOC	state of charge

Therefore, it seems a plausible idea to evaluate BEV in those fields of usage, where the vehicle range is of minor importance. Inner city taxi services are one of them. Each single task is usually short so that the vehicle range is unproblematic to fulfil single requests. On the other hand, a taxi's overall daily mileage is comparably high, so that they will have to be re-charged at some time of the day. Moreover, the use of BEV as taxis has the potential to reduce inner city greenhouse gas emissions, especially since conventional taxis have relatively high share in these emissions. At the same time, taxis may be seen as a lighthouse project for BEV usage in general: Taxi passengers gain the opportunity to try out an electric car on the passenger seat and some may get convinced to buy one at a later stage if they are satisfied with the quality of the electric taxi service.

However, to provide a high quality service, there are several issues that have to be addressed prior to introduction of electric taxis. Among them is the question where and when taxi drivers should recharge their vehicles' batteries and how many chargers are needed to warrant a smooth service. Another problem might be a sudden peak in taxi demand and the resulting level of taxi service. Also it seems worth considering to dispatch taxis out of taxi ranks by the state of charge (SOC) of their battery rather than sending out that vehicle which has been waiting the longest.

These and other questions will be dealt with in this paper using an agent-based transport simulation. This allows a detailed evaluation both on the level of taxi passengers and drivers. Therefore the exact consequences of BEV usage on individuals and the system as a whole may be made.

2. Related work

Although the use of electric vehicles for taxi services seems worth considering, especially when compared to other possible uses of electric vehicles, they have not been introduced on a large scale yet. There are electric taxis in several cities around the world, but except for the 500-strong fleet in Shenzhen (still less than 5% of 13000 taxicabs operating there), those fleets consist of up to 50 vehicles. Regardless of the size of a fleet, the biggest issues raised by taxi drivers and taxi operators are the limited charging infrastructure (resulting in queues at chargers), inadequate distribution of chargers (e.g. outside the city centre, which increases the non-revenue mileage) and the speed of charging (making waiting at taxi ranks longer and imposes longer intervals between consecutive rides) (Shengyang et al., 2013).

The research on electric taxis is relatively new and hence the literature limited. Wang and Cheu (2013) have proposed an algorithm for scheduling electric taxis for advance reservations in Central Business District in Singapore using a set of 1000 randomly generated trips. Lu et al. (2012) have implemented several different dispatching strategies for a fleet of 2000 taxis in Taipei. Jung and Jayakrishnan (2012) have simulated 600 electric taxis in Seoul. Only the second study deals with taxi dispatching on a relatively large scale (though still only about 6% of Taipei's fleet). Neither of these studies combined simulation of taxis with traffic simulation, which is vital for accurate calculation of the state of charge. Therefore, the authors consider the problem of electrifying a taxi fleet still open.

3. Methodology

3.1. General concept

In this paper a battery operated electric taxicab fleet is simulated in the Polish city of Mielec using MATSim (Multi-Agent Transport Simulation), the open-source agent-based transport simulation. This simulation platform allows carrying out activity-based microscopic traffic simulation on a large scale, where each agent has its own, modifiable behaviour, which is simulated over the day. This allows precise data analyses about individuals and vehicles. Over several iterations, agents attempt to maximise their personal utility by modifying their travel behaviour. The results approximate a Nash equilibrium (Grether, 2014).

The microscopic level of detail is vital both on the taxi demand and supply sides for:

- Modelling the influence of the traffic flow on the movement and energy consumption of taxicabs. This includes on-line monitoring of vehicles, and particularly, estimation of energy consumption while vehicles are moving, and updating their state of charge.
- Dynamic dispatching of taxicabs to new or awaiting requests, often taking into account several mutually-conflicting objectives, such as minimizing passengers' waiting times or drivers' pickup trip (non-revenue) times; this should also consider predicting the energy consumption for each request-to-taxicab assignment thus avoiding running undercharged or sending a partially charged vehicle to distant places with limited unallocated charging capacities.
- Dynamic scheduling of battery re-charging, balancing the infrastructure utilisation over time and space, while at the same time, reducing the non-revenue mileage by sending drivers to not-distant chargers and keeping them possibly close to the potential customers.

Based on the detailed outcomes of simulations, one may decide upon:

- size and composition (e.g. the electric-to-conventional ratio) of the fleet, including different types of electric vehicles and/or batteries
- size, type (e.g. 22kW or 50kW chargers) and distribution of the charging infrastructure
- dynamic taxi dispatching/scheduling algorithm
- pricing policy

Such a simulation platform may be used for finding not only the optimal final setup of the overall system, but also the best transition path since the electrification of a fleet is a complex and long-term process.

3.2. Implementation issues

The taxi service simulation is based on the DVRP extension to MATSim (Maciejewski and Nagel, 2013). To be able to run electric taxicabs in this study, taxi ranks equipped with chargers have been included into the simulation. During the simulation, each individual from the city population (represented by an agent that has a defined daily plan) may decide to travel by taxi and thus submit a request. On the supply side, there is a population of taxi drivers that are represented by special agents that do not have pre-calculated daily plans (the default approach in MATSim), but instead they dynamically adapt their plans to the current demand. The coordination of taxi drivers is the responsibility of the dispatcher, whose operation logic is modelled by means of an dynamic optimization algorithm. The algorithm used in this study reacts to the following events:

- Arrival of a new request – the nearest vehicle from all idle ones that have batteries charged above threshold T1 is dispatched to serve this request; if no vehicle is available, the request is queued.
- Completion of a request – the vehicle that served this request is dispatched to the first request in the queue provided that its state of charge is above threshold T_2; if the queue is empty or the vehicle is undercharged then it is dispatched to the nearest taxi rank.
- State of charge reaches threshold T_1 (when recharging) – the vehicle is sent to the first request in the queue (if there is one); otherwise the vehicle may continue recharging up to T_3.

As a taxicab traverses the network, its energy consumption is tracked on a link-to-link basis, using the average speed on the link and link length as indicators, and based on that, its state of charge updated (Waraich et al., 2009) When a vehicle arrives at a charging station, the charging procedure starts only if there is at least one unoccupied charger; otherwise the vehicle is queued. The charging stops either after the state of charge reaches T3 or if the taxi is dispatched to serve a new request.

4. Simulation scenarios

For the simulation experiments, a synthetic model of the Polish city of Mielec is used. The demand is spread over two peaks (around 9:00 and 17:00) with a smaller amount of off-peak trips. Overall, 42’000 trips are made over the day. Initially, 5% of the inner-city traffic, or 1528 trips, are made by taxi. These are served by 50 taxis that are distributed over the city and assigned to one of five different ranks. On average, this equals 126 revenue km per taxi, which, for instance, roughly amounts to a taxi’s daily average occupation in Germany. The taxis have home ranks where they return to after each trip if no immediate follow-up call has been assigned to them. This behaviour is typical for small cities where only a small percentage of taxi trips originate from taxis roaming through the streets. Both the base case, where conventional engines power the fleet, as well as the case with the fleet consisting wholly of electric cars, are simulated and compared to each other.

For experiments in this paper, the Nissan Leaf is used as a reference vehicle. This is mainly for the fact, that the Leaf has been available on the market since 2010 and thus its driving dynamics and consumption values have been subject of intensive research (Faria et al., 2012). Also the Leaf is an ordinary compact class car of an appropriate size for everyday taxi operations. Furthermore, the Leaf has fast charging capabilities (50 kW chargers), which allows the battery to be charged up to 80 % of usable state of charge within 30 minutes. Since the operational capacity of the Leaf battery is 20 kWh, the following charge thresholds used by the dispatching algorithms (see Section 3.2) are taken into account:

- T_1 – 6 kWh (SOC corresponds to 30% of the operational capacity)
- T_2 – 4 kWh (20%)
- T_3 – 16 kWh (80%)

In the experiments, BEVs start their day with a fully-charged battery. When needed, they can be re-charged at ranks up to 80% (T3) of the usable battery capacity, which equals the SOC that can be achieved by fast-charging within 30 minutes. The experiments were divided into 4 series, and run with different configurations according to Table 1.

Table 1. Overview of the experiment configurations.

Name	Taxi demand [%]	Chargers per rank	Charging power [kW]	Dispatch strategy	Fleet types
STD	5	10	50	FIFO	Gas, BEV
INC	5 – 11	10	50	FIFO	Gas, BEV
CHRG	5	1	50	FIFO	BEV
DISP	5	1	22	FIFO, SOC	BEV

5. Results

5.1. Everyday operations (STD)

In everyday operations, BEV usage does not seem to have an effect on the quality of taxi service in terms of waiting time for a vehicle (on average 7:12 min per request). Also the amount of daily overall mileage remains on a constant level (270 km on average). This means that taxi drivers have enough time to re-charge batteries during ordinary breaks at taxi ranks. As depicted in Fig. 1, all vehicles can recover battery capacity during the off-peak periods.

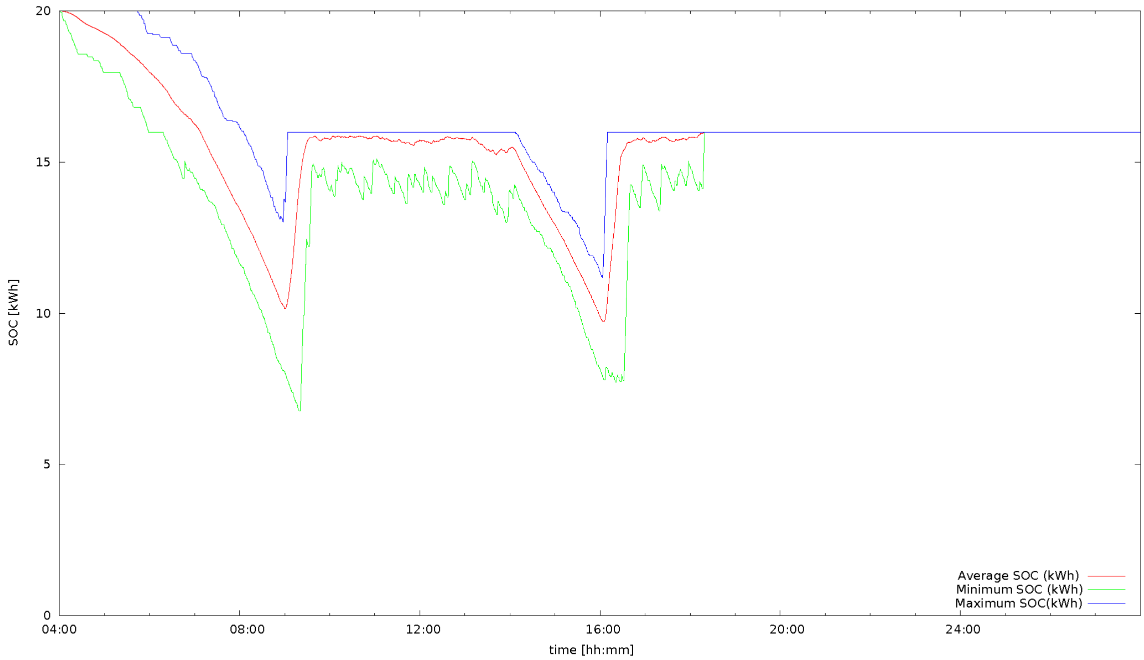

Fig. 1. State of charge of the electric taxi fleet over the day; the lines depict the fleet-wide: maximum (blue), minimum (green) and average (red).

5.2. Increased taxi demand (INC)

Taxi demand has certain peaks during big events, bad weather or disruptions in public transit. For taxi drivers these days are of especial interest, and the fear of not being able to serve all customers is one of the biggest restraints against using a BEV.

Increasing demand in steps of one percentile up to seven per cent (Fig. 2) is still manageable both by a fuel-driven as well as a BEV fleet. A further increase will result in a much steeper increase of average waiting times for the BEV fleet.

5.3. Charging outlet supply (CHRG)

Cost-efficient BEV usage depends also on the amount of chargers needed for stable operations. For the aforementioned everyday scenario the amount of chargers was therefore reduced to five, two and finally one per taxi rank. The latter equals one charger per ten vehicles. If a taxi requires charging while the charger is occupied, it will queue until the charger becomes available. A reduction to five and two chargers has no influence on the simulation outcome neither from passengers' nor drivers' perspective, but reduces the amount of charging energy used at peak times, and thus the grid power needed, drastically (Fig. 3). Even with only one charger per rank the average waiting time for customers remains the same, though the taxis are dispatched slightly different to the requests than with 10 chargers per rank. This reduction results in a slightly different request-to-taxicab assignments, however, the average waiting time for taxis remains the same.

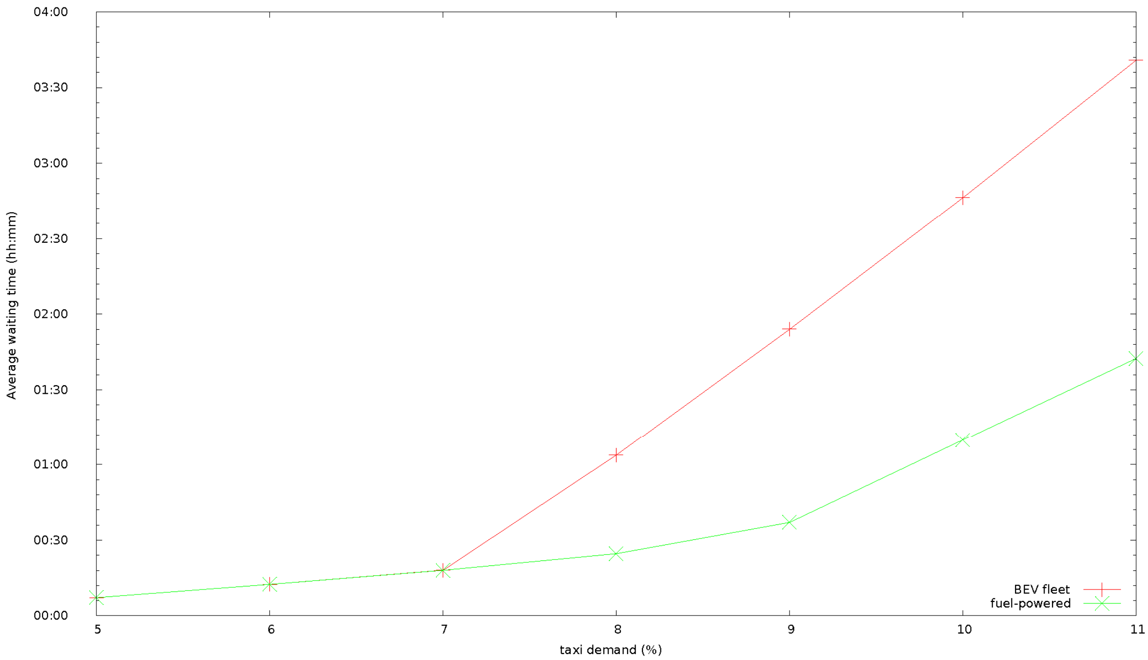

Fig. 2. Average waiting time for a taxi under increased overall taxi demand; the lines show the average waiting times for the fuel-powered (green) and BEV (red) fleets.

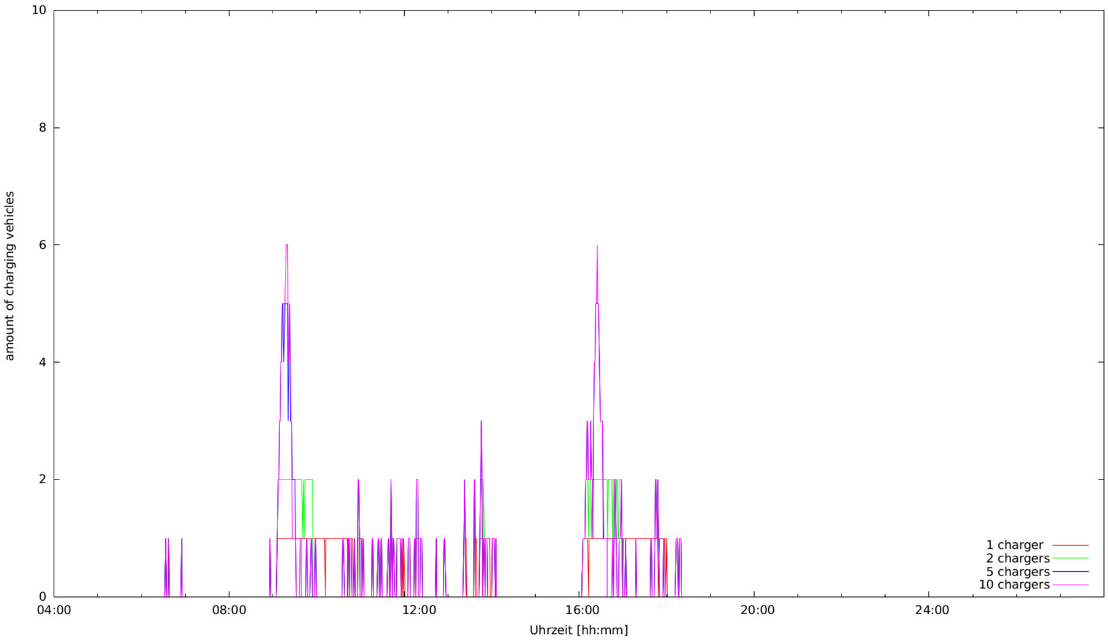

Fig. 3. Charger occupation at a selected taxi rank depending on the number of chargers available.

5.4. Modifications in taxi dispatch (DISP)

Usually taxis are dispatched from taxi ranks in order of arrival (first-in, first-out - FIFO). Dispatching them rather by highest SOC could possibly produce a more efficient-service. This could be especially relevant during winter time, when batteries cannot be charged at full power. It is therefore assumed, that only one 22 kWh charger per rank is available. In this case, the average waiting time would increase with the FIFO dispatch to 7:57 min. Dispatching vehicles by SOC decreases it to 7:24 min. At the same time, however, the overall average mileage per vehicle increases slightly from 272 to 273 km. Also, some vehicles receive significantly more requests than other vehicles from the same rank (Fig. 4), and thus the revenue from taxi trips is less even spread. There seems to be, however, no certain logic behind the pattern which driver is losing and which one gains from the modified dispatch.

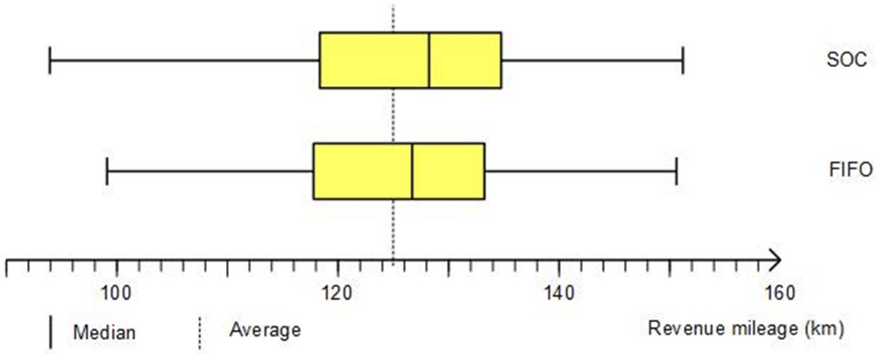

Fig. 4. Revenue mileage in dependence of dispatch algorithm. Dispatch by SOC moves increases the median, at the same time the absolute minimum decreases.

6. Conclusions

This paper shows that BEV may provide taxi operations in small cities at a high service level. In an everyday situation BEV usage is not likely to require significant changes in drivers' or customers' behaviours. Conventionally driven taxi fleets are however capable to serve sudden demand peaks better. Therefore, the further research will be focused on large-scale scenarios with a limited charging infrastructure and relatively high demand. Moreover, the influence of weather conditions on energy consumption will be taken into account in order to examine its effect on the performance of an electric taxi fleet.

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