# A Method for Evaluating and Optimizing Electric Bus Routes' Efficiency that Uses Multi-perspective Charging and Passenger Flow Management--With Case Analysis in Hangzhou, China

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**Abstract.** This paper introduces a method and three indexes that could help evaluate the efficiency of city Electric Bus routes from different aspects, including the level of effective carrying capacity and overall operational cost. Most Electric Bus routes may see difficulty managing different vehicles' charging and dispatching patterns and generate a large amount of wasted energy and human resources. Based on the case route in Hangzhou, China, and simulation conducted through calculation, showing this guidance and the indexes could enable people to spot the problem in operation and provide guidance for altering the charging-dispatching schedule to reduce approximately 20% of the operational inefficiency.

**Keywords:** Electric Bus, Effective Carrying Capacity, Operational Cost, Dispatching Management, Charging Management.

## 1. Introduction

During the second decade of this millennium, a huge uprising in the field of research about Electric Buses (EBs) and their possible applications in public transportation has appeared intending to create less environmental impact and bring passengers better experiences. Realizing that EBs will no longer discharge a large amount of Greenhouse Gas as fuel-powered Buses and provide a sheer edge of more than 40% of fuel usage reduction [1], more than 100 Car manufacturers worldwide have started to invent EBs with varied sizes ranging from 6-meter to 12-meter full-sized in recent years, which accelerated several cities to adopt them replacing the original fleet they were operating. One of the keenest countries adopting EBs is China, which sees an 834% increase from the end of 2014 to the end of 2018 with a tremendous number of 255000 vehicles, sharing 51% of the aggregate vehicle number [2].

While EBs indeed provided a sheer edge over the traditional fuel-powered ones, plenty of problems appeared. Lacking experience of in managing a large electric fleet, most of the new challenges such as recharging and battery management that emerged are generally unseen when cities are operating fuel-powered vehicles [3], which increased the cost of EB operation significantly. Researchers in [4] consider this problem might come from the maintenance and battery degradation problem, while many other investigations still have pointed the underlying problem toward the charging problem related to the EB' s nature and started handling this issue from the charging management perspective.

Though most of those researchers realized that the difficulty in managing the charging problem will then cascade into the problem of dispatching Buses, simply making improvements to the charging system might be unable to solve the problem. Most cities now have adopted multi-sized Bus vehicles responding to the variation of passenger flow (PF) within a day and dispatching them follows to an intricately designed table. The researcher has found ways to see an approximately 20% reduction in the economic cost of operating EBs [5] but this brings some difference between the real passenger demand and the capacity of the Buses' being dispatched. Nevertheless, the development of the modern 5th-generation (5G) communication technology has empowered people to devise several methods of tracking the PF from the perspective of a route, a station, or a single vehicle, with the accuracy of every minute. These methods will disclose the complexity beneath the PF fluctuation and make it possible for devising research methods that solve the charging-dispatching paradox from another scope of demand view.

Prior research and analysis conducted about the EB dispatching analysis in Davis, California indicated that the charging dispatching optimization will bring better passenger experience and higher cost efficiency [6]. However, in this paper, based on the new emerging technologies of monitoring the PF along the bus route, a system of combining the PF supervision, dispatching timetable modification system, and charging management will be formed, which could probably relieve the whole issue from its origin by proposing a high-efficiency operating-charging model.

Section 2 of this paper will provide more information that would have related to the issue that has been discussed, including the general performance of EBs and the existing problem they are facing at. Meanwhile, Section three and four of this paper aim to create an analytic method that incorporates the comparison of the PF function and Carrying-Capacity (CC) function, as well as the attribution of Bus vehicles of different sizes and the Total Operational Cost function related to it, to find the optimal efficiency of Bus route dispatching management, including the charging system and dispatching table optimization suggestion. Moreover, in Section 3 and 4 of this paper, the researcher has tried to apply the simulation method to a real Bus route in Hangzhou, China, confirming the 20-25% reduction in cost and electricity usage of the new dispatching-charging system could bring out in multiple situations.

## 2. Background information

### 2.1. Performance of Electric Buses and its Fast Development

EBs are pretty much a scheme that has received the most attention in recent decades, a series of brands now have invented their EB lineup with multiple-sized vehicles. From the traditional 12-meter standard model, manufacturers revised their existing models by reducing the battery size and number of seats to make several more compact configurations [7]. The compact models of EBs usually contain 10-meter, 8-meter, and 6-meter ones, which are devised for different situations that needed carrying capacities suited for the city traffic situation. In this study, the roles of EBs in different sizes will be a major consideration since it will be both related to the timetable analysis and the charging management. As China is a major country that now operates a large amount of EBs, s table below listed several most prevailing typical EB models in China of different sizes produced by 3 Chinese mainstream vehicle constructors A, B, and C.

**Table 1.** Features for 8 Prevailing Bus Models in China

| No. | **Length** | **Seat / Max Passenger** | **Normal/Theoretical Max Battery Range (Km)** | **Rough Operational Cost (Yuan/50km)** | **Manufacturer** |
|---|---|---|---|---|---|
| Model 1 | 12m | 32/86 | 210/320 | 148.4 | Brand A |
| Model 2 | 10m | 26/82 | 170/280 | 117.6 | Brand A |
| Model 3 | 8m | 17/60 | 160/250 | 14.2 | Brand A |
| Model 4 | 12m | 32/86 | 230/340 | 20.1 | Brand B |
| Model 5 | 10.5m | 24/86 | 210/330 | 16.2 | Brand B |
| Model 6 | 8m | 16/62 | 170/220 | 13.9 | Brand B |
| Model 7 | 12m | 30/88 | 220/300 | 20.6 | Brand C |
| Model 8 | 7.6m | 15/59 | 170/210 | 13.5 | Brand C |

For most of the cities that are now adopting EBs as the new generation vehicle in the Bus system, one important incentive comes from the support from the government or public incentive grant, despite there are some creative ways of promoting EBs such as contractual implementation [8]. In Shenzhen, China, the regulation on EB, accompanied by the huge amount of financial subsidies on the Bus company, led to the early elimination of fuel-powered Bus despite the cost for an EB is usually 2-4 times compared to the traditional diesel vehicles [9]. The most significant impetus for EB is certainly the environmental aspects. However, the actual environmental effect of EB is still under heated debate. While Greenhouse Gas (GHG) emission has been reduced at a level of nearly 75%

superficially, researchers still found the problem of the battery life-circle issue has still become unsolved constrain for the operation of EBs [10]. Though this research will not include the discussion about the real energy consumption and life-cycle aggregate cost issue of EBs, the researcher will still take energy consumption as an important judgment for the optimization scheme.

### 2.2. Typical Bus Route Types and Existing Charging Management Methods

A major setback during the operation compared to EBs merits is the difficulty in dispatching management. The underlying cause is that the charging time (CT) for a 12-meter full-sized bus is usually 3-6 hours with 110V-240V standard charging facilities, which could be 10-12 times over the time needed to fuel a traditional Bus. Meanwhile, the number of charging stations is usually only 10 percent numerically compared with the number of petrol stations in most cities. The scarcity of charging stations meant that vehicles sometimes need to spare even more time from operating and driving to the nearest charging station, costing them a longer period unable to be utilized. Researchers in [11] proposed that ideally, the charging problem will be alleviated by technologies of changing a depleted battery with a new one, but this solution is proved to be excessively difficult and incompatible with the traditional plug-in charging mode at the moment [12]. In addition, the travel distances for EBs are usually restrained to about 150-200 kilometers in city traffic, which means they can usually operate for 3-4 rounds in a route that have a length of about 50 kilometers a round. Being unable to operate long enough for a whole day points its central problem to the charging problem.

For each bus route, there will be 1 or 2 terminals that will be responsible for the dispatching and charging problems. For single terminal operation (ST) mode and dual terminal operation (DT) mode, the flexibility in bus dispatching will have a slight difference, since each cycle for ST Bus route is usually longer than the routes that are in DT mode. Some researchers will regard these two situations as significantly different and treat them with disparate analytic methods. Nevertheless, for ST routes and DT routes, the unchangeable fact is that all the Buses can only go to charging during the time they are in the terminal. So, regardless it’s under DT and ST situations, the methods of the charging-dispatching system discussed in this paper will both be effective, though could have a slightly different levels of effectiveness.

### 2.3. Online Real-Time Dispatching Application

The optimization scheme in this paper will include the alternation in the timetable for the Bus dispatching system. Some alternation plans might refer to a decrease in the dispatching density of the route. A possible consequence of this is the bringing inconvenience to the passengers. Nevertheless, for quite a lot of cities since the 2010s, the Bus company might have constructed a platform that could help the passengers to visualize the situation of the Bus on the route, aiming at building an extremely useful tool for passengers to plan their time if they need to take the bus [13].

An example of the Real-time Dispatching Application could be the “Bus Arriving” application in Macao. By using the application, passengers could see the route’s each Buses' position, arrival time, and crowd situation. With the aid of the high-speed 5th generation communication technology (5G), Global Positioning System (GPS) and Big Data stream calculation, the precision for the applications like “Bus Arriving” platform has now up to about 30-40 seconds [14]. The researcher believes that with an increasing number of cities adapting to real-time accurate Bus dispatching monitoring applications, the passengers could adjust their commuting plans and relieve the possible inconvenience consequence. Therefore, Section 3 and section 4 of this paper might not include a lot of extra discussion about the inconvenience issue brought out during the optimization managing scheme. On the other hand, the streaming platform could also provide the passenger data for the Bus company to adjust their operating strategies accordingly to the dynamic nature of PF. Even though the PF could have significant variation throughout the whole month or year, the method discussed in this paper will still be useful to keep tracking the changing PF and find a suitable schedule.

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# 3. Methods and Modeling

## 3.1. Methodology

In the first section of this paper, the researcher will demonstrate a PF analysis method that majorly focuses on the pattern of the whole route, since the PF pattern for each station along the route could vary significantly depending on their positions and specialties. By abstracting the relation between PF and time, a function could quantify the passenger demand for a route. In the second section of this paper, another function is the CC of the route, created based on the dispatched vehicles and the features of different models. With the PF data, the researcher will alter the existing dispatching system's CC based on the dynamic of PF. The efficiency of the bus route will be determined by the proportion of effective CC (PECC), which is the proportion of PF to 60% of CC (as a relatively comfortable level) on the route.

The PECC will reflect the energy efficiency of the operation in a certain bus route. The EBs' long charging times have restrained the closeness to the optimized plans. Meanwhile, not all dispatching could be best cost-minimized, considering some plans might involve vehicles to go for extra rounds and charging more frequently while some others are being used much fewer times than their counterparts. Such plans might be cost-inefficient compared to some plans that might have slightly lower PECC.

Therefore, the researcher has also considered the cost issue. The total operational cost (TOC) function included all the operational costs (which are fundamentally bus vehicle's features) and the extra cost for vehicles to go charging and back to operation. By dividing TOC by PECC, an index of the aggregate efficiency (AE) for the operation will be created to demonstrate the overall effectiveness of the optimized plan compared with the existing scheme.

A route in Hangzhou, China that has ST mode will be used for the optimizing simulation and case analysis, creating chances for AF comparison and demonstrating the effectiveness of the dispatching-charging management method described above.

## 3.2. Modeling

The PF (passenger per hour) for the whole route in a single direction during a fixed time period is simply adding all net passenger increment ( $P_{up}$ minus $P_{off}$ ) at each station:

$$\Delta PF_s = \Delta P_{up} - \Delta P_{off} \tag{1}$$

$$\Delta PF = \sum_{s=0}^{n} \Delta PF_s \tag{2}$$

$$PF_{avg} = \Delta PF / n \tag{3}$$

The overall CC function (passenger per hour) for a route during a fixed time period will be formed as well, by multiplying the number of certain vehicles n that was operating during certain period and CC for each individual vehicle has. H is an index for the vehicle type:

$$\overline{CC} = n_1 CC_1 + n_2 CC_2 + n_3 CC_3 \ldots \tag{4}$$

$$\overline{CC} = \sum_{h=0}^{n} n_h CC_h \tag{5}$$

The PECC index the percentage of Average PF ($PF_{avg}$) compared to 60% (An index for relative comfortable experience) of the overall CC. A route that has relative higher PECC will have higher operating efficiency. On the other hand, the ideal maximum PECC during the operation should be kept around 1, because that will show that through the whole operational period, the maximum situation will only take 60-70% of all the CC, preventing the huge crowd affecting passengers' experiences.

$$\overline{PECC} = \left(\overline{CC} - \overline{PF}\right) \div (60\%\overline{CC}) \tag{6}$$

Aside from PECC, TOC function will be created in the same way as CC function by finding the aggregate cost of operating the vehicles in the scheme and the extra cost of managing them to go charging. $C_s$ refers to the salaries paid to the employees including drivers and dispatch managers (human resource), $C_h$ is the average cost for operating certain type of vehicle and $n_h$ is the number for each type of vehicle running during the designated time period:

$$\sum C_h = n_1C_1 + n_2C_2 + n_3C_3 \ldots = \sum_{h=1}^{n} n_hC_h \tag{7}$$

$$\overline{TOC} = \sum_{t=0}^{i} C_s + \sum_{h=0}^{n} n_hC_h + (C_{charging}) \tag{8}$$

Finally, as PECC and TOC is optimized, its value would be numerically maximized. Meanwhile, for TOC, it's clear that a optimized plan is when its data is numerically minimized. For creating a straight forward index of overall efficiency of the route, AE index is created by dividing TOC by PECC. By weighting the AE in different periods by the length of the period, the weighted Average AE will also be derived:

$$AE = \overline{TOC} \div \overline{PECC} \tag{9}$$

$$\overline{AE} = \sum_{t=0}^{i} AE \div i \tag{10}$$

For Evaluation of the efficiency, a low AE value would show a high overall economical and management scheme, closer to the theorized optimized scheme.

## 4. Case Analysis

Route A in Hangzhou, China was selected as the case for this section. Firstly, the route operates under ST mode and have a total length at 21.6km with 19 stations. (About 1 hour in real operation). Two terminals are R and Q. Generally, Terminal R side locates in a residential area while Terminal Q is in business areas that comprise office buildings and malls. All 19 stations on Route A are divided into 5 sections that contains 3 (Section 2, 3, 4, 5 from R to Q) to 4 stations (Section 1 from R to Q) each. The average rate (passengers per hour) of passengers gets on the Buses and get off the Buses in both directions are listed in Table 2 and 3, which are then converted to the average total PF and Max PF of the routes.

**Table 2.** The PF in each section in route A and the aggregate pf from R to Q (5:30-21:30)

| Period | △PF in each section (people/hour) | | | | | Average PF | Max PF |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | |
| 5:30-7:30 | +87 | +63 | +12 | -75 | -87 | 81.3 | 162 |
| 7:30-9:00 | +253 | +156 | -45 | -174 | -190 | 205.3 | 409 |
| 9:00-11:00 | +179 | +103 | -39 | -135 | -108 | 137.6 | 282 |
| 11:00-17:00 | +101 | +92 | -33 | -76 | -84 | 90.3 | 193 |
| 17:00-20:00 | +182 | +136 | +32 | -167 | -183 | 172.7 | 350 |
| 20:00-21:30 | +76 | +20 | -23 | -42 | -31 | 47.3 | 96 |

**Table 3.** The PF In each section in route A and the aggregate PF from Q to R (6:30-22:30)

| Period | △PF in each section (people/hour) | | | | | Average PF | Max PF |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | |
| 6:30-7:30 | +56 | +42 | +6 | -35 | -69 | 51.6 | 104 |
| 7:30-9:00 | +182 | +147 | +21 | -154 | -196 | 166.9 | 350 |
| 9:00-11:00 | +145 | +99 | +18 | -112 | -150 | 126.5 | 262 |
| 11:00-17:00 | +96 | +103 | +30 | -91 | -138 | 104.5 | 229 |
| 17:00-20:00 | +245 | +133 | +11 | -156 | -233 | 196.6 | 389 |
| 20:00-22:30 | +94 | +41 | -31 | -48 | -56 | 61.4 | 135 |

Route A has deployed 4 types of vehicles that are model 5-8 described in Table 1. the number of each model, their operational cost in Route A and the cost for going to charging station and is given in Table 4.

**Table 4.** Vehicles Deployed in Route A and their features

| Bus model | Max. Carrying Capacity | Operating Range (Km) | Operating Cost in Route A (Yuan/Round (43km)) | Numbers of Vehicles |
|---|---|---|---|---|
| Model 5 (10.5m) | 86 | 210 | 113 | 2 |
| Model 6 (8m) | 62 | 160 | 96 | 4 |
| Model 7 (12m) | 88 | 190 | 127 | 6 |
| Model 8 (7.6m) | 59 | 160 | 92 | 2 |
| Min. Charging Time: | 3 Hours (2 Hour Charging, 1 Hour Traveling to charging station) | | | |
| Humanity Cost (Yuan/Worker/Day) | ≈220-280(4-5 Rounds)=50/Round | | | |

Since Route A is in ST operation mode, two terminals R and Q have different role Terminal R has the control for the dispatching management while all buses won't stay long in Terminal Q. Therefore, its dispatching system and its CC is same in both direction but have a 1-hour discrepancy. Some basic patterns have designed to meet the PF by dividing the time frame into 5 periods based on the vehicles that has been used, shown in Table 5, while its corresponding CC, average PECC (Avg. PECC) and max PECC are listed in Table 6.

**Table 5.** Vehicles Deployed in Route A and their features

| Period: | Vehicles from R to Q | Vehicles from Q to R | Nonoperating Vehicles | TOC (Hundred Yuan/Hour) |
|---|---|---|---|---|
| 5:30-6:30 | 2*Model 5<br>2*Model 6<br>(Gap≈15 min) | N/A | 6*Model 7<br>(In Charging Station)<br>2*Model 6+2*Model 8<br>(Stay in Terminal) | 6.18 |
| 6:30-7:30 | 2*Model 8<br>2*Model 7<br>(Gap≈15 min) | 2*Model 5<br>2*Model 6<br>(Gap≈15 min) | 4*Model 7<br>(In Charging Station)<br>2*Model 6<br>(Stay in Terminal) | 6.38 |
| 7:30-9:00 | 2*Model 5<br>2*Model 6<br>4*Model 7<br>(Gap≈8 min) | 2*Model 8<br>4*Model 7<br>2*Model 5<br>(Gap≈8 min) | 2*Model 7+2*Model 6<br>(Stay in Terminal) | 13.26 |
| 9:00-11:00 | 2*Model 8<br>4*Model 7<br>(Gap≈15 min) | 2*Model 8<br>4*Model 7<br>(Gap≈15 min) | 4*Model 6+2*Model 5<br>(In Charging Station)<br>2*Model 7<br>(Stay in Terminal) | 9.92 |
| 11:00-17:00 | 4*Model 7<br>2*Model 8<br>(Gap≈10 min) | 4*Model 7<br>2*Model 8<br>(Gap≈10 min) | 4*Model 6+2*Model 5<br>(In Charging Station)<br>2*Model 7<br>(Stay in Terminal) | 9.92 |
| 17:00-20:00 | 2*Model 6<br>4*Model 7<br>(Gap≈10 min) | 2*Model 6<br>4*Model 7<br>(Gap≈10 min) | 2*Model 7+2*Model 8<br>(In Charging Station)<br>2*Model 5+2*Model 6<br>(Stay in Terminal) | 10.0 |
| 20:00-21:30 | 2*Model 6<br>2*Model 5<br>(Gap≈15 min) | 2*Model 6<br>2*Model 5<br>(Gap≈15 min) | 6*Model 7<br>(In Charging Station)<br>2*Model 8<br>(Stay in Terminal) | 6.18 |
| 21:30-22:30 | N/A | 2*Model 6<br>2*Model 5<br>(Gap≈15 min) | 6*Model 7<br>(In Charging Station)<br>2*Model 6+2*Model 8<br>(Stay in Terminal) | N/A |

**Table 6.** CC, AVG.PECC, MAX.PECC for route A throughout the day

| Period | CC from R to Q | CC from Q to R | Avg. PECC | Max. PECC |
|---|---|---|---|---|
| 5:30-6:30 | 177.6 | N/A | 0.458 | N/A |
| 6:30-7:30 | 176.4 | 177.6 | 0.376 | 0.918 |
| 7:30-9:00 | 388.8 | 385.2 | 0.481 | 1.052 |
| 9:00-11:00 | 285.6 | 285.6 | 0.463 | 0.987 |
| 11:00-17:00 | 285.6 | 285.6 | 0.341 | 0.802 |
| 17:00-20:00 | 282 | 282 | 0.656 | 1.379 |
| 20:00-21:30 | 177.6 | 177.6 | 0.306 | 0.760 |
| 21:30-22:30 | N/A | 177.6 | 0.346 | N/A |

The original pattern for Route A operation is quite clear that large 12-meter Model 7 was used heavily during the morning and afternoon periods till the rush-hour during 17:00-20:00. 4 Smaller Model 6 adapted different strategy by charging in the afternoon while operate during early morning and late evening, staying in the terminal after a day's operation. With the value of PECC and TOC, Route A's Present efficiency value AE in each and weighted average of AE was calculated in Table 7.

**Table 7.** AE in different periods and weighted average AE

| | 6:30-7:30 | 7:30-9:00 | 9:00-11:00 | 11:00-17:00 | 17:00-20:00 | 20:00-21:30 | Weighted Average |
|---|---|---|---|---|---|---|---|
| AE | 16.06 | 27.78 | 21.43 | 29.09 | 15.24 | 20.20 | 23.41 |

From Table 6, 7, and 8, the pattern of PECC and TOC clearly shows that for Route A, a period that has generated a large amount of wasted efficiency and energy consumption is the 11:00-17:00. This observation is confirmed by the high AE index during 11:00-17:00 period. With a smaller PF demanded compared with the CC supplied during this period, the inefficiency during this period was significant. Meanwhile, since the total PF in the day is numerically close to the total CC, there is a period like 17:00-20:00 have less than optimal CC, shown by the max PECC much higher than 1 and approaching 1.3. The unbalance between insufficiency CC usage and excess PF refers to the fact that possible improvement could be found and executed.

By observing the operation pattern, the Researcher identified several major reasons for creating the insufficiency in the operation of Route A:

• 12-meter vehicles are usually stored in charging stations instead of terminals after a day's operation. They generally come back to operate later than the 8 and 10-meter models stored in the terminal.

• The high usage of 12-meter vehicles during 10:00-17:00 is in fact, contrasting the lower PF during the afternoon periods.

• From 7:30 to 9:00, there is more PF demand compared with the high amount of 8-meter smaller models.

• 8-meter vehicles and 10-meter vehicles have their battery depleted after morning operation, so the dispatching system has to use larger 12-meter vehicles for the afternoon and some night operation periods.

After understanding the current operational deficiency in Route A, the researcher has majorly altered the management about 12-meter vehicles and 8-meter vehicles for the simulation. The best result for all the possible simulations (New timetable, TOC, PECC, AE) are listed in Table 8 and Table 9.

**Table 8.** New optimized simulating operating mode for route A

| Period: | Vehicles from R to Q (Each hour) | Vehicles from Q to R (Each Hour) | Charging Vehicles | TOC (Yuan/Hour) |
|---|---|---|---|---|
| 5:30-6:30 | 2*Model 5<br>1*Model 7<br>(Gap≈20 min) | N/A | 4*Model 6+2*Model 8<br>(In Charging Station)<br>5*Model 7<br>(Stay in Terminal) | 5.03 |
| 6:30-7:30 | 3*Model 7<br>(Gap≈20 min) | 2*Model 5<br>1*Model 7<br>(Gap≈20 min) | 4*Model 6+2*Model 8<br>(In Charging Station)<br>2*Model 7<br>(Stay in Terminal) | 5.31 |
| 7:30-9:00 | 2*Model 5<br>5*Model 7<br>(Gap≈10 min) | 2*Model 5<br>5*Model 7<br>(Gap≈10 min) | 1*Model 7<br>(In Charging Station)<br>4*Model 6+2*Model 8<br>(Stay in Terminal) | 12.11 |
| 9:00-11:00 | 2*Model 5<br>3*Model 7<br>(Gap≈12 min) | 2*Model 5<br>3*Model 7<br>(Gap≈12 min) | 3*Model 7<br>(In Charging Station)<br>4*Model 6+2*Model 8<br>(Stay in Terminal) | 8.57 |
| 11:00-17:00 | 3*Model 6<br>2*Model 8<br>(Gap≈12 min) | 3*Model 6<br>2*Model 8<br>(Gap≈12 min) | 6*Model 7+2*Model 5<br>(In Charging Station)<br>1*Model 6<br>(Stay in Terminal, Start operating at at 15:00) | 7.22 |
| 17:00-20:00 | 1*Model 6<br>6*Model 7<br>(Gap≈10 min) | 1*Model 6<br>6*Model 7<br>(Gap≈10 min) | 3*Model 6+<br>2*Model 5+2*Model 8<br>(In Charging Station)<br>1*Model 7<br>(Stay in Terminal) | 12.08 |
| 20:00-21:30 | 2*Model 5<br>1*Model 7<br>(Gap≈20 min) | 2*Model 5<br>1*Model 7<br>(Gap≈15 min) | 4*Model 6+2*Model 8<br>(In Charging Station)<br>4*Model 7<br>(Stay in Terminal) | 5.03 |
| 21:30-22:30 | N/A | 2*Model 5<br>1*Model 7<br>(Gap≈20 min) | 4*Model 6+2*Model 8<br>(In Charging Station)<br>5*Model 7<br>(Stay in Terminal) | N/A |

**Table 9.** New CC, AVG. PECC, MAX. PECC for route A throughout the day

| Period: | 60% CC from R to Q | 60% CC from Q to R | Avg. PECC | Max. PECC |
|---|---|---|---|---|
| 5:30-6:30 | 156 | N/A | 0.521 | N/A |
| 6:30-7:30 | 158.4 | 156 | 0.426 | 1.023 |
| 7:30-9:00 | 367.2 | 367.2 | 0.506 | 1.114 |
| 9:00-11:00 | 261.6 | 261.6 | 0.632 | 1.002 |
| 11:00-17:00 | 182.4 | 182.4 | 0.534 | 1.255 |
| 17:00-20:00 | 354 | 354 | 0.521 | 1.099 |
| 20:00-21:30 | 156 | 156 | 0.348 | 0.865 |
| 21:30-22:30 | N/A | 156 | 0.394 | N/A |

The key idea is the role of shorter models and larger models will be exchanged. By keeping 12-meter Model 7 that have much larger carrying capacity in the terminal after a whole day's operation could enable them to play an important role as the major carrier during the morning and evening rush hours. Meanwhile, adjusting most shorter, smaller Model 6 and Model 8 to go charging in evening provides them the possibility to carry a suitable amount of passenger during 11:00-17:00 period where the demands drop significantly compared with two rush hours. From the Table 8 and 9, the new scheme has altered the existing situation, elevated the efficiency of 11:00-17:00 operation and reduced the crowd phenomenon that appeared during the evening rush hours, which is shown by the reduction in the max PECC. From the original plan of keeping 12-meter vehicles in charging station and start operating later than 8 and 10-meter vehicles, a better strategy would certainly be keeping 12-meter models inside the terminal.

**Table 10.** Optimized AE in different periods and weighted average AE

| | **6:30-7:30** | **7:30-10:00** | **10:00-17:00** | **17:00-20:00** | **20:00-21:30** | **21:30-22:30** |
|---|---|---|---|---|---|---|
| New AE | 12.46 | 23.93 | 15.70 | 13.52 | 23.19 | 14.45 |

**Table 11.** Comparison between PECC, TOC and AE

| | **6:30-7:30** | **7:30-9:00** | **9:00-11:00** | **11:00-17:00** | **17:00-20:00** | **20:00-21:30** | **Weighted Average** |
|---|---|---|---|---|---|---|---|
| Old PECC | 0.376 | 0.481 | 0.463 | 0.341 | 0.656 | 0.306 | -- |
| New PECC | 0.426 | 0.506 | 0.632 | 0.534 | 0.521 | 0.348 | -- |
| Old TOC | 6.38 | 13.26 | 9.92 | 9.92 | 10.0 | 6.18 | -- |
| New TOC | 5.31 | 12.11 | 8.57 | 7.22 | 12.08 | 5.03 | -- |
| Old AE | 16.06 | 27.78 | 21.43 | 29.09 | 15.24 | 20.2 | 23.41 |
| New AE | 12.46 | 23.93 | 15.7 | 13.52 | 23.19 | 14.45 | 16.81 |

The AE, PECC, TOC indexes comparison in Table 10 and 11 could provide us with a deeper insight into the overall effect the change in PECC and TOC have brought to the route as a whole. Numerically the new AE is approximately 72% compared with the original one --the theoretical optimal level would be roughly 28%. However, consider the possible varying traffic situation appeared during the operation as well as the constant changing of PF toward the lag in the timetable changing, the real-efficiency in the optimization will be smaller than the theoretical one, which is estimated at 20%.

## 5. Conclusion

This paper describes a new scheme of evaluating the efficiency of the operation of Electric Bus routes. By the PECC and TOC index, researcher have found a new scheme for overseeing the problem that possibly existing in the operational system. AE index, moreover, could be an intermediate to straightforwardly show the effectiveness for adjustment made in the operational plan. This scheme effectively combined the efficiency in the percentage of carrying capacity usage and total energy and human resources cost. The analysis of the effectiveness could be then employed to alter the dispatching schedule, which could increase the efficiency of the bus route and lessen the cost on a slight degree. The Case of Route A in Hangzhou proven the degree of optimizing level is at 20% to 25%. Although the central issues in their operation could vary significantly from the ones that emerged in Route A, many current EB operations still present high level of ineffectiveness. Therefore, the evaluation plan between passenger flow and carrying capacity could be a guide for people to figure out the spot f ineffectiveness and extend to a larger number of routes to optimize them for higher efficiency. While the AE index in this paper are not yet being fully designed to meet with the factual evaluation of the weight of the economical and passenger experience level, it could still provide a fairly useful tool in future EB route efficiency determining and optimizing plan.

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