Study on Utility Factor for Energy Consumption of Hybrid Electric Bus

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Keywords. Utility Factor, Plug-in HEV Bus, Comprehensive Energy Consumption, Travel Characteristics

Abstract. Due to the environmental benefits of hybrid electric vehicles, the vehicle population would steadily grow in the next several decades. This paper analyses a large number of road data of buses. The Daily Vehicle Kilometers Travelled of new energy vehicles is 139km and that of internal combustion engine vehicles is 143km. With 50% coverage, both NEVs and ICEVs are 135km. With 80% coverage, both NEVs and ICEVs are 185km. Hybrid electric buses are charged at least once a day. The average charging frequency is 2 times a day in summary. Then construct the utility factor of bus for calculating the comprehensive energy consumption. To verify the validity, a group of experiments were carried out and a new calculation formula was conducted. The comprehensive results by using UF(B) can help users to understand actual energy consumption more clearly.

1. Introduction
After the publication of SAE J2841 standard, the concept of Utility Factor (UF) has been gradually cited by the EU GTR15, Japan and CHINA VI[1][2][3][4]. No exception of the revised version of the GB/T 19753. However, what is different from utility factor of CHINA VI (UF(CN6)), utility factor of trip chain range (UF(TC)) is applied to that standard, which is defined as “the ratio of range of the vehicle in CD mode after one charge”[5]. In comparison, UF(TC) shows a certain degree of advancement in some aspects. First, it replaces the assumption of charging frequency with statistical results based on actual road data. Second, the mileage data comes from the uninterrupted collection of 41 typical cities in China for one year, which is massive and real. Finally, this theory reinforces the importance of the unique charging habits and travel characteristics in the energy consumption calculation process, especially for China's national conditions in which the charging piles are unevenly distributed.

Medium and Long Term Development Plan of Automobile Industry sets the goal of 2025 to be the international leading level of energy consumption of new energy vehicles, which further requires the relevant test method standards to evaluate and reflect the energy consumption truly and effectively[6]. The revision GB/T 19754-2015 Test Methods for Energy Consumption of Heavy-Duty Hybrid Electric Vehicles has clearly stated the terms for applying the UF(TC) to the weighted summation of the three test parts[7].

This paper explored the utility factor for hybrid electric commercial vehicle energy consumption calculation, and discussed the feasibility of method using UF through experiments.

2. Construction of Utility Factor

2.1. Vehicle type survey
Unlike light vehicles, there are many types of hybrid commercial vehicles, and more importantly, there are significant differences between key characteristics such as the operating range, usage and performance of different types [8]. The recently released GB/T 38146.2-2019 China automotive test cycle- Part 2: Heavy-duty Commercial Vehicles has constructed six curves for various types of vehicles [9]. New energy commercial vehicles are usually divided into two categories: commercial passenger cars and special vehicles. Passenger cars are mainly divided into buses and coaches. Data in 2017 showed that buses accounted for 88% of the total. In the same year, a total of 198,000 new-energy commercial vehicles were sold, of which 184,000 were pure electric commercial vehicles and 14,000 were plug-in hybrid commercial vehicles. In addition, 119,000 plug-in hybrid buses were sold, accounting for 85% of the total sales of plug-in hybrid commercial vehicles [10].

2.2. Travel characteristics

This study relies on Chinese Automobile Driving Test Cycle Information System supported by the ministry of industry [11]. The data downloaded from the original database contains speed, time and SOC. 70,000 kilometers of 300 vehicles from March to August 2018 were involved in calculation.

![Processing data diagram](image1)

**Figure 1.** Processing data diagram

On the basis of the SOC value of data, this study selected the fragments of the continuous decline stage of the SOC, called discharging, and restructure the data in chronological order in MATLAB, such as the Figure1 shown. This process is called data recombination and the resulting new data is classified as a primary database.

Calculate the following two characteristics: Daily Vehicle Kilometres Travelled (abbreviated to DVKT)[12] and charging frequency. The former is the mileage of a vehicle in one day, where the mileage is obtained by integrating speed and time. Draw the curve of SOC with time. Each wave peak corresponds to the end of a charging behaviour. The charging frequency is determined by the number of wave peaks, which is defined as the number of charging in one day.

![DVKT graph](image2)

**Figure 2.** The DVKT of hybrid electric buses.

![Charging frequency graph](image3)

**Figure 3.** The charging frequency of hybrid electric buses.
The DVKT and charging frequency of hybrid electric buses are shown in Figure 2 and 3. The DVKT of new energy vehicles (abbreviated to NEVs) is 139km and that of internal combustion engine vehicles (abbreviated to ICEVs) is 143km, which is basically the same. With 50% coverage, both NEVs and ICEVs are 135km. With 80% coverage, both NEVs and ICEVs are 185km. The preliminary conclusion is that the DVKT characteristics of NEV and ICEV buses are basically the same. Hybrid electric buses are charged at least once a day and rarely do not charge all day. The average charging frequency is 2 times a day in summary.

2.3. Utility factor of bus
On the basis of theory of UF(TC) and the travel characteristics data above, utility factor of hybrid electric bus (abbreviated to UF(B)) are established. The following Figure 4 illustrate a set of UF(B) curves, ranging from 0 to 1.

Reference SAE J2841, APPENDIX A - UTILITY FACTOR CURVE FIT ALGORITHM, this study calculates UF(B) fit parameters. The coefficients for the UF(B) fit calculations are shown in Table 1. While \( d_j \) is measured distance driven at the end of period \( j \).

\[
UF_j(d_j) = 1 - \exp\left\{-\left(\sum_{i=1}^{k-1} c_i \times \left(\frac{d_j}{d_n}\right)^{c_i}\right)\right\} - \sum_{i=1}^{j-1} UF_i
\]

(1)

**Table 1.** Parameters for the regional determination of fractional UF(B)

| Parameter | Value | \( d_n \) | \( c_1 \) | \( c_2 \) | \( c_3 \) | \( c_4 \) | \( c_5 \) |
|-----------|-------|-----------|-----------|-----------|-----------|-----------|-----------|
| Parameter | Value | \( c_6 \) | \( c_7 \) | \( c_8 \) | \( c_9 \) | \( c_{10} \) |
| \( d_n \) | 300   | 2.81      | 10.33     | -136.63   | 1270.35   | -5933.17  |
| \( c_6 \) | 16000.40 | -25701.11| 24109.94 | -12167.89| 2550.77   |

3. Energy consumption discussion
In this part, the energy consumption test was conducted in accordance with standards and UF(B) are used as weighting coefficient to evaluate comprehensive energy consumption of test vehicle.

3.1. Experiment data
The C-WTVC test of a hybrid electric bus was conducted in a four-wheel drive chassis dynamometer in accordance with GB/T 19754-2015. Unlike condition A and condition B in test method of light-duty HEV, three stages are defined in test method of hybrid electric buses. This includes pure electric driving (Stage I), charge adjustment of REESS (Stage II) and charge sustaining (Stage III). The energy consumption process is shown in Figure 5.
Stage I: pure electric driving
Stage II: charge adjustment of REESS
Stage III: charge sustaining

**Figure 5.** Schematic diagram of energy consumption process.
After running continuously at a constant speed of 40km/h for 51.2km, the vehicle completed the pure electric driving stage. Three test cycles were carried out in charge adjustment of REESS stage. Three cycles were also carried out in charging sustain charge, but only average results were recorded during processing in this study. Number these test cycles in turn (cycle 1~5) and record these results in Table 2.

**Table 2.** Results of energy consumption.

| Stage | Cycle | Mileage (km) | Fuel Consumption (L/100km) | Electric Consumption (Wh/km) |
|-------|-------|--------------|-----------------------------|-----------------------------|
| I     | 1     | 51.20        | 0                           | 478.71                      |
| II    | 2     | 11.58        | 27.79                       | -241.84                     |
| II    | 3     | 11.60        | 27.70                       | -240.56                     |
| II    | 4     | 11.59        | 27.63                       | -223.53                     |
| III   | 5     | 11.60        | 21.85                       | -8.79                       |

In the current standard, these results of the three stages(a total of 7 values) are recorded separately, such as pure electric mileage, fuel consumption and electric consumption of each stage. The average value of all test cycles in Stage II is taken as the final results of Stage II. The correction value of all test cycles in Stage III is taken as the final results of Stage III. This presentation is clear but verbose. It is difficult to establish uniform standards to measure the energy consumption level of vehicles. So how to weight the results is particular important.

### 3.2. Comprehensive energy consumption using UF(B)

However, there is no public revision on how to introduce UF into formula in GB/T 19754 at present. A formula suitable for heavy-duty HEV was composed by referring to the method of light-duty HEV. Actually, there are multiple possibilities for the weighting process, but only one is discussed in this study. The calculation of fuel consumption is taken as an example. No fuel consumption in the Stage I. Calculate the weighted fuel consumption (abbreviated to FC\( _W \)) with Weighted Sum Method for Stage II and Stage III. Similarly, the weighted electric consumption (abbreviated to EC\( _W \)) is weighted by other stage values. UF\( _s \) can be calculated by Equation1.

\[
FC_{W} = UF_{II} \times FC_{II} + (1 - UF_{I} - UF_{II}) \times FC_{III}
\]

(2)

\[
EC_{W} = UF_{I} \times EC_{I} + UF_{II} \times EC_{II} + (1 - UF_{I} - UF_{II}) \times EC_{III}
\]

(3)

**Table 3.** Results of comprehensive energy consumption.

| Stage | UF(B) | FC L/100km | EC Wh/km | FC\( _W \) L/100km | EC\( _W \) Wh/km |
|-------|-------|------------|----------|---------------------|-------------------|
| I     | 0.463587 | 0          | 478.71   |                     |                   |
| II    | 0.255023 | 27.71      | -235.99  | 13.22               | 161.74            |
| III   | 0.28139  | 21.85      | -8.79    |                     |                   |

The results of the experiments are represented by only two numbers, FC\( _W \) and EC\( _W \) in Table3. In fact, three stage are not completely independent when driving on the road. The user will not pay attention to the energy consumption of a single stage when driving. The focus may be more on the average fuel
consumption or electric consumption of a cycle, a day, a week or a month, etc. So it is easier and more acceptable for users to perform a comprehensive evaluation. In addition, the comprehensive energy consumption results can be used to obtain the unique ranking of vehicles, which reduce the probability of contradiction in multi-index evaluation process. It also be a means to optimize the energy management systems for manufacturers.

In summary, the application of utility factor in consumption calculation not only shows the strong correlation between travel characteristics and economic performance, but also simplifies the display of results.

4. Conclusion
Taking plug-in hybrid electric buses as the research object, this article constructed the utility factor applicable to such vehicles and a set of comprehensive energy consumption calculation formulas for the revision of GB/T 19754 standard. Analyzing the actual road data of a large number of NEV and ICEV buses, it is found that the travel characteristics are basically the same, and the average charging cycle of plug-in HEV is 2 times a day. According to the utility factor theory of trip chain and the above characteristics, utility factor for bus is constructed. The results aim at better representing the real-world scenarios energy consumption of plug-in HEV bus, in view of informing the UF revision for the next phase of standard. Then, the team will continue to improve the Utility Factor of other commercial vehicles.

5. Acknowledgments
This study is supported by the National Key R&D Program of China (2018YFB0106404) and Research and Development of Chinese New Energy Automobile Products Test Driving Cycles (CATC).

6. Reference
[1] SAE International. Utility factor definitions for plug-in hybrid electric vehicles using travel survey data, SAE J2841[R].SEP,2010.
[2] SAE International. Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, including Plug-in Hybrid Vehicles, SAE J1711[S].JUN,2010.
[3] ECE/TRANS/WP.29/GRPE. Global technical regulation on Worldwide harmonized Light vehicles Test Procedures (WLTP). 2019..
[4] Ministry of Environment Protection. GB 18352.6 Limits and measurement methods for emissions from light-duty vehicles (CHINA 6) [S]. 2016.
[5] An Xiaopan. Analysis of PHEV Utility Factor and Fuel Consumption Based on Real Road[C]. China Society of Automotive Engineers.2019SAE-China Congress Selected Papers. 2019:499.
[6] Ministry of Industry and Information Technology of the People’s Republic of China. Medium and Long Term Development Plan of Automobile Industry,2017.
[7] GB/T 19754-2015 Test Methods for Energy Consumption of Heavy-Duty Hybrid Electric Vehicles [S].2015.
[8] GB/T 15089. Classification of power-driven vehicles and trailers[S].2011.
[9] GB/T 38146.2 China Automotive Test Cycle – Part 2: Heavy-duty commercial vehicles[S].2019.
[10] Zhongwen Xi. Statistical Chart of Sale of Commercial Vehicles (Incomplete Vehicles) across China from Jan. to Dec in 2017[J]. Special Vehicles & Spare Parts and Components,2018(01):61-63.
[11] Chinese Automotive Driving Test Cycle Information System. http://www.chinacatc.com/.
[12] Lywei Wu. A GPS-based research on the driving patterns of private passenger vehicle in Beijing[D]. Tsinghua University, 2013.