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Lessons learned from electric cars in daily taxi operation in Gothenburg

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Summary

Shared mobility solutions consisted of electric bike pool, electric car pool, and electric taxi service was assumed to enable similar mobility flexibilities as owning a car. The concept was tested in Gothenburg for about a year in the local ELMOB project. This article focuses on the feasibility of the electric taxi as part of the shared mobility package. Both customers' and drivers' perspective were studied regarding changes in their behavior and fulfillment of their mobility needs. Data collected from the vehicles show vehicle performance, usage patterns and charging behavior of the drivers. The results imply that policy and regulations which favor electric taxis are crucial for enabling electric taxis at a larger scale.

Keywords: Electric vehicle, mobility as a service, user behavior, case study

1 Introduction

Personal transportation is one of the major causes of emission, noise and smog in cities [1]. Vehicles powered by clean energy such as electricity could potentially resolve these issues. Besides, to reduce the number of vehicles on the roads can also contribute. Public transport, car-sharing or bike-sharing services have the achieve that goal but they might not suite everybody. To secure both flexibility and a reduced number of vehicles, combined or shared mobility services come into the picture. Today, there is a growing trend of creating platforms for coordinated and shared mobility services with either bicycles [2] [3], cars [4] [5] [6] or taxis [7].

The two-year research and development project ELMOB (Electrified Mobility in Gothenburg) [8] has been conducted to, among others, investigate the possibilities enabled by a platform that gives users access to several different shared electric vehicles. It is assumed that a shared mobility service that includes electric bike (pedelecs) and electric car-sharing together with electric taxis can complement the travel modes walking, cycling and public transport to eventually create a seamless and sustainable mobility system. The ELMOB project had gone through many difficulties to place each mobility service in today's traffic and to create a smooth transition among them. This paper discusses the feasibility of using electric vehicle in taxis services with real data collected under ELMOB.

Electric taxis have been tested in several cities and in large numbers [9] [10]. Some trials have been reported failed due to battery performance and the need to frequently charge the vehicle [11]. An electric vehicle with long enough range could potentially avoid charging during the work time. Electric taxis with longer range, and thereby providing similar mileage as a fossil-fueled taxi based on drivers' habits today, were chosen to be tested in this case.

1.1 Aim

The aim of this paper is to study the driving forces and barriers of an electric taxi service operation, changes in user behavior and how well the user needs are served. This is described both in terms of driving a different type of vehicle as a driver and choosing to sit in one as a customer. The performance of the long-range electric vehicle is to be analyzed.

2 Method

Both quantitative and qualitative methods were applied in this study (Table 1). A trial with two electric taxis in commercial operation was carried out during twelve months starting from late 2015. The Tesla Model S 85D was chosen specifically for its cargo capacity and long electric range. One of the cars operated in Gothenburg, Sweden, and the other in Lerum, a satellite city which is about 20 kilometers east of Gothenburg. The vehicles were logged to evaluate how the use pattern changed over time. Data from the vehicles were collected using the program Visible Tesla [12] and plotted with Matlab. In addition, surveys and interviews were performed to depict the drivers' and customers' opinions regarding their experience with the electric taxi.

Table1: An overview of methods applied in the study.

	Type of data		Data source			
Methods for data collection	Qualitative	Quantitative	Drivers	Vehicle	Present customers	Potential customers
Semi-structured in-depth interviews	✓		✓			✓
Questionnaires		✓			✓	✓
Vehicle sensors		✓		✓		

2.1 Qualitative Analysis

The survey process includes an online questionnaire and telephone interviews. Before the vehicles started to run an initial online questionnaire was conducted with potential passengers that had not yet tried to sit in an electric taxi. The questionnaire captured the main trip purpose for an electric taxi and the motivation for users to choose an electric taxi over a fossil-fueled one with combustion engine. The potential customers were approached via newsletters, flyers, newspaper ads and the project homepage. A total of 80 people responded to and completed the questionnaire.

Participants of the questionnaire were given the option to leave their contact details if they were willing to join a follow up 30-minute telephone interview. Interviewees were informed about the date earlier and were able to prepare for the interview. Nine invitations were sent and five agreed to participate and completed the interview. The questions cover three themes: Today's travel needs, Opinions about shared electric vehicles and Current valuation and expectations of mobility services with shared electric vehicles. Interviewees were selected based on gender, age, major transport mode and their attitudes regarding shared mobility services.

To capture customers' perception about the ride and the willingness to pay for an electric taxi, tablets were installed in the taxi vehicles to get direct feedback from passengers. The tablets were locked in kiosk mode so that they could only be used for the survey. Passengers were also asked if they would choose an electric taxi the next time considering the overall experience. A total of 60 responses were received for analysis.

The taxi drivers were interviewed with open ended questions twice during the project period. The first interview focused on what types of additional services that could help bolster electric taxis. The second interview was about the experience and customer feedback they received during the time. Taxi drivers were also asked to describe changes in their usage behavior and working environment, and finally the barriers for electric taxi and how they could be avoided.

2.2 Quantitative Analysis

Vehicle data were collected from onboard sensors. Data were uploaded in real time and stored at a server. Data were collected at approximately 0,3 Hz during movement and approximately every fourth minute during charging. Each entry includes charge voltage, charge current, remaining estimated range, stage of charge, battery current flow, GPS-coordinates, vehicle direction, speed, cumulative distance driven, battery output power, time and date. Data within the interested period were extracted and sorted, visualized in MatLab and analyzed with statistical methods including tendency and occurrence.

3 Results

Results obtained from vehicle sensors, interviews with drivers and potential users of the mobility service, and questionnaires distributed online and in the taxis, were presented in this section. The results concern both the driver's and customer's experience and during the ride, and behavior and needs with electric taxis in the trial period.

3.1 Driver Experience

Driver's experience after one year of field operation with a Tesla Model S as a taxi is presented. It includes the barriers of adoption, changes in user behavior, and how the drivers' needs were meet concerning the taxis business.

3.1.1 Barriers and Driving Forces

Several pros and cons of using electric vehicles as taxis were discovered in the interviews with drivers. The cost to purchase a long-range electric car such as Tesla Model S was perceived as the most significant barrier to entry. The reduced operating costs of an electric taxi was on the other hand perceived as a driving force. Fast-charging was free during the project period but a fee should be paid today, which was also identified as a barrier to use electric cars from the taxi drivers. Eventually, less expensive slower charging such as semi-fast charger (up to 22 kW) should be evaluated against a longer charging time to create better economics for electric taxis. A better income possibility, enabled by less trips without passengers and longer working hours, is then critical to market penetration of electric vehicles in the taxi business. Incentives for both drivers and customers to take electric taxis were expressed crucial from the drivers. For example, prioritizing electric taxis in customer queues.

When it comes to usage, although the long-range feature of the vehicles should allow drivers to value slower charging possibilities, limiting charging events to an overnight charging. It failed to keep drivers away from chargers during the day. The drivers also believed that passengers would be willing to pay more for an electric taxi. However, this has not yet been tested.

3.1.2 Changes in User Behavior

The driving experience in an electric taxi was expressed satisfactory and attractive comparing with that in a conventional taxi; above all, drivers were proud of being an early adopter to eradicating fossil fuel from the transport sector. Drivers said that they were hired directly from enthusiastic customers more often. Behavior change observed from drivers was surprisingly little. For example, instead of visiting a gas station, drivers parked at a charging station when having their lunch. According to one driver, driving an electric taxi gave him a better self-esteem but the freedom to choose resting places is limited to charging possibilities.

Tesla Model S offers similar operational capacity in terms of trips with customers. Using an electric vehicle did not hinder their business with customers in the driver's eyes. Before the project started, the hypothesis was that an overnight charging would last for a day's driving and no opportunity charging during the day should be required. However, it turned out that drivers were inclined to gain more miles by doing opportunity charging, which enables longer rides with better pay afterwards, than receiving shorter trips for the time that is considered safe with their remaining battery without charging. In the interviews, the driver explained that he could make more money charging the vehicle (with trips he could receive afterwards) when he saw a fast charger than taking the trips that were not so well paid during the time of charging. Even so, the waiting time for charging was still not desirable for the drivers. None of the electric vehicles had experienced depleted battery during the twelve months. As a result, no emergency handling resulted from the lack of battery was performed.

3.1.3 Vehicle performance and driver's needs

A large enough battery that can survive a day's driving would be appreciated but not necessary according to the drivers. The range demand varies from day to day and there are time slots available for charging during their working hours. Drivers charged their vehicle when they have the possibility to compensate the range needed in taxi business. Besides, easy access to a charger when wanted is crucial to the drivers. To avoid queue time for charging, abundant semi-fast chargers (around 20 kW) would be more valued by the taxi drivers than few fast chargers (at least 50 kW).

During the project, both taxis drivers declined approximately five rides due to the lack of range. Between one to six times a month, drivers prioritized fast charging the vehicle to a trip regardless the remaining amount of battery. However, drivers still felt comfortable about their business because the range offered by free fast charging during the project period, and the possibility of driving more customers with full battery usually compensated the time they lost on charging.

3.2 Customer Experience

The online questionnaire received 80 completed responses. Most of the respondents have experience with electric vehicles but not electric taxis particularly. An additional 60 passengers gave their opinion on the ride before leaving the electric taxi on a separate questionnaire. The results below show customers' opinion on electric taxis offered as one of the alternatives in the shared mobility service package.

3.2.1 Barriers and Driving Forces

From the ELMOB project we found that, besides availability, price is an important factor that affects customers' decision in transport alternatives. Unlike the other modes of transport offered in the mobility service package where people generally can consider paying more for electric alternatives, people who have not previously tried an electric taxi would mostly like to pay a similar price (Fig. 1). Among those who answered the same question after using an electric taxi, the willingness to pay increased remarkably. After the ride, a total of 40% found it worth it to pay a higher price than the corresponding service with a fossil-fueled taxi, and this was 15% before the ride. The share of customers who would pay a lower price dropped from right above 10 % to 3 % after experiencing the ride.

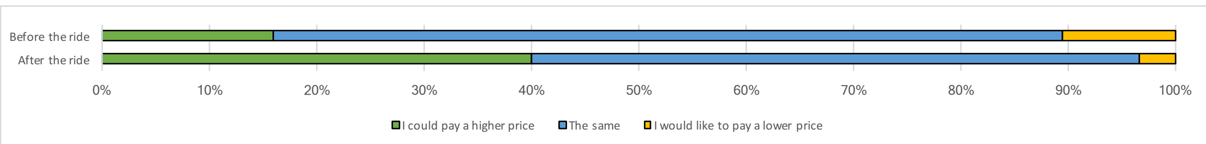

Figure1: Willingness to pay for an electric taxi compared to a fossil-fueled taxi.

3.2.2 Changes in User Behavior

Behavior change required from passengers sitting in an electric taxi is slight. The results show that customers do not explicitly express their preference to electric taxis when they were asked to compare one with a fossil-fueled taxi (Fig. 2).

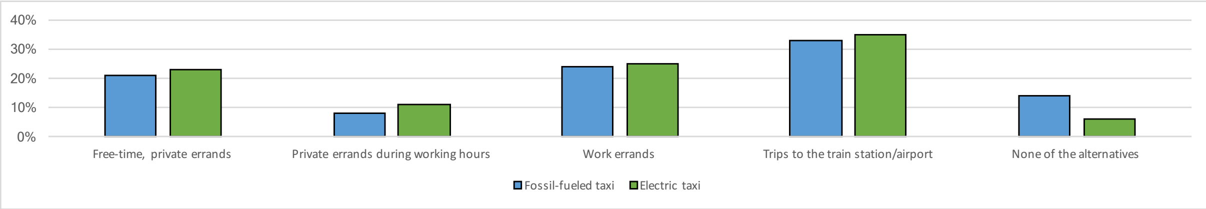

Figure2: Purpose of use for electric taxi and fossil-fueled taxi.

3.2.3 Fulfilment of Mobility Needs

To understand if electric taxis can satisfy customer needs at the same level as fossil-fueled taxis, respondents were asked if they would choose an electric taxi providing the price of a ride is the same. When asked directly if they would choose an electric taxi over a conventional one, 86% said yes, 13% said it did not matter and only 1% said no. The results show no difference regardless respondents' experience with electric taxis (Fig. 3).

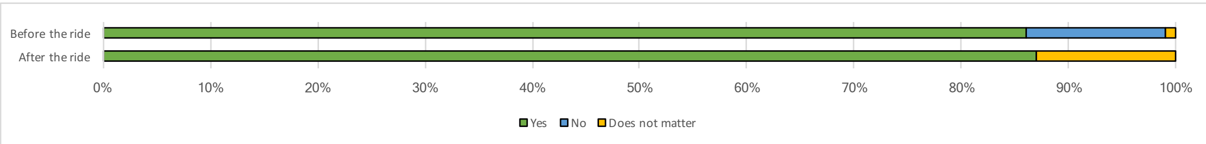

Figure3: The possibility of favoring an electric taxi the next time.

When it comes to the experience and comfort of rides, electric taxis were much more in favor. 85% of respondents were convinced that the ride provided by an electric taxi is much better than that with one with combustion engine. This result aligns with feedbacks from passengers retrieved from survey on Tesla taxis (Fig. 4). No one reported a negative experience after the ride.

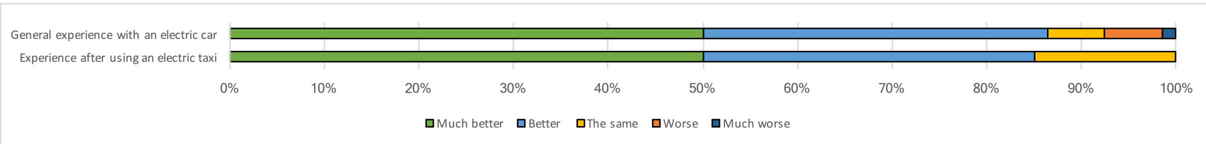

Figure4: Experience with an electric car and experience from riding an electric taxi compared with a fossil-fueled taxi.

3.3 Vehicle Data

The two vehicles together logged over 180 000 km in regular taxi service during the total project period. The total average annual mileage is comparable to a fossil-fueled taxi. The analysis of the vehicle data indicates some changes in driver's usage behavior and its effect on the vehicle performance. In addition, no data were uploaded while the vehicles were not in use, except for charging time.

3.3.1 Barriers and Driving Forces

The maximum daily state of charge (SOC) for each vehicle was plotted respectively in Fig. 2 and Fig. 3. One of them (Fig. 5 left) mainly used fast chargers (50 kW) and often charged to 100%. After one year, its battery capacity has decreased by 3%. In some days, the driver had to interrupt the charging event before the vehicle was fully charged for reasons. The other vehicle (Fig. 5 right) that mainly charger overnight with semi-fast chargers (up to 22kW) was primarily set to stop at 90% of battery but charged up to 100 % occasionally. During the first few months, it was set to charge to even lower than 90%. This vehicle had approximately retained its original estimated battery capacity after one year of using.

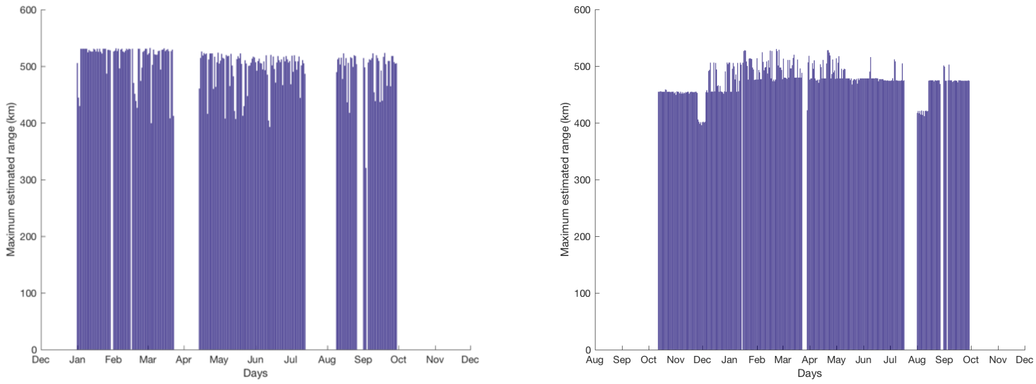

Figure5: Left: Maximum estimated range over time. Vehicle mainly used fast charging (50 kW) and was adjusted to use 100% of state of charge. Right: Maximum estimated range over time. Vehicle mainly used semi-fast charging (22 kW) and was primarily adjusted to charge up to 90% state of charge but occasionally up to 100%.

3.3.2 Changes in User Behavior

The hypothesis we had was that the electric taxis would have sufficient range to last an entire day on one overnight charge. However, the actual amount of battery required per day varied with the amount and types of trips drivers received every day. The results show that four to nine charging events were performed during the day of each vehicle. The one that charged mostly at the fast chargers registered on average four charging events per day, and the other one using semi-fast chargers had about three per day (Fig. 6).

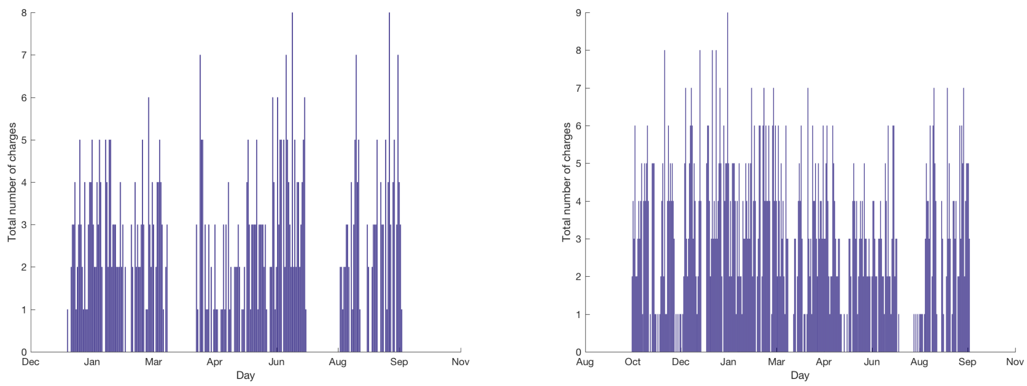

Figure6: Charging event count per day. Left: vehicle mostly using fast chargers. Right: vehicle mostly using semi-fast chargers.

The vehicles were charging at different places in the metropolitan Gothenburg as illustrated in Fig. 7. Fast chargers were usually used for daytime charging. During the project, there were up to 10 fast chargers available in these areas. However, the reliability of the chargers was not very high. Near the end of the project most of the fast chargers that are shown in Fig. 7 were either replaced or removed. Nine new fast chargers have become available in the area since then.

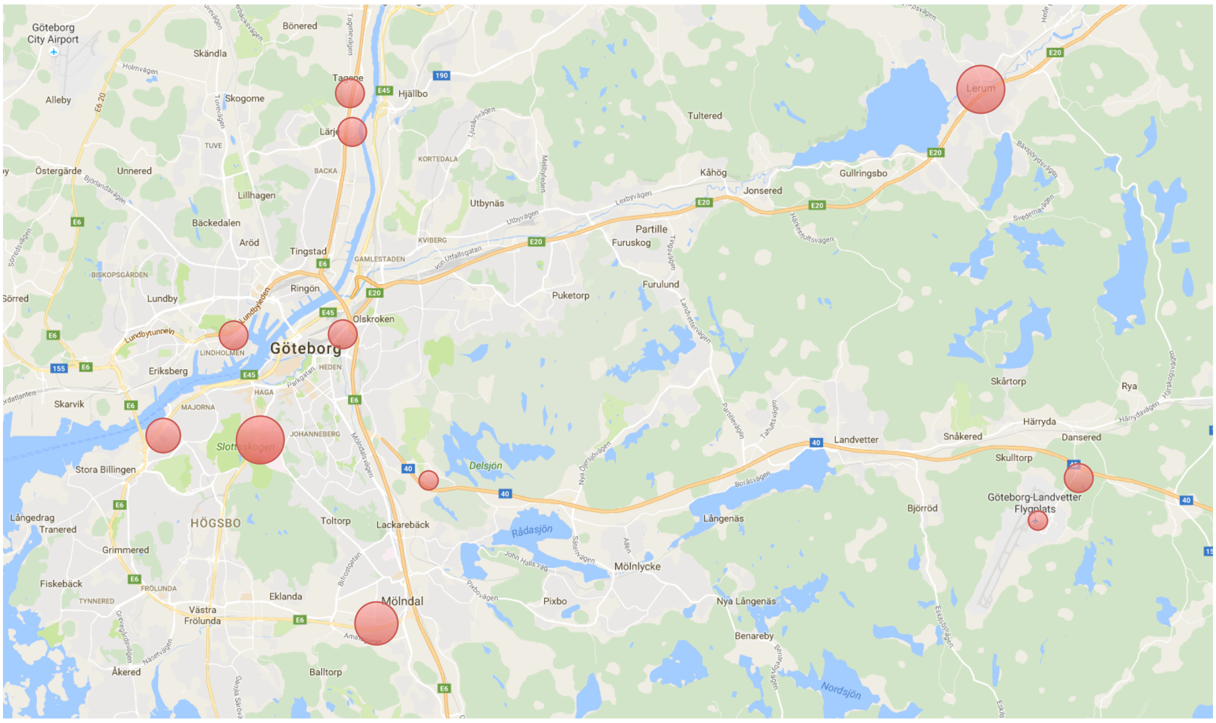

Figure7: Location of frequently used chargers in metropolitan Gothenburg. The size of the circle correlates with the frequency of use of a charger (i.e. the bigger the circle is, the more often it is used).

3.3.3 Battery Status

The average amount of energy transmitted to the vehicles during the period was also recorded and plotted in Figure 8 below (kWh per hour). Although Fig. 8 may not represent every day's charging event, they still show that the charging events are generally spread out during the 24 hours with peaks during lunch time and evening. According to the diagrams, vehicles were seldom charging between five and six in the morning.

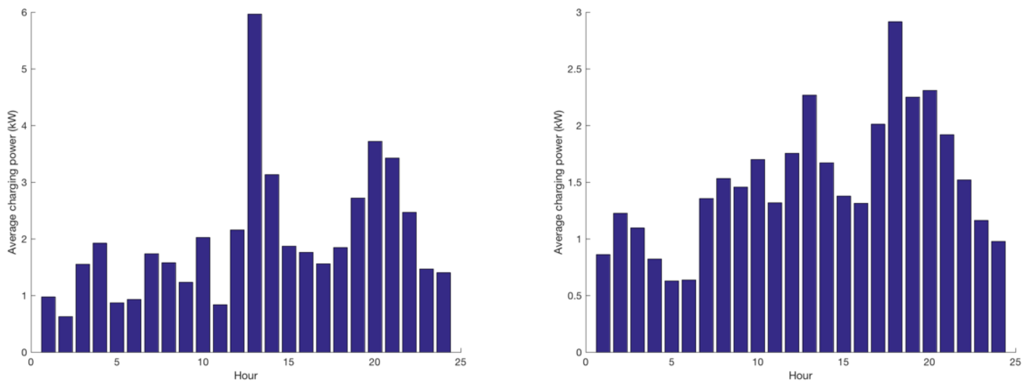

Figure8: Average kWh charged per hour in the vehicle during the project. The taxi mostly charged with fast chargers is presented to the left and the taxi mostly semi-fast charging is presented to the right.

During the recorded period, both vehicles drove at more than 80% SOC most of the time on an average day (Fig. 9). Only a small part of the time per day was spent with SOC lower than 60 %, which corresponds to more than 200 km available range.

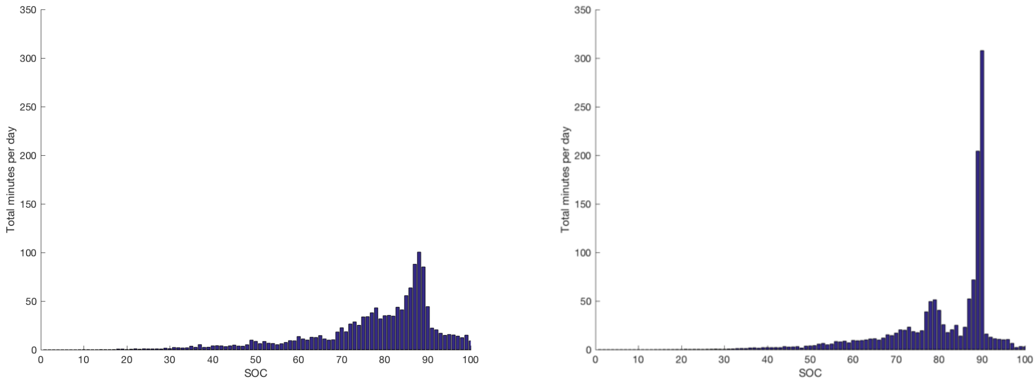

Figure9: Time span at respective SOC percent. Left: the vehicle mostly using fast chargers. Right: the vehicle mostly using semi-fast charger and charged overnight.

Different charging patterns were observed from the vehicle data. Unlike the electric taxi which usually fast charged, the one using the semi-fast charger parked and charged overnight. As a result, the battery level stayed at 90 % at a very long period of time. The other car had to drive to the final destination to rest after fast charging was completed.

Each vehicle had visited the workshop seven time in the project for various purposes, including receiving regular vehicle service. The drivers claimed that one workshop visit for Tesla Model S took about two or three hours, which was considered short compared to a new fossil-fueled car in taxi operation.

4 Discussion

The cost of a long-range electric car is still significantly higher than the equivalent vehicle with an internal combustion engine, which creates a major entry barrier. The operating cost saved on fuel per kilometer is not sufficient to cover the extra expense from vehicle purchase. To cover the difference, the vehicle needs to reach a higher utilization rate and be allowed to be in operation for a longer time. Driving forces to adopt electric taxis therefore need to come from the external, meaning the support from the government or the industry. For example, policy or regulations in favor of electric taxis could strengthen their position on the market. The utilization rate can for instance be increased by prioritizing electric taxis in the customer queue by any means. For example, prioritizing electric taxis at the coordinator [13-15], or allowing drivers transferring their time for charging the vehicle to customer queue time. These features could potentially be managed by innovative ICT service solutions, for example, a smart queue system that helps electric taxi drivers to keep their position while charging. However, when it comes to longer service lifetime, the permission to use older models of electric vehicle is something that may need to be approved by the taxi company and or certain points of interest such as airports.

The 85 kWh batteries equipped on Tesla Model S were deemed sufficient for daily taxi operation and therefore did not pose any barrier to the drivers. However, there were times that drivers had to decline longer rides and prioritize fast charging to full. The interesting thing was that batteries rarely dropped below 60 % SOC because drivers charged the vehicle as often as they could. The frequent charging, on the other hand, imposes a change in drivers' behavior where they feel limited to rest only near a certain number of chargers. As the number of electric vehicles grows, the time spent on searching for an available charger will increase. This implies that more chargers would be in demand to support the deployment of electric taxis. For both vehicles, the batteries showed very little sign of depletion. Longitudinal studies are needed to determine if the batteries can last the entire service lifetime of the taxi, especially when it extends.

From the results, customers generally valued the riding experience in an electric taxi more than a similar ride in a fossil-fueled one. The reason behind this could be the concerns over electric vehicles are commonly reported as range anxiety and long charging time, which are not of the customer's concern. Yet, very little difference between electric taxis and other transport modes was observed from potential customers based on specific travel purposes. electric taxis and other types of transport mode based on specific trip purposes. This suggests that there is no specific trip purpose that would give electric taxi an advantage over a fossil-fueled one. This could be explained by that electric taxis do not offer much more extras beside satisfying mobility needs of customers' and fulfilling the goal of transportation. The positive riding experience is appreciated but does not seem to weigh enough to influence customers' decision of transport mode in this case.

When it comes to taxi fares, people were willing to pay the same price as what they paid for a fossil-fueled taxi. This is especially true for the people who do not have experience with electric taxis. The lack of active user experience, meaning that user does not have control over the vehicle and therefore cannot fully experience the interaction between machine and human, hinder passengers to see the extra value they are paying for. However, the willingness to pay did appear to be higher from the results obtained from users who just had a ride in an electric taxi. One explanation is the acquiescence bias, meaning that respondents are likely to be more agreeable resulting from, for example, the desire to be polite [16] [17]. Another way to look at this is since people who have tried the electric taxi were generally satisfied and would choose one the next time if possible, they might also be ready to pay a higher fair. However, the reasons why people value the electric taxi need further investigation.

In ELMOB, the ambition was to create a shared mobility service package that includes different transport alternatives, which electric taxis were one of them. In the end the project failed to offer shared mobility as a package; instead, all the mobility modes were run separately. The electric taxi operation with two Tesla Model S functioned well and worked independently of the electric carpool or electric bike pool. There was no evidence that could argue that it is beneficial to offer electric taxis service in the shared mobility package with these two other modes. Comparing to them, electric taxis demand less maneuver and offer less control from the customer's side. In a way, it is easy for the customer to accept this innovation because it demands little change from them. The real challenge here is to keep the electric taxis attractive among the others so the drivers are motivated to move away from fossil fuel. Policy and regulations, infrastructure and innovative ICT solutions are then important to support the electric taxis deployment at a bigger scale. Electric taxis came from a test object in a R&D project to steady operation that runs on its own today. The operation is deemed applicable under similar conditions in other environment, e.g. cities that have similar population, mobility pattern and demands.

5 Conclusion

Long-range electric vehicles were proved to be feasible for taxi operation in specific contexts. Both drivers and customers were satisfied with what the vehicle offered but some barriers still exist to obstruct the electric taxis operation to expend at larger scale. Results from the study is applicable in cities with similar characteristics.

From the driver's side, the need to access charging infrastructure was strongly mentioned. Drivers intended to perform opportunity charging during their rest hours and prioritize fast charging over trips with lower income most of the time. Resting place limited by the location of chargers and a foreseeable queue to the fast chargers in the near future appear to be the common concerns of the drivers. ICT solutions that help to prioritize electric taxis with customers in any means are in demand to allow smoother operation and make them competitive among their peers.

From the taxi customer's perspective, no significant advantage brought by electric vehicle was found regardless the purpose of trips. A similar, or in some cases, a higher fair was expected by the majority respondents in the study. However, a motivation which can potentially drive the customers to demand electric taxis was found lacking.

When it comes to the economics, the higher purchase cost of the long-range electric vehicle was an entry barrier that could yet solve by cheaper fuel. Intervention from the policy and regulations are expected to lower this barrier via, for example, prolonging the service life of electric taxis. More and more operators in Sweden has begun to allow zero-emission vehicles to be in service for more than three years. With the possibility to operate in a longer period with a lower depreciation rate, electric vehicles could be more attractive to the taxi drivers.

Acknowledgments

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