Overcoming the operational challenges of electric buses: lessons learnt from China
New energy bus adoption in China

- China’s battery electric buses (abbreviated for “e-bus” thereafter) totaled 324,231 in 2019, accounting for around a half of the bus fleet—becoming the mainstreamed bus technology.
New energy bus adoption in China (cont.)

Top 15 cities with the largest number of new energy buses on street (in 1,000 buses, including BEV + PHEV) as of 2019

- Harbin: Cold climate
- Chongqing: Hilly terrain
- Foshan: 3rd or 4th tier Chinese city
- Jinan: 3rd or 4th tier Chinese city
- Hangzhou: 3rd or 4th tier Chinese city
- Chengdu: Cold climate
- Zhengzhou: 3rd or 4th tier Chinese city
- Jining: 3rd or 4th tier Chinese city
- Dongguan: Cold climate
- Xi'an: 3rd or 4th tier Chinese city
- Shanghai: 3rd or 4th tier Chinese city
- Changsha: 3rd or 4th tier Chinese city
- Beijing: Cold climate
- Guangzhou: 3rd or 4th tier Chinese city
- Shenzhen: 3rd or 4th tier Chinese city

Even distribution of new energy buses (or e-buses) across Chinese cities, regardless of city sizes & economic development stages, operating temperatures, and landscapes.
BEV’s charging technologies converge to slow & fast charging:

- **Slow charge**: depot charge
  Examples: Shenzhen (battery range 250km)

- **Fast charge**: terminal charge (recharge every 1-3 cycles)
  Example: Guiyang (battery range 90~120km)

- **Opportunity charge (pantograph/trolley)**: costly infrastructure investment & lack of operational flexibility

- **Battery swap**: extra battery reserve will drive up the cost & large land occupation

- **Wireless charge**: costly technology, energy loss, and safety concerns

Source: WRI 2019
Setting the scene: lengths of e-buses

The mainstreamed e-buses in China are 8~12 meter buses, with a limited number of articulated e-buses and electric double deckers.

![Diagram showing annual sales ratios of e-buses with different lengths from 2015 to 2019.](image)

- **Articulated buses**
- **Double deckers**

Source: CATARC 2020
Research question:

- The total cost of ownership of e-bus (8-year service life) is already lower than that of diesel bus.
- The central question is no longer how to lower the TCO of e-buses to accelerate the adoption, but improve the operation efficiency.
Research Method

- **E-bus “big data” analysis**
  Collaborated with National New Energy Vehicle Big Data Lab to gather city-level e-bus fleet’s operation statistics of 15 Chinese cities based on e-bus On-Board Diagnostic data (OBD), including city-level vehicle availability, daily operating mileages, and statistics of charging behaviours.

- **Survey through purposive sampling**
  Conducted a survey to bus operators and transit bureau officials in 10 sampled cities to triangulate the big data analysis (use Bootstrap sampling to balance the sample size of each city).
City Representativeness

- Different levels of e-bus adoption, development stages, and environment like temperature and landscape
- E-bus charging technology deployed
- Major OEMs and market landscape

Sampled cities with different levels of e-bus adoption
(% of e-buses in the fleet)

Yellow bar is the sampled city and their e-bus adoption levels

Geographical locations of the sampled cities
City Representativeness: Brand coverage

- China’s domestic e-bus market is fragmented. Although it increases the market competition and lower the prices of e-buses, it also creates the challenges of bus operators to discern e-buses’ technical performances and qualities.

### Top 10 OEMs with the largest annual sales as of 2019

<table>
<thead>
<tr>
<th>OEM</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yutong</td>
<td>25%</td>
</tr>
<tr>
<td>BYD</td>
<td>16%</td>
</tr>
<tr>
<td>Zhongtong</td>
<td>8%</td>
</tr>
<tr>
<td>CRRC Times</td>
<td>7%</td>
</tr>
<tr>
<td>Zhuhai Guangtong</td>
<td>6%</td>
</tr>
<tr>
<td>BAIC Futian</td>
<td>5%</td>
</tr>
<tr>
<td>Xiamen Golden Dragon</td>
<td>4%</td>
</tr>
<tr>
<td>King Long-Nanjing</td>
<td>2%</td>
</tr>
<tr>
<td>Ankai</td>
<td>2%</td>
</tr>
<tr>
<td>King Long-Xiamen</td>
<td>2%</td>
</tr>
</tbody>
</table>

### The brand coverage of the selected sampled cities

<table>
<thead>
<tr>
<th>City</th>
<th>Yutong</th>
<th>Zhongtong</th>
<th>Nanjing</th>
<th>Hangzhou</th>
<th>Beijing</th>
<th>Qingdao</th>
<th>Zhuzhou</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenzhen</td>
<td>√</td>
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<tr>
<td>Zhengzhou</td>
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<tr>
<td>Nanjing</td>
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<td>Hangzhou</td>
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<td>Beijing</td>
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<tr>
<td>Qingdao</td>
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<td>Zhuzhou</td>
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<td>√</td>
</tr>
</tbody>
</table>

Source: CATS 2019

Source: WRI 2019
City Representativeness: Charging technologies

- The way to operate slow charging e-buses differs from that for fast charging e-buses.
- Many sampled cities rely on slow charging, but there are also quite a few cities deploying fast charging. Hybrid cases also exist (like Nanjing and Suzhou).

<table>
<thead>
<tr>
<th>Charging technologies and e-bus operation schemes of the sampled cities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Slow charging operation</strong></td>
</tr>
<tr>
<td>Battery range (rough)</td>
</tr>
<tr>
<td>Above 120km</td>
</tr>
<tr>
<td>Daytime recharging</td>
</tr>
<tr>
<td>0~1 recharge</td>
</tr>
<tr>
<td>1~2 hour charging sessions</td>
</tr>
<tr>
<td>Overnight charging</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>Sampled cities</td>
</tr>
<tr>
<td>Shenzhen, Zhengzhou, Hangzhou, Shanghai, Wuhan, Qingdao, Z</td>
</tr>
<tr>
<td>hou Zhou, Yichang</td>
</tr>
</tbody>
</table>

Source: WRI 2019
Evaluating city-level e-buses’ operation efficiency

• Pre-condition: Bus electrification will not affect existing operation like route alignment or timetables.

• Operation efficiency indicators
  1. (City-level) average daily vehicle availability
  2. (City-level) average daily mileage
  3. (Route-level or city-level) replacement rate between diesel buses and electric buses
1. Vehicle availability

Low vehicle availability rates due to:
1. Vehicle downtime
2. Back-up vehicles not deployed when passenger demand is low
3. Unfit for operation resulting from limited ranges and etc.
4. Issues with OBD data reporting

Average availability rates of e-buses for 15 cities in summer workdays

Source: WRI 2019
2. Daily mileage

The national average daily mileage of e-buses was 123 kilometers, nearly half of that for diesel buses.
Sizes of e-buses deployed and routes typically targeted for electrification (survey result)

Unit: bootstrapped sample size

Source: WRI 2019
The chart illustrates the daily mileage of electric buses and diesel buses in different cities under three penetration scenarios: high, moderate, and low.

### High penetration of e-buses
- **Shenzhen**: 228 km
- **Beijing**: 228 km
- **Qingdao**: 174 km
- **Wuhan**: 170 km
- **Chongqing**: 158 km

### Moderate penetration of e-buses
- **Shenzhen**: 170 km
- **Beijing**: 71 km
- **Qingdao**: 114 km
- **Wuhan**: 99 km
- **Chongqing**: 158 km

### Low penetration of e-buses
- **Shenzhen**: 170 km
- **Beijing**: 71 km
- **Qingdao**: 99 km
- **Wuhan**: 99 km
- **Chongqing**: 158 km

The table below shows the e-bus penetration rates for each city:

<table>
<thead>
<tr>
<th>City</th>
<th>E-bus penetration rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenzhen</td>
<td>96%</td>
</tr>
<tr>
<td>Beijing</td>
<td>23%</td>
</tr>
<tr>
<td>Qingdao</td>
<td>23%</td>
</tr>
<tr>
<td>Wuhan</td>
<td>21%</td>
</tr>
<tr>
<td>Chongqing</td>
<td>4%</td>
</tr>
</tbody>
</table>

Source: WRI 2019
3. Route-level replacement rate between diesel buses and e-buses

Source: WRI 2019
### 3. Route-level replacement rate between diesel buses and e-buses (cont.)

- **Options to replace an all-day diesel bus with e-buses**

<table>
<thead>
<tr>
<th>Option</th>
<th>Time</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>An all-day diesel bus</strong></td>
<td>6:00am - 22:00pm</td>
<td>Diesel #1 (260km)</td>
</tr>
<tr>
<td><strong>1:2 (e-bus) replacement</strong></td>
<td>6:00am - 14:00pm</td>
<td>E-bus #1 (130km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E-bus #2 (130km)</td>
</tr>
<tr>
<td><strong>2:3 (e-bus) replacement</strong></td>
<td>6:00am - 17:00pm</td>
<td>E-bus #1 (190km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E-bus #2 (80km)</td>
</tr>
<tr>
<td><strong>Efficient replacement</strong></td>
<td>6:00am - 19:00pm</td>
<td>E-bus #1 (220km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E-bus #2 (40km)</td>
</tr>
</tbody>
</table>

Source: WRI 2019
Factors that affect electric bus's operational inefficiency

Source: WRI 2019

Unit: bootstrapped sample size
1. What technical specifications would be required from e-buses that won’t affect operation efficiency?

- **Slow charging operation** *(depot charging)*:
  - Battery range: 120~280 km (depending on route length and daily operating mileage)
  - Daytime charging: 0~1 times, 1~1.5 hour duration for each session
  - Night-time charging: a must
  - Example: Shenzhen

- **Fast charging operation** *(terminal charging)*:
  - Battery range: 60~120 km (depending on route length, layover time, terminal points, and charger availability)
  - Daytime charging: 2~4 times, 10~20min duration for each session
  - Night-time charging: no need
  - Example: Guiyang
1. What technical specifications would be required from e-buses that won’t affect operation efficiency? (con.t)

- **Fast-charging case 1: ample chargers**
  - One terminal point
  - 15min recharge after each roundtrip (30km)
  - Range: above 50km

- **Fast-charging case 2: limited chargers**
  - One terminal point
  - 15min recharge every two roundtrips (60km)
  - Range: above 100km

- **Fast-charging others:**
  - Two terminal points
  - Different route lengths
  - Range: above 83km

Assume the maximum DOD is 40%.

Source: WRI 2019
1. What technical specifications would be required from e-buses that won’t affect operation efficiency? (con.t)

- **Fluctuations of battery ranges:**
  - Local drive cycles (NEDC, real world)
  - Winter vs. summer; with AC vs. without AC
  - Battery degradation

- **Fluctuations of charging speeds:**
  - Winter vs. summer

Deviation of actual ranges to the ranges labelled by manufacturers (%)

<table>
<thead>
<tr>
<th>Temperature of charging</th>
<th>Prolonged charging duration (SOC from 20% to 100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 15°C</td>
<td>Within 5 mins</td>
</tr>
<tr>
<td>5°C</td>
<td>10 mins</td>
</tr>
<tr>
<td>0°C</td>
<td>25 mins</td>
</tr>
<tr>
<td>-15°C</td>
<td>50 mins</td>
</tr>
</tbody>
</table>

Sources: CATS 2019, Yutong 2019
2. How many chargers would be needed for e-buses at the planning/procurement stage?

<table>
<thead>
<tr>
<th>City</th>
<th>Ratio of e-buses to chargers (Target)</th>
<th>Ratio of e-buses to chargers (Reality)</th>
<th>Rules-of-thumb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenzhen</td>
<td>3 : 1</td>
<td>3 : 1</td>
<td></td>
</tr>
<tr>
<td>Zhengzhou</td>
<td>2 : 1</td>
<td>2 : 1</td>
<td>2 : 1 or 3 : 1</td>
</tr>
<tr>
<td>Nanjing</td>
<td>1 : 1</td>
<td>14 : 1</td>
<td></td>
</tr>
<tr>
<td>Qingdao</td>
<td>3 : 1</td>
<td>3 : 1</td>
<td></td>
</tr>
<tr>
<td>Chongqing</td>
<td>6 : 1</td>
<td>6 : 1</td>
<td></td>
</tr>
<tr>
<td>Guiyang</td>
<td>--</td>
<td>6 : 1</td>
<td>6 : 1</td>
</tr>
<tr>
<td>Beijing</td>
<td>--</td>
<td>9 : 1</td>
<td></td>
</tr>
</tbody>
</table>

Source: WRI 2019
2. How many chargers would be needed for e-buses at the planning/procurement stage?

- E-bus charger installation is often prohibited by lack of bus terminals (or depots) and grid capacity.

Factors affecting e-bus charger deployment

<table>
<thead>
<tr>
<th>Factor</th>
<th>Most Important</th>
<th>Moderate Important</th>
<th>Least Important</th>
<th>Unit: bootstrapped sample size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Others</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of business model</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid constraints</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Lack of terminals/deposits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incompatible chargers</td>
<td></td>
<td></td>
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<tr>
<td>Lengthy approval process</td>
<td></td>
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</tr>
</tbody>
</table>

E-buses require dedicated distribution substations

<table>
<thead>
<tr>
<th>Operation</th>
<th># of e-buses at terminal/depot</th>
<th>Charging power</th>
<th>Rated capacity of substations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow-charging operation</td>
<td>20 e-buses, 2:1 vehicle-to-charge ratio</td>
<td>40kW</td>
<td>500kVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120kW</td>
<td>1500kVA</td>
</tr>
<tr>
<td>Fast-charging operation</td>
<td>20 e-buses, 6:1 vehicle-to-charge ratio</td>
<td>120kW</td>
<td>600kVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>240kW</td>
<td>1200kVA</td>
</tr>
</tbody>
</table>

Source: WRI 2019
3. How should be the operation scheduling/blocking updated for e-buses?

- No one-size-fits-all solutions: e.g., shall e-buses prevent charging at peak-hours?

<table>
<thead>
<tr>
<th></th>
<th>6:00am</th>
<th>Diesel #1 (260km)</th>
<th>22:00pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A full-day diesel bus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:2 (e-bus) replacement</td>
<td>6:00am</td>
<td>E-bus #1 (130km)</td>
<td>14:00pm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>22:00pm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E-bus #2 (130km)</td>
<td></td>
</tr>
</tbody>
</table>

Percent of e-bus charging sessions that are within peak hours

Source: WRI 2019
3. How should the operation scheduling/blocking be updated for e-buses?

- Optimizing e-bus scheduling/blocking has to take many new factors into consideration that the old diesel bus operation scheduling doesn’t consider, like charging duration vs. layover/break duration, battery range vs. daily mileage needs, time of charging vs. operation schedules.

### a. 2:3 e-bus replacement

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<thead>
<tr>
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<tbody>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Daily operating mileage</th>
</tr>
</thead>
<tbody>
<tr>
<td>200km</td>
</tr>
<tr>
<td>160km</td>
</tr>
</tbody>
</table>

### b. More efficient replacement

<table>
<thead>
<tr>
<th>Full-day e-bus 1</th>
<th>Full-day e-bus 2</th>
<th>Full-day e-bus 3</th>
<th>Full-day e-bus 4</th>
<th>Full-day e-bus 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Daily operating mileage</th>
</tr>
</thead>
<tbody>
<tr>
<td>240km</td>
</tr>
<tr>
<td>200km</td>
</tr>
</tbody>
</table>

Source: WRI 2019
3. How should be the operation scheduling/blocking updated for e-buses? (con.t)
3. How should be the operation scheduling/blocking updated for e-buses? (con.t)

- OBD send risk alerts of vehicle malfunctions
- Check the alerts
- Evaluate maintenance needs
- Send maintenance notifications

Source: Jinan Bus Company
Summaries and recommendations

- Bus operators\transit authorities
  - Plan bus routes’ electrification sequences
  - Plan charging infrastructure ahead of the time
  - Research before procurement (one spec for all routes vs. different spec for different routes)

### Determinants of e-bus technical specifications

<table>
<thead>
<tr>
<th>Charger availability</th>
<th>E-bus selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available grid capacity</td>
<td>Option 1: Fast charging with a higher battery range per a certain period of charging</td>
</tr>
<tr>
<td>Land availability for terminals/depots</td>
<td></td>
</tr>
<tr>
<td>Route feature</td>
<td>Option 1: Fast charging</td>
</tr>
<tr>
<td>Daily operating mileage</td>
<td>Option 2: Slow charging with larger battery sizes</td>
</tr>
</tbody>
</table>

Source: WRI 2019
Summaries and recommendations

- Bus operators\transit authorities
  - Send staffs to OEMs for on-site supervision for vehicle quality assurances and product consistency
  - Test runs with AC on
- Government & associations
  - Establish a national testing, scoring, and noticing system for the technical performance of different e-bus brands

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Measurement method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy intensity (kWh/100km)</td>
<td>E-bus departs with 100% SOC and travel for 50km (localized drive cycles). Then recharged to 100% SOC and log the energy amounts.</td>
</tr>
<tr>
<td>Battery range (km)</td>
<td>Utilize the above energy amounts (correspondent to 50 km travel) and the vehicle’s total energy amounts to derive battery range.</td>
</tr>
<tr>
<td>Battery range per a certain duration of charging</td>
<td>E-bus departs with 100% SOC and travel for 50km (localized drive cycles). Then recharged to 100% SOC and log the charging time duration.</td>
</tr>
</tbody>
</table>

Source: WRI 2019
Summaries and recommendations

- Bus operators
  - monitor e-bus operation.
  - adopt bus scheduling/blocking software to ensure efficient and coordinated operation and charging schedules for e-buses.
  - peer-to-peer exchanges on e-bus scheduling and blocking.

Example: bus scheduling software
### Recommended e-bus operation schemes at different stages of e-bus adoption

<table>
<thead>
<tr>
<th>Operation schemes</th>
<th>Advantages</th>
<th># of additional buses</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix of e-buses and diesel buses</td>
<td>No additional buses</td>
<td>No addition</td>
<td>Early stage √</td>
</tr>
<tr>
<td></td>
<td>No change to schedules</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:2 (e-bus) replacement</td>
<td>Easy adjustments to schedules</td>
<td>Approx. 30%~50% additional buses</td>
<td>Early stage (limited operation experiences or battery ranges)</td>
</tr>
<tr>
<td>2:3(e-bus) replacement</td>
<td>Relatively each adjustment to schedules</td>
<td>Approx. 15%~30% additional buses</td>
<td>Early stage √ (limited operation experiences or battery ranges)</td>
</tr>
<tr>
<td>More efficient replacement</td>
<td>Reduction of the number of additional buses</td>
<td>Approx. 5%~15% additional buses</td>
<td>Matured stage √ (improved operation experiences)</td>
</tr>
<tr>
<td>1:1 (e-bus) replacement</td>
<td>No additional buses</td>
<td>No addition</td>
<td>Matured stage √ (improved operation experiences and battery ranges)</td>
</tr>
</tbody>
</table>

**Source:** WRI 2019
Thank you!