

## **Optimization of an all-electric connected taxi fleet**

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### **Summary**

The objective of this entrepreneurial project was to establish the optimal practices and mode of usage of a purely-electric taxi fleet in an urban environment subject to both very harsh winters and hot summer conditions. Operating such a fleet of electric passenger cars in a commercial 24/7 duty also brought the question of EV's battery life subject to frequent quick-charging events and the evaluation of its degradation.

After more than one year and a half in full revenue generating operation, and over 7 million kilometers, we will present here our observations and conclusions about using EVs in harsh weather. This paper will present the results of the case study we introduced at EVS29 [1]. After more than 30,000km driven on dynamometer, and 18 months of daily battery testing, we present some interesting observations about battery degradation. We also share our experience about EV choices and charging equipment for such a large fleet, and we will expose noteworthy challenges and key factors of such an endeavor.

*Keywords: passenger car – fleet – deployment – case-study – mobility as a service*

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### **1 Introduction**

Started in fall 2015, Taxelco's fleet of fully electric taxis has now driven over 7 million kilometers to serve its customers in Montreal, Canada. Given the current mutations within the taxi industry of large cities caused by the introduction of new players offering taxi-like ride-sharing [2][3], Montreal's market demonstrated a need for a different approach to this type of urban transportation. Being oriented towards the promotion of transportation electrification, the Government of Quebec launched many initiatives and incentives to facilitate the growth of EV presence on its roads [4]. For Taxelco, this momentum provided the ideal opportunity to leverage the environmental benefits and comfort of EVs, providing an environmentally-friendly option to users.

After more than one year and a half in operation, and a growing fleet of 125 pure EVs, Taxelco's team has gained extensive hands-on experience of real-life operation of such a fleet. We will present here our observations and challenges concerning the use of EVs in such an intense duty and in harsh winter conditions. We will also share our direct experience in regards to charging strategies of such a large fleet as well as the deployment of private charging infrastructures. We aim to share some conclusions about the key factors in successfully operating a fleet of taxi EV in such an urban environment.

A subset of 20 vehicles from the initial fleet has also been subjected to lab testing, to evaluate the battery capacity degradation of the various models of EV used in our taxi application [1]. After more than 30,000km driven on the dynamometer in controlled conditions and 18 months of daily lab tests, we present here some interesting results that might help other projects planners to roughly gauge how their fleet might be affected if operated in a similar duty.

## **2 Overview of the project**

### **2.1 Role of IVI**

IVI is a research centre that supports businesses and organizations in the fields of applied research, development, assessment and implementation of innovative vehicle technologies. The goal of IVI services is to support its clients, mostly SMEs, in order to develop innovative and technologically advanced products. IVI's projects target transport electrification, vehicle energy efficiency and reduction of greenhouse gases (GHG) and polluting emissions.

IVI dedicated a team of four members to support Taxelco's EV taxi project: support engineer, test engineer, lab technician and overall project leader. The mandate they had, over the initial period of 18 months, was threefold:

- Complete a study about the degradation of the HV batteries in a such a rigorous taxi-fleet-duty
- Train Taxelco's technical and non-technical team members and numerous taxi drivers to the basics and best practices of operating an EV fleet
- Act as a dedicated local engineering support for the implementation of the EV fleet and their additional onboard systems, facilitate deployment of charging infrastructure from different partners and help team to ramp up daily operation strategies

### **2.2 Presentation of Taxelco**

The objective of Taxelco is to consolidate the interests of the taxi industry. With this approach, they want to ensure that the economic and social benefits derived from the use of fully electric vehicles, the creation of operational synergies and the efficient use of information technologies will remain in the hands of its constituents. This ambitious project helps position Montreal as a green, avant-garde city where public transportation is a means to responsible economic and social development, echoing the unique, cultural and innovative personality of its citizens.

This collaborative and supervised pilot project started in November 2015 with 60 electric vehicles driving around Montreal. From a technical standpoint, the objective of this project was to optimize the performance of EVs operating as taxis and in Montreal's rigorous weather conditions. This helped to shape the company's methods and models for its own fleet growth, but it also helped to shape Taxelco's commercial offer to other cities who are looking into launching their own EV taxi fleets. Today, 124 EV taxis drive around Montreal area each day and the objective is to reach a fleet of 350 vehicles in 2018.

### **2.3 Distinctive elements of Taxelco's project**

#### **2.3.1 Low downtime and company-owned cars**

While Montreal taxis and Uber cars are privately-owned and operated by independent workers, Taxelco's project differs from the local taxi scene because it is based on a company-owned fleet, operated by employee drivers. With work shifts covering 24h per day, Taxelco makes a really heavy duty usage of its EVs. On busy weeks, many of them achieve very low downtime, only stopping for synchronized events of cleaning and charging. Furthermore, as any fleet manager would concur: having non-owner drivers generally results in a situation where the cars endure a rougher handling in any aspect of their usage. Urban driving, charging equipment manipulation, onboard equipment handling, everything is done with a little less care when "it's just another company car".





### 2.3.2 EV in harsh weather conditions

The city of Montreal is subject, yearly, to substantial snowfalls, heavy usage of salt as road abrasive, as well as very low temperature episodes that can last more than one week. Sub-freezing temperatures can be expected for more than 4 months. With a very broad weather range going from humid summer days of over 34°C to deep freezing winter nights of close to -30°C, this has proven to be a very interesting proofing-ground for vehicles of any type. Adding heavy winter snowfalls to the mix makes it a challenging place to be an EV driver. These are considered harsh winter conditions even in Norway, a great leader in EV usage, where the climate is more temperate and snowfall less abundant [5]. Using electric vehicles in commercial taxi duty in these conditions has proven to be an interesting test and a clever way to prove the performance of EVs to the skeptics.

### 2.4 Current fleet of EVs

Taxelco's fleet of 124 taxis includes Kia Soul EV, Nissan LEAF and five variations of Tesla Model S and Model X. The following table combines, in a quick glance, a comparison of each model's pros and cons, as we observed them operate in taxi service, under heavy-duty conditions.

Table1: Comparison of fleet EV models

| Qty | Model         | Body style  | Battery size and type                  | EPA-rated range       | Pros  | Cons   |
|-----|---------------|---|--|-----------------------|---|--|
| 78  | Kia Soul EV   |   | 27kWh NMC (LiNiMnCo)                   | 149km                 | <ul style="list-style-type: none"> <li>- Excellent winter energy efficiency (Wh/km)</li> <li>- Pleasing visual signature as a fleet car</li> <li>- Comfortably-sized rear passenger zone</li> <li>- Quick charging almost not affected by cold temperatures</li> <li>- Popular amongst taxi drivers</li> <li>- Strong regenerative braking</li> </ul> | <ul style="list-style-type: none"> <li>- Some parts are very fragile and already required replacement on many vehicles: 12V battery (35 cars affected), quick-charging ports (10 cars affected), onboard charger (18 cars affected)</li> <li>- Some operating modes are counterintuitive: very difficult to preheat cabin using power from a charging station</li> </ul>   |
| 22  | Nissan LEAF   |  | 30kWh NMC (LiNiMnCo)                   | 172km                 | <ul style="list-style-type: none"> <li>- Very low occurrence of repairs</li> <li>- Slightly lower battery capacity loss (vs Kia Soul EV)</li> <li>- More control over operating modes: ex.: pre-heating of cabin using charging station power</li> </ul>  | <ul style="list-style-type: none"> <li>- Less interesting body appearance</li> <li>- Lower range in urban-duty</li> <li>- Slower quick-charging in cold temperature</li> <li>- Smaller rear passenger zone</li> <li>- Generally less popular amongst taxi drivers</li> </ul>   |
| 17  | Tesla Model S |  | 70kWh / 90kWh NCA (LiNiCoAlO2)         | 386km / 434km         | <ul style="list-style-type: none"> <li>- Impressive range</li> <li>- Very popular with customers</li> <li>- Prestigious vehicle that helps to promote the brand</li> <li>- Rear passenger zone is ideal for taxi duty (with panoramic roof option only)</li> <li>- Very large cargo space</li> </ul>  | <ul style="list-style-type: none"> <li>- Powerful acceleration and braking requires a gentle driver to ensure passenger comfort</li> <li>- Expensive purchase price</li> <li>- Frequent downtime caused by many failing OEM electric components (charging ports, door handles, mirrors, hatch actuators, power steering, parking brake, etc.)</li> <li>- Expensive parts outside warranty</li> <li>- Aluminum body is hard to repair</li> <li>- No access to OEM tools and documentation to perform self-repair</li> </ul> |
| 7   | Tesla Model X |  | 60kWh / 75kWh / 90kWh NCA (LiNiCoAlO2) | 320km / 379km / 411km | <ul style="list-style-type: none"> <li>- Excellent range</li> <li>- The most popular vehicle amongst customers</li> <li>- Stunning vehicle appearance that promotes the brand image</li> <li>- Very spacious rear passenger zone, perfect for taxi duty</li> <li>- Colossal cargo space</li> </ul>  | <ul style="list-style-type: none"> <li>- (Same as with Model S)</li> <li>- Poor energy consumption numbers compared to Model S</li> <li>- Large falcon doors openings are causing the comfortable cabin heat to escape very fast on cold winter days</li> <li>- Premature wear on expensive large tires</li> </ul>   |

## **2.5 Ecosystem of real-time of monitoring, datalogging and dispatch**

The deployment of such a fleet cannot be achieved without support of various partners and systems. While they are less visible than the EVs themselves, those systems are just as much important to achieve a functional and optimized fleet. Taxelco's fleet represent a real global ecosystem that comprises many subsystems, both localized onboard in each vehicle, but also centralized to overview the global operations. This large system also incorporates the client mobile application that allows patrons to hire a taxi from any mobile device. Mobility-as-a-service is truly part of the DNA of this architecture.

### **2.5.1 System architecture**

An overall fleet control system backbone interacts constantly with all vehicles through their onboard systems. This backbone system also provides web-based real-time monitoring tools for the team of dispatchers in the control room. By bridging all subsystems together, this system relays dispatch information to drivers about their upcoming taxi trips or upcoming charging events.

### **2.5.2 Onboard systems**

Each EV is equipped with a lot of onboard hardware, most important are RFID card vehicle access-control, driver interface tablet (includes dispatching application, GPS, IP phone, etc.), passenger entertainment tablet, passenger Wi-Fi access point, electronic payment system, taximeter, datalogging hardware, etc.

### **2.5.3 Datalogging**

Our fleet analysis work is based around FleetCarma services. This Canadian company offers web-based services aimed at fleet managers. Their web-portal tool allows the user to generate reports based on cloud-stored data harvested in the fleet by datalogging devices installed in each vehicle. FleetCarma engineers have gained access to the appropriate CAN-BUS messages found on the diagnostic port of most EVs. This system allows us to access each car's SOC and charging status in relative real time. The refresh rate of such info to the cloud is once per minute and is accessed by Taxelco's backbone system, via an API, to run its taxi dispatch algorithm. Other useful info is also being logged by this equipment, such as instant energy consumption, type of recharge, vehicle speed, vehicle position, etc. All this information is logged into FleetCarma's cloud and can be studied by fleet engineers and coordinators through a set of pre-configured reports.

## **2.6 Charging infrastructure**

### **2.6.1 Charging strategies and planning**

In the current state of Taxelco's fleet, approximately 75% of the total energy usage is provided through fast-charging equipment (level 3). While Taxelco's charging strategy and car-swapping method has been exposed in the case study paper we presented at EVS29 [1], lets summarize the general deployment rules:

- While in service, Kia and Nissan vehicles are charged at unmanned car-swapping fast-charging level 3 stations spread in the taxi service zone
- During off-service periods, these smaller EVs are charged at service centres on level 2 stations
- While in service, Tesla vehicles are charged at a dedicated location, at Montreal airport, where a combination of fast and normal charging equipment is installed and no car-swapping is used.
- During off-service periods, Tesla vehicles are charged at a service centre where a combination of normal charging equipment and fast-charging car-washing station is installed

### **2.6.2 Selection and geographical distribution**

Challenges about selecting and locating electric vehicle supply equipment (EVSE) for Taxelco's project also has been covered in the case study paper we presented at EVS29 [1]. Here is a simple depiction of the general rules we applied while deploying the charging equipment, as well as the currently adequate vehicle ratios which we had taken into account:

*Level 2 EVSEs* (standard J1772 version, 7kW) were exclusively installed at Taxelco service centers, where off-duty taxi cars are stored. These are the locations where car washing, repair and maintenance events are centralized. The appropriate L2 EVSE to vehicle ratio is approximately 1:2.

*Tesla level 2 EVSEs* (branded as “High Power Wall Connector” or HPWC, 20kW) were equally installed at service centers and airport location. The appropriate HPWC to Tesla vehicle ratio is around 1:1.

*Level 3 rapid chargers* (standard 50kW DC charger, with CHAdeMO & Combo connectors) were installed at service centers (in car preparation and washing areas) and through the city (as car-swapping stations). Here is the distribution:

- One quick-charger in every car-washing station: one station per 40 vehicles
- A second quick-charger is installed in the preparation area, near each washing station (ratio 1:40)
- Unmanned car-swapping stations are spread through the city with a ratio of 1:20 vehicles

*Level 3 Tesla superchargers* (60kW maximum per connector) were installed at two locations. A total of four 60kW connectors are used for the fleet. (ratio 1:6 Tesla vehicle):

- Two 60kW connectors at the airport charging lot (adjacent to a group of 12 HPWC)
- Two 60kW connectors in the Tesla washing station (adjacent to a group of 9 HPWC)

Deployment of most of this charging equipment is the result of an effort to prepare the 124-vehicle fleet for the highest service peaks during the lowest temperature days of winter. With an approximative total charging power ratio of 14kW per vehicle, the taxi fleet was able to serve an average of 600 000km per month in Montreal’s freezing winter season.

### 2.6.3 EVSE integration

Managing the EVSE spread across the city brings many challenges similar to those of managing the EV fleet itself. In such a heavy usage, EVSE is playing a key role into supporting the fleet, so this equipment has to do more than simply delivering energy to the EVs. This means that charging stations must be treated as an essential part of the global ecosystem and, consequently, all unmanned charging locations have to be adequately monitored in real-time and connected to the cloud. This is an important factor to keep in mind when choosing an EVSE supplier.

The following figure represents the pyramid of what needs an EVSE should fulfill. The more intensive one’s EV fleet operations would get, the higher levels of service one will need from its charging equipment:

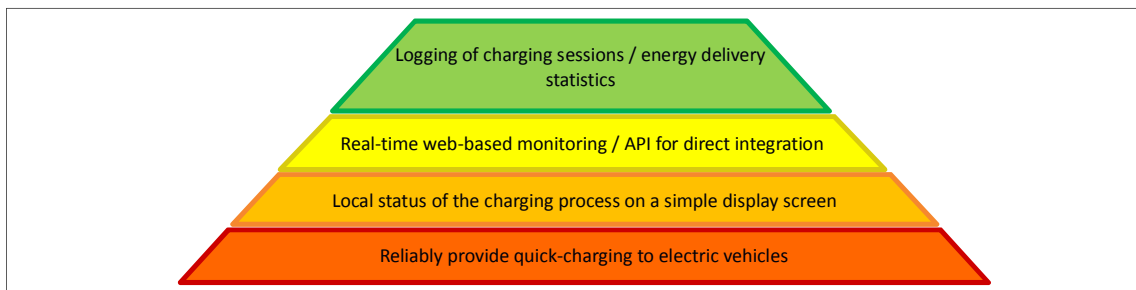


Figure 1: Pyramid of EVSE needs

## 3 Fleet analysis in operation

### 3.1 Energy consumption comparison

The variety of EV models within the fleet allows us to do a comparison of their energy consumption. This is a value that we monitored constantly during the project, as the fleet was getting busier each month. In the cold of winter, it also became obvious that some vehicles, like the Kia Soul EV, performed better than others. Even with an official EPA-rated range worse than the Nissan LEAF, we discovered that, in a pure-city duty, the Soul EV was the real champion. While they are equal in favorable weather conditions, the Kia

proved to have a better range than the Nissan during the freezing days of winter. This difference yields an average 5% advantage in favor of the Kia Soul EV. The following figure presents the comparison of the average power consumption of each model.

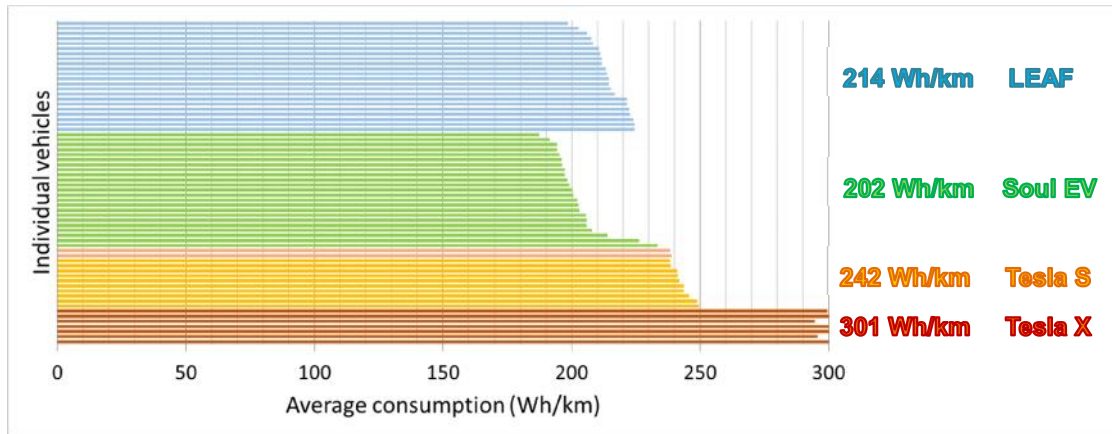


Figure 2: Power consumption per model

In Taxelco's taxi fleet, Tesla consumption is always higher because their duty is very different from the Kia and Nissan vehicles. The Tesla are mainly serving airport trips, using highways where the average speed is much higher than the sub-30km/h average speed of urban taxi duty of the rest of the fleet. Higher consumption of Tesla vehicles is also linked to their size. The addition of Model X vehicles to the fleet helped us to observe that phenomenon by comparing their performance with Model S numbers. Both models, while being mechanically very similar and used in the same airport taxi duty, differ only in their size, their weight and their tire and wheel sizing (which are noticeably bulky on Model X). Another difference, less easy to detect, comes from those impressive falcon-style doors on Model X. On cold winter days, each time they are deployed to let customers board the taxi, these slow-moving automatic hatches (that comprise a large part of the roof opening) allow the warm air to escape very quickly from the passengers' compartment. This contributes to the low score of the Model X compared to the Model S. One last strike for the larger Tesla model X is that its enormous wheels are factory-adjusted with a lot of negative camber at the rear. While this improves handling on such a large vehicle, in intensive taxi-duty it proved to cause rear tires to go from new to totally worn-out in just one winter season (30 000km). Other than the cost of those large tires, it also contributes to the Model X's poor energy consumption numbers compared to the Model S.

### 3.2 Energy consumption model

To help predict taxi fleet behavior in different situations and weather conditions, one objective of our team was to build a model of energy consumption. An important need for this model was to evaluate charging infrastructure requirements for worst case scenarios, such as a busy fleet on a very cold night of winter. To build a model of EV energy consumption through various weather conditions over a complete twelve-month cycle, we gathered massive amounts of data obtained from our fleet of onboard dataloggers. Thousands of hours of driving statistics collected over more than 18 months have been analyzed. This includes two winters of useful data.

If you drive an electric car, you probably realized that the power consumption value that your car displays in the dashboard screen is an aggregated value (in Wh/km or in km/kWh) that includes a part for the drivetrain consumption, a part for the HVAC system, as well as a part for the auxiliary systems. While the drivetrain power consumption is obviously proportional to the distance driven, the two other parts of the consumption value are rather proportional to the time that the car was in function (either driving or stationary). The goal of our model was simply to build a simple tool to dissociate those three portions of the energy consumption tally.

The base hypothesis is that, in a climate oscillating yearly from 30°C to -30°C, the moment of the year where the energy consumption is at its lowest represents the “ideal” situation, where the need for HVAC is negligible. Based on our data, the month of September is always the one with the lowest power consumption for the fleet, with an average of 186Wh/km. Most EV car owners in Montréal would confirm, September is the month where you usually just sit and drive: gone is the need for A/C, while no heating is required yet. Another assumption had to be made concerning the auxiliary load. While this consumption is variable from one model to the other, it is usually measured in the 100W-200W range. We estimated this load at an average of 150W for our average fleet car model.

Then, using monthly distance and “on time” logged for our fleet in September, we can simply calculate the real « net » average power consumption of the fleet per distance (subtracting a 150Wh auxiliary load for each hour that the cars were in service). The important resulting value is a net drivetrain consumption of 176Wh/km, on average, for the fleet.

Finally, knowing already two of the three components of our model (*auxiliary load* and *drivetrain* consumption) we simply processed all the data we logged for the monthly average energy consumption, in order to calculate the third component: HVAC power consumption for each month. This value is indeed proportional to the time the car is in service (i.e. not a value per km driven, but rather a rate of energy per hour, like the auxiliary load). Resulting HVAC consumption values, one per month for the entire year, complete our simple consumption model. The next figure illustrates this model and shows how the HVAC portion of the energy consumption correlates well with the monthly average daily temperature in Montréal.

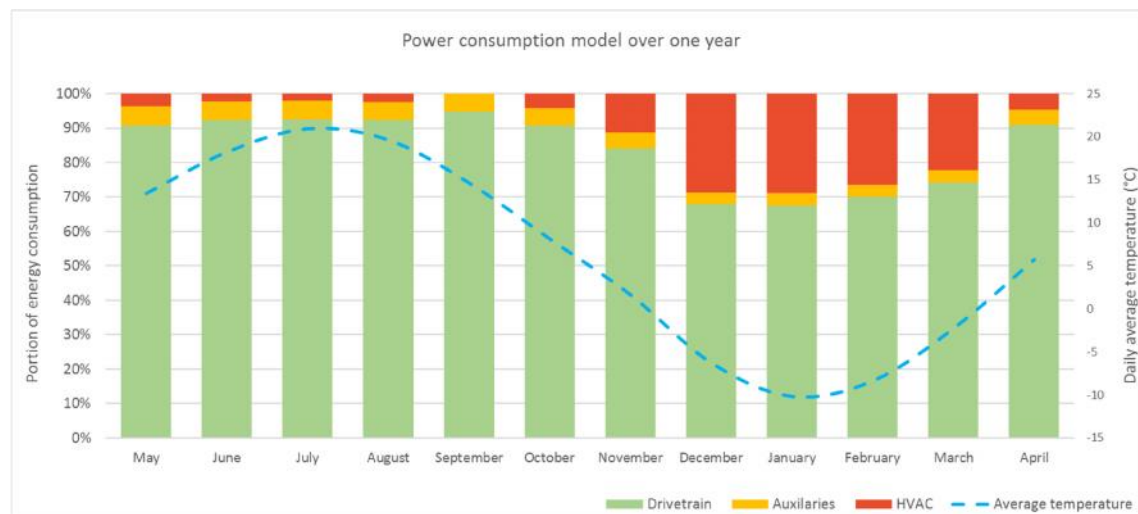


Figure3: Power consumption model

Using this model as a tool, the team can evaluate the power need for different scenarios to operate the taxi service. As an example: more cars on the road will lower the daily distance per car and help spread the charging events, but the associated increase in downtime might cost too much energy in HVAC in winter.

*Note:* This model is obviously a simplified one, as it does not incorporate some secondary effects (such as the fact that a part of HVAC load is proportional to the distance driven because of wind chilling effect, or the fact that some of the drivetrain consumption is proportional to the time the car was driven because of some thermal effects, or other cross-linked effects). While these effects are present, their relative importance is lower in the net numbers (given we are not using this model to evaluate the energy needs of another type of EV application, but simply the same taxi duty in the same conditions). It would be non-trivial to incorporate all secondary effects into this model, as they are beyond the scope of this analysis.

## 4 Battery degradation study

In order to conduct the battery-degradation study on the EV taxi fleet, IVI's lab team performed tests on a subset of 20 cars from the fleet. By testing the same group of 9 Soul EVs, 9 LEAFs and 2 Teslas, once per month, IVI gathered battery capacity data over the initial 18-month of fleet operation.

### 4.1 Lab test protocol

While the testing protocol and conditions have to be rigorously controlled, the test itself is very simple. It consists of driving a fully-charged vehicle on a dynamometer until the battery is totally discharged and the drivetrain bring the wheels to a complete stop.

To ensure the precision of such each monthly test, each vehicle must be prepared following strict guidelines. The EV battery has to be fully charged to 100% SOC, then stabilized overnight at an ambient temperature of 25°C, after the charging is complete. Vehicle driving tires are changed for a set of regular all-season tires, inflated at the manufacturer's recommended pressure. The vehicle is anchored to the dynamometer with minimal downforce, to avoid any extra parasitic load on the rollers. Prior to the test, all of the vehicle's electrical accessories are turned off to avoid altering the results. Radio, GPS, lights, roof dome, and all onboard taxi-related devices are turned off to make sure the drivetrain is the only load that drains the EV battery. All ECO-modes and special energy management options are turned off to ensure we run the same test every month. When testing the Tesla, we also have to put the vehicle in two wheel-drive mode, by deactivating the front wheel drive-unit system.

The dynamometer itself is calibrated each week using the manufacturer's method. Before each test, the dynamometer is run through a warm-up cycle. During the test, the operator has 1 minute to bring the car to 80km/h. The load applied on the vehicle drivetrain by the rollers is automatically controlled by the dynamometer, at 20kW (25kW for Tesla). This speed is then maintained by the test operator using the car's own cruise-control system until the drivetrain limits its power at low SOC. At this moment, the test operator takes back control of the accelerator pedal and applies maximum throttle until the wheels stop turning the dynamometer's rollers. The final distance and energy transmitted to the dynamometer is then recorded, along with the complete run log, from 100% to 0% SOC. This process takes around 1 hour on the LEAF and Soul EV and more than 2 hours on the Tesla.

Each step of the preparation and testing procedure is part of a thorough checklist that the lab technician has to fill in for each test as he performs it on the vehicles of the fleet. This list represents one of the many logs gathered for each test. It includes details such as the vehicle's system firmware version number (as this might affect display of SOC and behaviour of the car traction system at low SOC), vehicle odometer, tire pressure, lab temperature, dynamometer calibration parameters, etc.

While all these steps and configurations do not represent the real-life usage scenario, their importance is tremendous in the repeatability of the tests and consistency of the results over time. The goal was not to achieve a measurement of "real-world distance" on the dynamometer, it was rather to compare the evolution of this "controlled-test distance" over the year and a half of the study period. In order to add more precision to each test data, we also extracted the total battery usage from the datalogging system. This value, obtained from the vehicle's own battery management system, is a direct report of how many kWh were used from the battery, from fully charged to fully depleted.

### 4.2 Test results

On a new battery, the average total useable battery capacity during the test cycle was 25,3kWh for a low mileage Kia Soul EV and 27,3kWh for a Nissan LEAF. These usable battery capacities are approximately 9% lower than their respective nominal battery capacity numbers advertised by each manufacturer. This initial usable battery capacity was measured at 67kWh for Tesla S 70D and 80kWh for Tesla S 90D.

#### 4.2.1 Kia Soul EV and Nissan LEAF

At the end of the 18-month test period, the average Kia Soul EV and Nissan LEAF odometer was around 55 000km, Both the Kia and the Nissan are used on the same taxi duty, dense urban driving, with frequent 50kW fast charging. This intensive usage yielded a measured battery capacity loss of roughly 10%-11% at

the end of our study. The following figure combines the battery capacity measurements of the complete test period, for the Kia and the Nissan. Interestingly, the fluctuating curve is a direct consequence of the intensity of the fleet usage. While the first six months of service were not very intense, with less than 20km/day per car, fall 2016 has been busier, with an approximate distance of 150km/day for each vehicle.

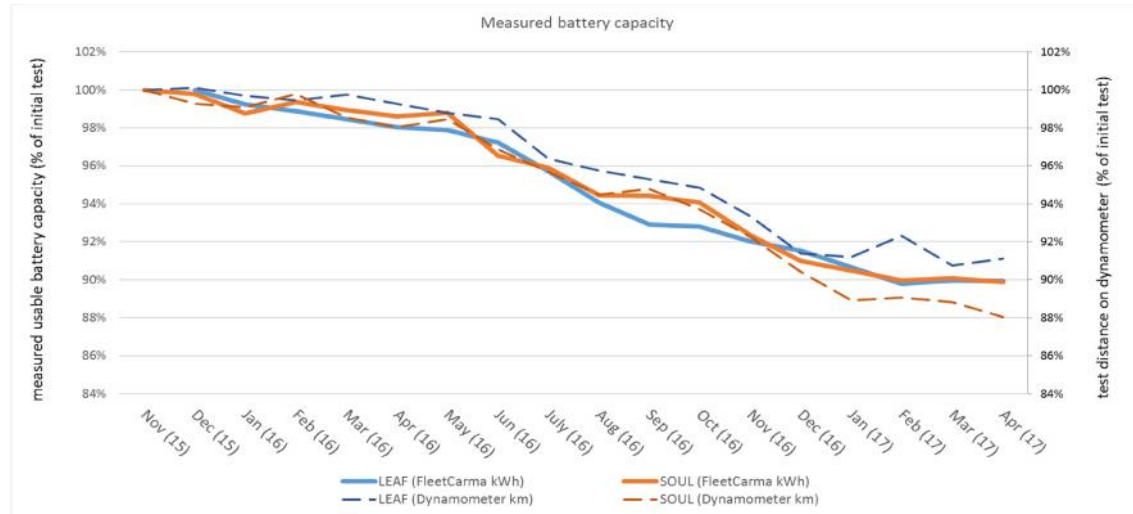


Figure 4: Battery capacity loss for Kia and Nissan

As an example, this average distance of 150km/day on a Kia, correlates to roughly 30kWh/day being used on a battery that now holds approximately 22,5kWh. This means need for fast charging events and the number of daily battery charging cycles is increasing each month. This increase is also accelerated by the taxi service getting more popular and optimised over time. This will contribute to the battery capacity loss phenomenon that we observe here. While we do not possess the precise models to completely predict this degradation process, we can evaluate that this phenomenon is important enough that it could bring the Kia vehicles in our fleet to meet the battery-servicing criteria under manufacturer's warranty. Even at the current rate, by losing roughly 11% of battery capacity each 50 000km, the Kia Soul EV could meet the warranty limit of 30% capacity loss before 160 000km. Nissan LEAF warranty is a little less strict and, by losing a little less capacity, roughly 10% of battery capacity each 50 000km period, it would probably not meet Nissan's warranty criteria.

#### 4.2.2 Tesla Model S

The two Tesla S odometers were around 110 000km at the end of our tests. These vehicles are used in a different duty than the Kia and Nissan. Driving twice the distance each day on partly-highway trips, the Teslas are mainly used to serve airport customers. Their large cargo area and larger battery capacity make them a very good fit for this duty. While Taxelco is using four Tesla 60kW superchargers for this fleet of 24 Teslas, this does not represent a stress as important on the battery as using a 50kW CHAdeMO DC charger on a small 27kWh Kia Soul EV battery. Driving twice the daily distance with a battery 3 times larger also lowers the burden on the Tesla batteries. Finally, the active liquid-cooling of the Tesla cars, the different battery chemistry and the conservative BMS algorithms in cold weather (especially if compared to a Kia Soul EV) are also factors that affect the rate of capacity loss in an EV battery.

With only two vehicles, our sample size was very small for the Tesla Model S. While this situation obviously made our results less precise, we can still benefit from the fact that the measurements were taken on vehicles with a lot more distance on the odometer. Based on our measurements, we obtained an average loss of 4% of battery capacity for each 50 000km period.

## 5 Improving fleet performance

With all the hands-on experience that IVI and Taxelco gained from this project, and lessons learned from creatively solving problems as they come up, we can already boil down a digest of key facts that will inexorably come to play in any heavily-used EV fleet deployment.

### 5.1 Challenges

#### 5.1.1 Equipment and vehicles

*Charging equipment will break, more often than you think:* quick-charging connectors, both on EVSE and car side, are high-priced parts. They wear, they crack, they heat up, and manufacturers absolutely do not offer spare parts ( housings, pins, cables), only complete assemblies with four-digits price tags. Breaking four CHAdeMO connectors in a single week could rain on your parade. (Sumitomo used to offer an aluminium version of its CHAdeMO connector, we pray for its return.) Changing a complete Tesla charging port at \$750, if outside of warranty, when only the contact pins would need to be replaced (as they are easy to dismantle from housing and HV cables), also feels like a waste of resources.

*Cars will inevitably break and their repair paradigms have changed:* EVs are a new field in the automotive industry. Some large manufacturers are exploring and developing this new market, but their innovation potential is often conservatively held down by their long experience at making conventional ICE vehicles. On the other end of the spectrum, there is a very innovative manufacturer that was created for the sole objective of building EVs. However, its ability to break the mould sometimes comes with a lack of some wisdom of the older manufacturers. In all cases, every OEM is relatively new in the field of EVs and this leads to unexpected failures or special mechanical repairs that no one would expect. Replacing a ball-joint is a simple task of half an hour on a Kia, but on a Tesla, it requires lowering the complete HV battery-pack away from the car, which represents a complex 4h-job that could not be performed by an average mechanic. Oppositely, replacing a charging connector is a straightforward task on a Tesla, while it becomes a complex chore on a Nissan.

*HV battery will lose capacity faster than your average home-duty EV:* as covered in our study, while it is not as dramatic as one might have expected, the battery degradation process will be faster than a normal-duty EV. On currently available EVs in the 25-35kWh range of battery capacity, you can expect to reach numbers close to the manufacturer's warranty threshold.

#### 5.1.2 Human factors

*Employee drivers are rougher on equipment and vehicles:* as briefly explained earlier, non-owner drivers tend to be generally rougher in handling company-owned equipment and vehicles. Budget reserved for collisions and spontaneous road-induced damage could easily be higher than expected. This will become even more obvious when dealing with the rare and exclusive aluminium-body repair specialists shops in your area.

*Guilt-free EV driving:* this commonly known phenomenon, where new EV drivers develop a newfound thrill to depress the accelerator and braking pedals more abruptly, is not an urban legend. Not only this increase the overall burden on fleet cars, but it also has a negative effect on energy management optimisation and, in taxi-duty, comfort of passengers.

*Range anxiety:* An important part of the fleet's power management equation is the human aspect. The overall experience with drivers, fleet dispatchers and site coordinators, all of whom were new to the world of EV, made it clear that range anxiety is a phenomenon that is not only inherent in the average person, but also hard to shake off. In a city where weather can go from one extreme to another, the situation gets worse because the expected range of an EV varies from one season to another. A 15% SOC threshold in winter does not represent the same safety buffer it was in summer.

### 5.2 Key factors

*There is no such thing as too much data:* Starting a new fleet, especially with EVs, is not a simple task. Learning is part of the project and your team will have to face a new unexpected phenomenon each day.

Thorough datalogging and real-time monitoring is a crucial aspect of any similar project. You will need it to analyse each problematic situation and unfold the root causes of problems, as well as perceive the patterns of usage of your fleet that would not be obvious to the naked eye.

*Establish good partnership with OEM:* New vehicle delivery in batches, instant availability of common spare parts, free OEM diagnostic tools and service manuals for your mechanics, priority service for warranty and recalls (ex.: Nissan even sent its technician to do ECU reprogramming onsite, in Taxelco's garage).

*Establish good partnerships with electrician / EVSE providers:* For your EV fleet, EVSEs are the only way to "refuel". This represents a critical aspect of the ecosystem where there should be as little downtime as possible. It is essential to find partners who will quickly answer service calls and replace defective and broken material.

*Design charging infrastructure capacity for the worse day you can expect:* It might seem like an obvious design rule, but most managers will feel frightened to see what that peak number is, on worse winter days. If you operate in a city subject to harsh winters, do your homework and accept to plan for the worse.

*Peak power demand management should not rely only on hardware:* Many EVSE manufacturer offer elaborate built-in power peak management and patented automatic load-sharing mechanisms that will help you to maintain your peak power (and utility bill) under the desired level. In the field, those systems could prove to interfere with vehicle internal charging algorithms (ex.: on very cold days, we saw vehicles stuck in a very low current charging mode when connected to a load-sharing EVSE). Your peak-management could be better handled on the "soft" side, by staggering charging events and spreading them in time. This also keep 100% of your power capacity available for unexpected days of very high demand.

*Keep it simple and user friendly:* With employee drivers, new to EVs and often sceptical about their capabilities, you need to keep things as user-friendly as possible. Each different EV model your drivers have to drive, each different EVSE type they have to manipulate, each onboard system they have to interact with, are all sources of little mistakes, mishandling, questions, hesitations, etc. Keeping everything simple is a tremendously important rule, especially with unmanned charging stations. (ex.: Taxelco's uses car-swapping at unmanned stations, quick chargers access-control is disabled to minimize user manipulation and chargers now automatically start a charging session when the connector mates with the car, minimizing the chance that drivers leave without charging the car they just left at the station).

### 5.3 Ideal taxi-duty EV

Based on all this experience and enlightened by all the gathered data and our battery study, one would think we could depict the ideal EV to use in such a demanding duty. The truth is that our ideal model is still being refined over time, as we continue to learn and experience new situations. Experimenting with fleet operation, charging station locations, doing our due diligence with new models coming soon to the market is also shaping our opinion on the subject. Although it is far from being a definitive turn-key guide, here are some criteria and conclusions we gathered from our experience. An ideal EV for heavy-duty urban-taxi operation in a large city subject to harsh weather would feature:

- large cargo capacity of a Toyota Prius V
- battery capacity and degradation curve of a Tesla S 70
- quick-charging capability of around 100kW (Tesla Supercharger or 100kW CHAdeMO / Combo)
- price tag in the range of the Chevrolet Bolt
- good reliability and EV product maturity of a Nissan LEAF
- manufacturer cooperation (tools, documentation and parts availability) of a Kia Soul EV
- driving style of a Kia Soul EV (both acceleration and regenerative braking around 80kW)
- cold weather performance of Kia Soul EV (unhindered fast charging and energy efficient HVAC)
- rear passenger space and comfort of a Tesla X

Some very close hypothetical contenders meeting many of our criteria could be pictured as these "EV unicorns":

- a station-wagon version of the new Chevrolet Bolt
- a 50-60kWh version of the actual Kia Soul EV

- a Nissan eNV-200 featuring the 60kWh battery of the soon-coming 2<sup>nd</sup> generation LEAF
- an economic fleet-ready tamed-down version of the Tesla Model S, priced as the coming Model 3

## 6 Conclusion

While this EV fleet project brings a lot of challenges every day for Taxelco's team, it also proves to be an invaluable opportunity to learn about this field of activity. By gradually increasing fleet activity, adding cars, drivers, charging infrastructure and by refining the taxi fleet ecosystem, its algorithms and patterns of operation, Taxelco is establishing the basis of its best practices related to EVs. The lessons learned and the expertise gained from launching this taxi service will also translate into other services based on electric transportation, such as adapted transportation for disabled people and urban package delivery, but also soon with inter-city heavy transportation. For IVI, this project also represents an excellent showcase of its ability to support businesses into leveraging innovation in their transportation solutions.

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## Authors



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Passionate about cars, Pascal has always been driven by his curiosity to take a hands-on and self-directed approach to extending his multidisciplinary knowledge. He has explored many technical domains and completed an MBA. Pascal has worked in systems engineering since 2002, where he applies his experience to interfacing the multiple and contrasting aspects of projects. Pascal worked, notably, in EV development teams at Nova Bus, Lito Green Motion and now at the Innovative Vehicle Institute where he focuses on Taxelco's taxi project.



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Engineer, graduate from Université de Sherbrooke, Thierry has been project manager at Motorola (2001-2006), Member of federal Parliament (2006-2011). He was then Chief of Staff for the Ministry of Transportation, of Municipal Affairs, Regions and Land Occupancy (2012) and for the Québec Ministry of Natural Resources (2013). He then became Director – strategic development at RER Hydro (2014). EV driver since 2012, Thierry has already acquired a strong expertise in electrical transportation. Thierry is now the lead of EV fleet and infrastructures, along with special projects and public relations at Taxelco, operating its fully electric taxi fleet in Montreal.