A Study of driving range estimation for city electric buses based on Taiwan EV Pilot Run Project
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Abstract
The driving range is an important issue of electric car manufacturers and electric vehicle fleet operators, and it directly influences the cost, operation and customer satisfaction. The estimation of Battery performance which has a significant impact on the driving range is an immature technique, however ARTC (Automotive Research & Testing Center) proposed to estimate parameters including energy consumption and battery aging. ARTC estimates the driving range by referring the following parameters like the speed, the times of start and stop, and the temperature. Battery capacity is another impact factor, and it will diminish when battery aging and degradation. However, the decreasing capacity has the enormous implications of the range. ARTC presents the down trend of the battery capacity by the EV’s driving data statistics, and then the capacity will be predicted from the trend. The bus is characterized by specific time, position, path and driver, and it’s suitable to electrification of bus systems. This paper is focused on estimating the energy consumption of electric bus. The driving range can be estimated by the speed, the times of start and stop, the temperature, and battery capacity, and it will be more accurate. Furthermore, this paper will present the trend of the battery aging by the charging capacity of battery. The research will help to improve the vehicle’s design, and then support the expansion of electric vehicles.

Keywords: electric vehicle, driving range, OBU (On-Board Unit)

1 Introduction
It’s been over hundred years since the first electric vehicle was built. However, the development of electric vehicle has no breakthrough until recently. According to the environment pollution, the electric vehicles are gradually taken seriously. Although the performance of electric vehicles today is better than hundred years ago, the EVs still can’t meet customer satisfaction in the driving range, the price, and charging infrastructure. Hence, vehicle manufacturers make efforts in developing EV to improve the car’s performance in reducing the price and increasing the driving range. In the meantime, governments and institutions worldwide are implementing the EV pilot run to make masses experience and understand the EVs.

1.1 Taiwan EV Pilot Run Project
In the first stage, 5 pilot projects are launched and over 250 electric passenger vehicles are driven around Taiwan including Taipei metropolitan area, Taichung metropolitan area, Tainan metropolitan area, and Sun Moon Lake National Scenic Area.
The EVs are used as the government cars and rental cars. The main purpose of government cars is to show EVs to the Public. They are used as shuttle bus between the government buildings or squad cars. The rental car can be rented by the Public. It helps the Public to approach and understand EVs.

In the second stage, the electric buses (eBus) are introduced to the project. So far, there are 3 projects are ongoing, and introduce over 30 electric buses which are made by Taiwan manufacturers. Nowadays, the eBuses run in many areas in Taiwan such as Kaohsiung metropolitan area, Dapeng Bay National Scenic Area, and Hsinchu Science Park and the operation modes of eBus in Taiwan EV Pilot Run Project are including city bus, intercity coach service, and shuttle bus. Next, the eBuses will be the shuttle bus running on campus and national park.

Because the buses are characterized by specific time, position, path and driver, and they are suitable for electrification of bus systems. The paper focuses on the city eBus because of the operational mode’s features. This research expects to simplify the environment and summarize the relation between parameters and energy consumption by analysing the data from city eBus.

1.2 The driving and charging data evaluation in Taiwan EV Pilot Run Project

In order to evaluate the project’s performance, the first step is to make the operational plan. Next step is to establish the model that is what and how to evaluate. The third and fourth steps are data capturing and processing are. Then verify the outcome and produce the report. The flows are shown on Figure 1.

Figure 1 flow of data evaluation

Taiwan i-EV Pilot Project collects and analyses the EV data to evaluate the user’s driving and charging habits, and infrastructure appropriateness of EVs. The goal of this project is to gain the constructive suggestions to make policy and popularize EVs. Based on the goal, ARTC brings up the method to collect EV data in motion and in charging. The detail contents are as following:

Figure 2 flow of data collection and analysis

The paper will focus on what are the impact factors of the city eBus driving range, and the relation between the driving range and the impact factor.

2 Related Work

The primary task of the promotion of electric vehicles is to improving the driving range. However, it’s difficult to increase the driving range within short time. In order to reduce the range anxiety, the electric vehicle is similar to the traditional car; the remaining driving range is displayed on the dashboard. The general method is to estimate the remaining driving range by average energy consumption of the past 5 miles, 10 miles, etc. There are two techniques as below to compute the remaining driving range.

2.1 Big-Data Framework for Electric Vehicle Range Estimation

The estimating technique purposed by North Carolina State University is through big data analytics by collecting the environment parameters as route, terrain, temperature, and wind, etc., driving behaviour, vehicle, and battery information, the framework is as the Figure 3.
driving cycles of constant speed, and analyses the influence of the vehicle mass, battery capacity, and the electric auxiliary on the energy consumption and endurance mileage.

3 The driving range estimation

It’s important for driver to get the remaining driving range when using the electric vehicle. The driving range is affected by the vehicle model, driver’s behaviour, and environment’s status. The paper takes the city bus as an example, and focuses on the speed, temperature, and the times of start and stop.

In order to study the electric bus, the conditions need to be simple. Because the city buses are used by the same driver, and the same route, the city bus are chosen to be an example. The city bus offers 26 seats; the vehicle weight is 13,000kg; the battery capacity is 250kWh. The city electric buses which are taken as an example run in one of the metropolitan areas in Taiwan, and the route is busy while the commuting time.

3.1 Speed

The speed will direct influence the energy consumption, and generally the higher speed will cost the more energy. Figure 5 is the relation between the average speed and the energy consumption when the average speed per trip is between 10 and 25 km/h, the x-axis is the average speed and y-axis is the mileage per kWh. It shows that when the average speed is under 15.1 km/h, and the average speed decreases 5 km/h, and it reduces 5.54% energy consumption, equal to raising the driving range 9 km; conversely, if the average speed is higher than 15.1 km/h, the average speed increases 5 km/h, and it reduces 5.54% energy consumption.
3.2 Times of start and stop

![Figure 6](image)

Figure 6 the relation between energy consumption and the times of start and stop

Start and stop will influence the energy consumption. In Figure 6, the times of start and stop is through the distance and times of start and stop per day; and the energy consumption is the energy consumption per day. In Figure 6, the energy cost lower when the times of start and stop is lower. If the times of start and stop is 2, the energy consumption is 0.72 km/kWh; and the times is 2.5, the energy consumption is 0.69 km/kWh, the rate of decreasing is about 4%, and the driving range reduces 7.5 km.

3.3 Temperature

When the temperature is different, the battery performance will change. And when the temperature is lower, the energy consumption will cost less. From Figure 7, it costs higher energy when the temperature is higher.

![Figure 7](image)

Figure 7 the relation between temperature and energy consumption

By Figure 7, the temperature will influence the energy consumption. From Sep. to Dec., when the bus is driven, the condition is the same; the energy consumption of auxiliary system doesn’t change except air-condition. User will lower or raise the air-condition’s temperature by the weather. Assume the condition is the same, when the vehicle is idling; the only factor influence the energy consumption is air-condition. From Figure 8, it shows the trend of the output of battery current from July 2014 to Jan. 2015. It display that the output of current is 17.38A/s in Sep. 2014, and one is 14.13 A/s in Dec. 2014. The temperature decreases 9.2°C, and the output of current lower 17.80%.

4 The Estimation of State of Health for eBuses

In this case, the driving range of the eBus is around 190 km. Because of battery’s property, the battery pack will get capacity aging after using it. However, how to find out the SOH by using total voltage, total current, and total distance? Here shows a case study for explaining the estimation of State of Health (SOH) for eBuses with Yttrium Lithium Battery.

For getting the information of SOH of EVs in this project, there are many driving data should be collected, key items are SOC, voltage, current, and driving distance. Figure 9 shows the detail analysis procedure for this case study. First of all, the SOC accuracy and the power consumption per km should be confirmed. Because SOH doesn’t change in the short term, the analysis items should be compared one moment and few months later than that moment.
Therefore, with the analysis item during a period of time, the SOH of EVs can be found out. In this analysis, the key method is data integration, there are two situations must be know: 1. Power consumption calculates by total voltage and total current. Moreover, the SOC reliability and correction should be confirmed by current integration. 2. Data process and screening method cause the correction of results. For avoiding short data influences the analysis result. In this case study, entire cycle is adopted in this analysis, entire cycle is defined by SOC start from 95% till run out which driver define eBus should charge immediately.

By adopting the proposed analysis procedure, SOC accuracy and SOH estimation result can be find out. In this case study, we choose half year data to check analysis result.

The driving data is showing below, Table 1 is entire driving data from 95% SOC in July; Table 2 is entire driving data from 95% SOC in December.

<table>
<thead>
<tr>
<th>Jul.</th>
<th>SOC usage (%)</th>
<th>Run capacity (Ah)</th>
<th>Driving Distance (km)</th>
<th>Energy Consumption (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle1</td>
<td>86</td>
<td>650.7</td>
<td>178</td>
<td>237.1</td>
</tr>
<tr>
<td>Cycle2</td>
<td>81</td>
<td>637.5</td>
<td>175</td>
<td>232.5</td>
</tr>
<tr>
<td>Cycle3</td>
<td>81</td>
<td>663.3</td>
<td>178</td>
<td>242</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dec.</th>
<th>SOC usage (%)</th>
<th>Run capacity (Ah)</th>
<th>Driving Distance (km)</th>
<th>Energy Consumption (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle6</td>
<td>69</td>
<td>582.3</td>
<td>159</td>
<td>210.3</td>
</tr>
<tr>
<td>Cycle7</td>
<td>69</td>
<td>562.6</td>
<td>158</td>
<td>203.4</td>
</tr>
<tr>
<td>Cycle8</td>
<td>63</td>
<td>624.1</td>
<td>163</td>
<td>226.2</td>
</tr>
<tr>
<td>Cycle9</td>
<td>74</td>
<td>615.2</td>
<td>160</td>
<td>222.2</td>
</tr>
<tr>
<td>Average</td>
<td>70.2</td>
<td>603.54</td>
<td>160.2</td>
<td>218.14</td>
</tr>
</tbody>
</table>

In Table 1, the average SOC usage is 83%, but the average SOC usage is 70% in December. Assume the charge judgement of driver is the same; the run capacity decreases between Table 1 and Table 2. Driving distance and energy consumption is decrease, too. So we know the SOH is decrease, the capacity of Pack is decrease in EV, too. But, how many aging is taking place? We should define carefully. Therefore, the proposed analysis procedure deals with more items are showing below:

<table>
<thead>
<tr>
<th>Jul.</th>
<th>Cycl e1</th>
<th>Cycl e2</th>
<th>Cycl e3</th>
<th>Cycl e4</th>
<th>Cycl e5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ah/SOC</td>
<td>7.57</td>
<td>7.87</td>
<td>8.18</td>
<td>7.64</td>
<td>7.73</td>
<td>7.8</td>
</tr>
<tr>
<td>km/kWh</td>
<td>0.75</td>
<td>0.75</td>
<td>0.73</td>
<td>0.70</td>
<td>0.73</td>
<td>0.73</td>
</tr>
<tr>
<td>Wh</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>9</td>
<td>74</td>
</tr>
<tr>
<td>Dec.</td>
<td>Cycl e6</td>
<td>Cycl e7</td>
<td>Cycl e8</td>
<td>Cycl e9</td>
<td>Cycl e10</td>
<td>Average</td>
</tr>
<tr>
<td>Ah/SOC</td>
<td>8.44</td>
<td>8.15</td>
<td>9.91</td>
<td>8.31</td>
<td>8.34</td>
<td>8.6</td>
</tr>
<tr>
<td>km/kWh</td>
<td>0.75</td>
<td>0.77</td>
<td>0.72</td>
<td>0.72</td>
<td>0.70</td>
<td>0.73</td>
</tr>
<tr>
<td>Wh</td>
<td>606</td>
<td>679</td>
<td>600</td>
<td>007</td>
<td>429</td>
<td>56</td>
</tr>
</tbody>
</table>

In Table 3, the driving distance of each energy consumption is almost same between July and December, that is an explanation of the current and voltage of EVs are near correctly data. However, How about SOC? Is trustable? Here shows 7.8Ah/SOC and 8.6Ah/SOC difference. It’s wired about the Pack capacity is increase. First of all, the current and voltage data is confirmed, compare
with the information of Ah/SOC in July, the 7.8Ah/SOC can be as a reference to add in Table 2. The run capacity divide with 7.8Ah/SOC is almost 77% SOC, comparing with SOC usage in December, near 7% SOC difference is SOC error rate, and then SOH is difference between 83% and 77%. If driving data is a reference in December, the SOH is 94%.

5 Conclusion
Taiwan EV Pilot Run Project provide the platform to let the public understand the electric vehicle. Especially, when traditional buses turn to electric buses, the public can take the electric bus go to work or school, and experience the electric bus’s advantage such as low pollution and low noise. However, the driving range estimation will confuse the driver, this paper summarize the impact factors like speed, temperature, the times of start and stop, and battery aging. Through this study, the result is as following:

1. When the speed is under 25 km/h, the energy consumption is a quadratic curve, there is an inflection point, the value is bigger than the point, and the trend is that the high speed cost low energy; On the other hand, the value is lower than the point, the high speed cost more energy, In this case, when the average speed is higher than the value of inflection point, for every 1 km/h increase in average speed, the driving range increases by 1.8 km.

2. The energy and the times of start and stop are in direct proportion. The more times cost more energy. In this case, When the times increase 1, the energy cost increases 8%, equal to the driving range decrease 13.2 km.

3. The energy and the temperature are in direct proportion. The higher temperature costs more energy. In this case, When the temperature increases 1 °C, the energy consumption increases 1.93%.

4. The battery SOH, in the case, through the battery capacity, the capacity decreases 6% in 6 months.

This paper provide the research of the impact factor of the energy consumption, and take city eBuses as an example to figure out the relation between the energy consumption and impact factors. Through the energy consumption, the driving range will be estimated. It’s expected the research will provide information to the vehicle manufacturer and help bus operator to manage the driver.

References
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