Promoting the Marketization of Battery-Electric-Bus (BEB) based on the Satisfaction Model

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Abstract

Battery-electric-bus (BEB) is the breakthrough to promote the development of new energy vehicles. This paper aims to optimize the BEB operation mode, measure subsidies efficiency and anticipate the subsidy time to speed up the marketization of battery-electric-bus. At first, the BEB system has been abstracted and a satisfaction model with almost all the factors has been established to reflect the inter relationships. By the analysis of Hefei NO.18 bus line, a BEB demonstration line in China, we get conclusions that NO.18 bus line is suitable for Slow Charging Mode rather than Battery Leasing & Displacing Mode and the subsidy to NO.18 bus line is appropriate. Then the reliance of subsidies on battery cost is discussed. Considering the progress of battery technology and decrease of battery cost, Subsidies should be reduced appropriately over time. It is demonstrated that when the cost degrades by 60%, operators will profit even without any subsidies under the market mechanism and it is anticipated that BEB marketization will be realized in the next decade with strong and sustaining policies support from the government.

1. Introduction

The transportation sector is recognized as an important part to meet the energy and air quality goals by Chinese economic and energy policies. “The twelfth five-year special plan of electric vehicle technology development” which was released by Ministry of Science and Technology in 2012 explicitly indicated that in order to improve new energy vehicle technology, BEV should be a top priority. To achieve the strategic task, the change and upgrade of transportation energy, the new-energy auto industry should be supported by government. The “Plan on Shaping and Revitalizing the Auto Industry” was announced in 2009, which is significant for the...
alternative fuel vehicle (AFV) industry in China. This Plan launched a demonstration program of eclectric vehicle (EV) deployment in 13 Chinese cities. BEB demonstration lines are implemented in most pilot cities [1].

BEV is a research hotspot. Most of the present studies focus on the technical improvement and infrastructure development, such as vehicle structure, range extender, battery system and charging station construction. Their study showed that if the cruising distance of the electric bus extends to an acceptable range, the BEB could be the best alternative [2-5]. Though technology is advancing constantly, the performance of vehicle and the cost of batteries will not meet the demand of private car in the near future. But it is possible for BEB due to its convenience to be controlled by government and tolerant demands to battery performance. BEB marketization is a path to guide the new-energy transportation system from demonstrable operation to market-adaptive development. As a result, the popularization of BEB will gather experience for BEV marketization. And it is also significant to accumulate the optimum development of public transit at the same time.

The government has offered BEB subsidies because of the high costs of construction and operation. However, after a period of demonstration operation, as the subsidy policies have little effect, the BEB market-resilient transition has fallen short of expectations. Some BEB demonstration lines have even become no ability to support their own operation. In conclusion, the development of BEB faces many barriers in a market environment. The following problems should be solved.

What is the BEB system? Compared to traditional bus system, BEB system includes charging station infrastructure and equipment and the restraining relationships among inner elements are more complicated.

How to choose the operation mode? There are two operation modes: slow charging mode and battery leasing & displacing mode. An unreasonable choice will lead to a disappointed effect in actual operation as it takes no account for the law of BEB operation system.

How to identify whether the subsidies are useful or not? There are many types of subsidies. In most pilot cities, subsidy policies are unable to coordinate the benefit of different stakeholders, hence fail to regulate the tripartite behavior effectively. Therefore public finance leverage did not function very well. A criterion is needed to judge the availability of different subsidies combinations.

How long will it take before the government stops subsidies? The high price of batteries is the most difficult obstacle to overcome. The battery cost will go down with support policies, and as a result, the battery subsidy will be cut appropriately.

2. BEB System

2.1. Three Elements

The planning of traditional bus operation is usually based on the balance between passengers and bus operators. Passenger satisfaction and bus operator satisfaction are two elements which are needed to be considered in the operation. However, the situation becomes more complicated in BEB system because of the addition of batteries. BEB system includes three profit-driven stakeholders: passengers, battery electric bus operators (BEBO) and battery leasing & charging operators (BLCO) which will have gaming behaviors in market environment. These three elements serve each other, interact with each other, promote each other and restrict each other (Fig. 1). BEBO offers passengers with transport services to meet their travel demand, and BLCO provides battery leasing & charging services to BEBO.

2.2. Two Modes of BEB Operation

Slow Charging Mode. BEBs are charged at night when the electric price is relatively lower, and their batteries have no need to be exchanged in the day time. Each bus will run all day with one battery pack. Due to the shortage of current battery technology that batteries age fast, it is hard for one battery pack to keep a bus all day
running. As the terminal, the service station needs to have some charging equipment which are used to charge dead batteries to ensure the whole day operation. This mode is suitable for the lines with less passengers, shorter routes and shorter operation time relatively.

**Battery Leasing & Displacing Mode.** BLCO provides battery leasing and displacing service to BEBO; BEBO should pay for it. Battery leasing & displacing station which is constructed by power companies is installed in the service station. When the battery pack of electric bus is going to run out, the bus should run to the station. Its battery pack will be swapped out and replaced with a full battery pack. Battery leasing & displacing mode is suitable for the lines with more passengers, longer routes and longer operation time compared to the former mode.

![Fig. 1. The Internal Relationship of BEB System](image)

### 3. The Satisfaction Model

#### 3.1. Passenger Satisfaction

Passenger satisfaction of transit trip is mainly affected by ticket price, wait time and ride comfort. The value of satisfaction is defined in the interval between 0 and 1 where 0 means “disappointed” and 1 means “very satisfied”. Passengers will be most satisfied with free rides, so in that case, the satisfaction is set to 1. The value keeps dropping down until 0 with the ticket price growth. Hence, the ticket satisfaction is defined by:

\[
s'_t = k_0 e^{-rt}
\]

where \( t' \) is ticket price, and \( k_0 \) is a constant according to actual condition. Waiting passengers always have a tolerance limit of wait time, which means if wait time exceeds a certain value \( T_w \), people will not be satisfied with transit serve. Thus there are two kinds of passengers on one bus. Some passengers get on in time whose wait
time satisfaction is 1. The others’ wait time is longer than $T_w$, and their satisfaction is 0. Hence wait time satisfaction is defined as the ratio of former passengers to the all passengers on a bus, which is given by:

$$s^*_0 = \frac{\sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{i=1}^{I} \lambda_{ijk} T_{\phi}}{\sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{i=1}^{I} \lambda_{ijk} t_k}$$  \hspace{1cm} (2)

Where $\lambda_{ijk}$ is passengers arrival rate in time $k$ on platform $i$, and $t_k$ is BEBO departure intervals. Ride-comfort satisfaction is mainly reflected by the congestion level on the bus. When every passenger gets a seat, their ride-comfort satisfaction value is 1. Standing person satisfaction is $d_i$ when the number is no more than $r_0$.

The satisfaction of standing person is as follows:

$$f(V_{ijk}) = \begin{cases} d_i & (S < V_{ijk} \leq r_0) \\ \frac{Q - V_{ijk}}{Q - r_0} d_i & (r_0 < V_{ijk} \leq Q) \end{cases}$$  \hspace{1cm} (3)

where $V_{ijk}$ is the number of passengers, $S$ represents the number of seats on a bus, and $Q$ means the maximum number of passengers on a bus.

The ride-comfort satisfaction of a bus is given by:

$$v_{ijk} = \begin{cases} V_{ijk} & (0 < V_{ijk} \leq S) \\ S + (V_{ijk} - S) f(V_{ijk}) & (S < V_{ijk} \leq Q) \end{cases}$$  \hspace{1cm} (4)

Hence, the line ride-comfort satisfaction is given by:

$$s^w_0 = \frac{\sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{i=1}^{I} v_{ijk}}{\sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{i=1}^{I} V_{ijk}}$$  \hspace{1cm} (5)

Finally, passenger satisfaction is given by:

$$s_0 = \alpha s^*_0 + \beta s^w_0 + \gamma s^m_0$$  \hspace{1cm} (6)

where $\alpha$, $\beta$, $\gamma$ are preferences.

### 3.2. BEBO Satisfaction

The marketization of BEB decides that the most attention of BEBO is also business profit. When the income is less than the cost, the BEBO satisfaction is 0. When profits go up, the BEBO satisfaction is rising with a slower rising trend. BEBO Satisfaction is defined as:

$$s_i(\mu_i) = 1 - k_i e^{-\mu_i}$$  \hspace{1cm} (7)

where $\mu_i$ is BEBO annual profit, and $k_i$ is a constant according to actual condition. BEBO annual income is given by:

$$I_i = P_i \times W \times 365$$  \hspace{1cm} (8)
where $W$ is the total number of passengers in one day, and $W = \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{i=1}^{I} V_{ijk}$. BEBO annual cost is given by:

$$C_i = P_e \times f \times l \times E_s \times 365 + (C_v + m_i) \times V + P_e \times N_b + O_i$$

(9)

Here $P_e$ is the charging price, $f$ stands for daily departure times, $l$ denotes the lap length, $E_s$ represents the power consumption per kilometer, $C_v$ denotes the annual depreciation of BEB, $m_i$ means the annual maintenance cost of BEB, $V$ is the number of buses, $P_e$ stands for annual battery leasing cost, $N_b$ is the number of batteries, and $O_i$ is BEBO staff cost. Considering the divers need to rest, buses stop at service station for two departure intervals per lap, so $V$ is given by:

$$V = \frac{1}{v \times T_h} + 2$$

(10)

where $v$ denotes average speed, and $T_h$ stands for the departure interval during peak time. $N_b$, the number of batteries is different in two operation modes. In the slow filling mode, $N_b$ equals $V$. Nevertheless, in the slow charging mode, $N_b$ can be computed by:

$$N_b = \left[ \frac{T_{ch}}{T_y} + 1 \right] V + \left[ \frac{T_{ch} + 2T_h - (T_y + 2T_h)}{T_h} \right]$$

(11)

where $T_{ch}$ is battery charging time, and $T_y$ is the time a bus can run with a full battery. $T_y$ can be calculated by:

$$T_y = \left( \frac{L}{l} \right) \left( T_y + 2T_h \right) - 2T_h$$

(12)

Here $L$ denotes the range of BEB, and $T_y$ is average lap time. Hence, BEBO annual average margin can be calculated by:

$$\mu_1 = \frac{I_1 - C_1}{C_1} \times 100\%$$

(13)

3.3. BLCO Satisfaction

Just like BEBO, the most attention of BLCO is business profit. When the income is less than the cost, the BLCO satisfaction is 0. When profits go up, the BLCO satisfaction is rising with a slower rising trend. BLCO satisfaction is defined as:

$$s_2(\mu_e) = 1 - k_2 e^{-\mu_e}$$

(14)

where $\mu_e$ is BLCO annual profit, and $k_1$ is a constant according to actual condition. BLCO annual income is given by:

$$I_2 = P_e \times N_b + E_s \times P_e \times 365$$

(15)
and BLCO annual cost is given by:

\[ C_2 = E_c \times P_g \times 365 + (C_b + m_b) \times N_b + (C_r + m_r) \times R_c + (C_e + m_e) \times C_e + O_2 \] (16)

Here \( E_c \) is the electricity consumption per day, and \( E_c = f \times l \times E_c \), \( P_g \) stands for feed-in tariffs per kilowatt, \( C_b \) denotes the annual battery depreciation, \( m_b \) represents the annual maintenance cost of a battery pack, \( C_r \) denotes the annual depreciation of a battery displacing machine, \( m_r \) means the annual maintenance cost of a battery displacing machine, \( R_c \) is the number of battery displacing machines, \( C_e \) stands for the annual depreciation of a charging equipment, \( m_e \) represents the annual maintenance cost of charging equipment, \( C_e \) is the number of charging equipment, and \( O_2 \) is BLCO staff cost. \( Ch \) is defined as the minimum number of charging equipment that can ensure smooth operation of BEB system. \( Ch \) can be calculated by:

\[ Ch = \left( \frac{T_{ch}}{T_y} \right)^{q} + \left[ \frac{T_{ch} + 2T_y - (T_y + 2T_h) \left( \frac{T_{ch}}{T_y + 2T_h} \right)}{T_h} \right] \] (17)

Hence, BLCO annual average margin can be calculated by:

\[ \mu_2 = \frac{I_2 - C_2}{C_2} \times 100\% \] (18)

4. Analysis of Hefei No.18 Demonstration Line

4.1. Data Collection

Hefei NO.18 bus line which is the first line that has 30 BEBs in China has been operating for two years so far. It has set a new record for Chinese BEB commercialization that the running mileage of a NO.18 bus has broken through 110,000 kilometers. At the same time, Hefei becomes the city whose BEBs running mileage is longest; Statistics shows that the cumulative mileage of all Hefei BEBs has reached the 8,000,000 kilometers milestone, and these BEBs have carried over 5,000,000 passengers. In two years operation, NO.18 buses comprehensive failure rate per thousand kilometers is 0.9%, which is far less than 1.5%, the traditional buses comprehensive failure rate.

As can be seen from above data, this BEB line has met the market demands basically, and the operation status trends to be stable gradually. For more than two years, NO.18 bus line has gathered a lot of experiences for further electric vehicle commercialization. Then the NO.18 bus line is analyzed by using the above model to find a way to promote BEB marketization. There are two departure intervals in actual operation, peak time and off peak time. NO.18 BEB line operation data which are obtained from Hefei Bus Company are shown in the Table 1.

4.2. Mode Selection Analysis

We had calculated the satisfaction values with Hefei NO.18 bus line data in two operation modes. In the slow charging mode, we got \( s_0 = 0.70 \), \( s_1 = 0.47 \), and \( s_2 = 0.58 \). Satisfaction 0.6 is regarded as the criticality value which means satisfied basically. If the value is bigger than 0.6, it represents that passengers/BEBO/BLCO is pleased. The value is higher, the satisfaction level is higher. Bus if the value is lower than 0.6, it represents that passengers/BEBO/BLCO is disappointed. From the data above, we can see that passengers are very satisfied with
traffic services. Ticket price satisfaction is 0.6, wait time satisfaction is 0.74, and ride-comfort satisfaction is 0.83. BEBO is disappointed because of its heavy financial deficit. Ticket fare accounts for all the revenue of BEBO. Battery leasing cost has the highest share of BEBO cost which is followed by bus depreciation, charging cost and staff cost (Fig. 2a). BEBO has no ability to keep the buses running without any government subsidies. BLCO satisfaction is slightly below 0.6, while it is acceptable to the BLCO in pre-market promotion because BLCO need to acquire market share to ensure its future profits.

In the battery leasing & displacing mode, we got $s_0=0.70$, $s_1=0.33$, and $s_2=0.60$. Passengers are pleased as well, but BEBO satisfaction is lower than the one in slow charging mode because of the much higher cost of batteries. The cost of BEBO is nearly twice as much as its revenue. Public transport companies will not help to promote the BEB marketization (Fig. 2b). Although BLCO is basically satisfied in this operation mode, the BEBO satisfaction is obviously lower than that in slow charging mode.

From the above analysis, we get a conclusion that this BEB operation line is suitable for slow charging mode. Hefei NO.18 bus line is operated in slow charging mode and that is why its operation is relatively successful.

Table 1. The Operation Data of Hefei NO.18 Bus Line

<table>
<thead>
<tr>
<th>The range of BEB [km]</th>
<th>$L$</th>
<th>200(160)</th>
<th>Peak departure interval [min]</th>
<th>$T_n$</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lap length [km]</td>
<td>$l$</td>
<td>35</td>
<td>Normal departure interval [min]</td>
<td>$T_p$</td>
<td>12</td>
</tr>
<tr>
<td>Peak time [min]</td>
<td>$t_0$</td>
<td>120</td>
<td>Period number</td>
<td>$K$</td>
<td>2</td>
</tr>
<tr>
<td>Off peak time [min]</td>
<td>$t_1$</td>
<td>600</td>
<td>The number of displacing machines</td>
<td>$V$</td>
<td>(2)</td>
</tr>
<tr>
<td>Tolerant time [min]</td>
<td>$T_m$</td>
<td>8</td>
<td>Criticality satisfaction</td>
<td>$d_1$</td>
<td>0.6</td>
</tr>
<tr>
<td>Ticket price [RMB/y]</td>
<td>$P_t$</td>
<td>1</td>
<td>Congestion number</td>
<td>$r_0$</td>
<td>42</td>
</tr>
<tr>
<td>Feed-in tariffs [RMB]</td>
<td>$P_f$</td>
<td>0.2</td>
<td>Depreciation of BEB [RMB/y]</td>
<td>$C_c$</td>
<td>135,000</td>
</tr>
<tr>
<td>Charging price [RMB]</td>
<td>$P_c$</td>
<td>0.4(0.85)</td>
<td>Depreciation of battery [RMB/y]</td>
<td>$C_{b}$</td>
<td>150,000</td>
</tr>
<tr>
<td>Battery leasing price [RMB]</td>
<td>$P_L$</td>
<td>200,000</td>
<td>Maintenance cost of BEB [RMB/y]</td>
<td>$m_c$</td>
<td>5000</td>
</tr>
<tr>
<td>Power consumption [kwh/km]</td>
<td>$E_p$</td>
<td>1.1</td>
<td>Maintenance cost of battery [RMB/y]</td>
<td>$m_h$</td>
<td>2500</td>
</tr>
<tr>
<td>Depreciation of displacing machines [RMB/y]</td>
<td>$C_d$</td>
<td>187,500</td>
<td>Maintenance cost of displacing machines[RMB/y]</td>
<td>$m_e$</td>
<td>6000</td>
</tr>
<tr>
<td>Depreciation of charging equipment [RMB/y]</td>
<td>$C_{e}$</td>
<td>20,000</td>
<td>Maintenance cost of charging equipment [RMB/y]</td>
<td>$m_{e}$</td>
<td>2000</td>
</tr>
<tr>
<td>Bus capacity</td>
<td>$Q$</td>
<td>90</td>
<td>BEBO staff cost b</td>
<td>$O_b$</td>
<td>28000<em>5</em>V</td>
</tr>
<tr>
<td>The number of seats</td>
<td>$S$</td>
<td>32</td>
<td>BLCO staff cost b</td>
<td>$O_c$</td>
<td>40000<em>10</em>V</td>
</tr>
</tbody>
</table>

Source from Hefei Bus Company and questionnaire survey

Fig. 2. (a) The Composition of BEBO Revenue and Cost; (b) The Composition of BLCO Revenue and Cost
4.3. Subsidy Effect Analysis

In order to accelerate the marketization progress of BEB, government should take some steps to balance these three stakeholders’ interests. Relative policies and subsidies are needed in the pre-market promotion to help BEBO/BLCO break down market barriers. Subsidies to BEBO are classified into three types: charging subsidy, bus purchase subsidy and battery leasing subsidy; Subsidies to BLCO are also classified into three types: charging equipment construction subsidy, battery displacing subsidy and battery purchase subsidy. Different subsidies combinations we called subsidies packages result in different market effects. Only if the BEBO/BLCO satisfaction is over 0.6 can the subsidies package be considered to be effective.

As the Fig. 3(a) shows, coordinate axes means the proportion of three subsidy types and the orange slope represents the subsidies packages that make the BEBO satisfaction be 0.6. The space under this surface stands for ineffectual subsidies combinations. BEBO will have a certain profit margins to promote BEB marketization. On the contrary, the space above the surface means the subsidies packages are effective. The subsidies package point of HeFei NO.18 BEB line is drawn on the BEBO subsidies analysis graph (Fig. 3). The point (0, 0.36, 1) is just above the basically satisfied surface, which gives the fact that the subsidies package of Hefei NO.18 BEB line is successful and appropriate. The distance between the point and orange surface is close, which means government does not waste taxpayers’ money.

The BLCO basically satisfied surface is shown in Fig. 3(b). The space below the orange surface is extremely narrow, which means government just should offer less financial support to make BLCO be satisfied. In the situation of Hefei NO.18 BEB line, government does not offer any subsidies to BLCO because of the power companies’ ambition. Battery leasing & charging stations are operated by power companies which want to gain market share to ensure their future profits.

4.4. Subsidy Time Analysis

Subsidies are necessary for a period of time, but those will not last too long with the improvement of external market environment. Government should reduce subsidies appropriately over time with advances in technology. Nowadays, BEV is in the climax of development and the priorities of all are improving energy storage technology and decreasing the cost of batteries. Charging cost and bus purchase cost are too small compared with battery cost and they will not plummet significantly in the near future. For now, present battery performance is able to meet BEB operation demand and therefore the price of batteries becomes the primary factor that hinders the BEB marketization. Battery cost will decline steeply as production volumes increase. Individual parts will become cheaper thanks to large scale production. Equipment cost will also drop with lowering depreciation. Higher levels of automation will further trim cost by increasing quality, reducing scrap levels, and cutting labor
cost. It can be anticipated that active materials and purchased parts will make up nearly half of overall battery cost in 2020. Therefore, it is suggested that from 2009 to 2020, the price of batteries will decrease by roughly 60% to 65% [14].

From the bar charts shown in Fig. 2, battery-related charges account for over half of BEBO/BLCO construction and operation cost. When the battery cost drops to 90%, BLCO should and will be satisfied. And if the cost falls below 40%, BEBO will be glad to operate BEB lines without government subsidies (Fig. 4). With the current rate of decrease in cost, BEB commoditization may be reached in as soon as 10 years, which means that the government can stop subsidies in a decade. The battery subsidies can gradually falling over time to make sure that market mechanisms is useful. However, if the governmental economic support is to fall short of our expectations, the market penetration rate will grow more slowly.

5. Conclusion

This paper has provided advices to eliminate BEB market barriers within scientific analysis of experience from Hefei N0.18 BEB line, a successful demonstration line in China. The satisfaction model that analyzes the interior mechanisms of BEB operation system has been established to evaluate the rationality of BEB operation mode and subsidies package. In the BEB line operation, BEBO and BLCO should choose a suitable mode according to the satisfaction level. In the terms of policy making, the subsidies package is expected to be effective to market and economical to government, and the subsidies package point should be beyond the basically satisfied surface.

Government should promote the early commercialization of BEB strongly, which can help gather experience for the popularization of BEV in the near future for economists, scientists and policy makers because of its simplicity to control and tolerant demands for battery performance. Considering the progress of battery technology and the decrease of battery cost, subsidies should be reduced appropriately over time. It is anticipated that the government can stop subsidies in a decade.

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References


