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Road Test-Based Electric Bus Selection: A Case Study of the Nanjing Bus Company

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Abstract: Globally, the use of electric vehicles, and in particular the use of electric buses, has been increasing. The city of Nanjing leads China in the adoption of electric buses, supported by city policies and infrastructure. To lower costs and provide a better service, vehicle selection is crucial, however, existing selection methods are limited. Accordingly, Nanjing Bus Company developed a test method based on road tests to select a bus. This paper presents a detailed description of the test method and a case study of its application. The method included an organization structure, selection of eight test vehicles (four 10 m length, four 8 m length) from four brands (a total of 32 test vehicles), selection of indicators and selection of routes. Data was collected from repeated drives by 65 drivers over an 8-week period. Indicators included power consumption, charging duration, failure duration and driving distance. It is concluded that the road test method designed and conducted by the Nanjing Bus Company provides a good framework for the selection of pure electric buses. Furthermore, subsequent experience with selected buses supports the validity and value of the model.

Keywords: electric bus; vehicle selection; road operation test; sustainable development

1. Introduction

In recent years, the demand for improved transportation systems has been on the rise owing to the enhancements in the quality of individual living. Public transportation plays an increasingly significant role in urban centers worldwide in the terms of its economic, environmental and sustainable capacity [1]. As part of the expansion of urban public transport networks, bus transit systems make up a growing proportion of urban passenger transport. There were 608,600 public buses in China by 2017. At this time, the passenger volume for the bus transit system was approximately 74.5 billion annually, accounting for 58% of the total urban passenger transport volume, which was far more than the rail transport volume [2].

However, concerns regarding air pollution triggered by the emission of traffic exhausts are unavoidable. Consequently, the appeal for the amelioration of air quality to guarantee a certain standard of living led considerable attention to the electrification of urban transportation systems [3]. It is noteworthy that the use of electric buses is not a new concept. The use of battery-powered electric buses can be traced back to the early 2000s, which matured gradually during the mid-2000s, followed by dramatic developments during the past decade [3].

Energy efficient vehicles are being promoted worldwide as an acceptable approach to address vehicle-based air pollution. Some developed countries, like the United States and Sweden, are making efforts to improve energy efficiency and reduce the use of fossil-fuel buses in mass transit systems [4]. Nevertheless, China has been increasing its number of fossil-fuel vehicles rapidly—vehicles with comparatively high emissions and excessive energy usage, which has resulted in severe health, energy and congestion problems [5]. In order to address this dilemma, and keep the pace of the trend of global cities, China has been embracing the use of pure electric buses owing to their characteristics of zero emissions, low noise, superior driving stability and good economic efficiency [6].

The Chinese government has promulgated policies to support this transition, such as financial subsidies for bus-related industries and companies to vigorously promote the use of electric buses [7]. In 2015, Green development has become a national strategy [8], and national ministries have enacted some approaches to managing a mass transit infrastructure in relation to electric vehicles [9].

Vehicle performance indicators are fundamental factors for selecting the proper bus type. However, certain weaknesses of pure electric buses, such as a relatively short endurance mileage and a long charging time, are pending obstacles to be overcome. Therefore, the selection process for pure electric buses is more complicated than it is for common buses.

There are three generally accepted methods used to carry out dynamic behavior testing of new electric vehicles—computer simulation test, test bench simulation, and road testing [10].

Compared with the first two methods, which have shorter test cycles and lower costs and are generally used by manufacturers, road tests are more intuitive to reflect the vehicle properties, as the consequence of their superior capacity to provide accurate results in a setting close to real operational conditions, thus increasing the reliability for bus companies to test vehicle performance.

In regard to the selection of electric vehicles, Zhang et al. concluded that the evaluation and selection of new electric vehicles from certain developed countries like United States, Germany and Japan, relies on relevant research institutions and is based on the advanced vehicle testing activity and fuel cell technology [11], however, it is not the case in China. Although Chinese government has enacted several standards related to pure electric vehicles in terms of basic safety and power systems [12], the selection processes based only on the minimum criteria set out in these standards is inadequate and may not provide sufficient information relevant to actual operation.

In spite of the aforementioned policy deficiency in the standard setting of the pure electric vehicle selection, some research has been conducted in light of the assessment of the pure electric buses, defining some critical performance indicators of the pure electric buses, which can serve as a reference for the selection, e.g., Wang and Zheng used energy consumption per kilometer to evaluate the economic efficiency of pure electric buses [13]. An analysis by Wan et al. argued that that vehicle purchase cost, maintenance cost and energy consumption should be taken into account as well [14].

More recently, Li stated that, in Urumqi, when comparing two different buses and Bus Rapid Transit (BRT) vehicles from different manufacturers, energy consumption and service life should be used [15]. Zhang et al. compared the speed and power consumption of several kinds of electric buses in Kunming and several other cities using road tests [11].

However, there are two main limitations lying in the existing research: (1) The assessment for the pure electric buses is not systematic enough, and thus couldn't provide a clear guidance. (2) The current studies focus on the definition and establishment of theoretical indicators but lack practical validation and specific implementation of the current assessment evaluation model. (3) The environmental impact of electric buses should be emphasized more in the literature, which has been paid increasing public attention these years.

Therefore, the purpose of this paper is to present how the Nanjing Bus Company selects suitable pure electric buses based on a comprehensive selection model. In addition, this paper aims to provide a suitable example of a framework and a method of electric bus selection for other public transportation companies in terms of the environmental indicators.

2. Materials and Methods

2.1. Overview

Nanjing provides a favorable atmosphere for the development of pure electric buses. As a result, it was recognized as a C40 (an international joint urban organization dedicated to climate change) City in 2015 based on the Nanjing New Energy Vehicle Promotion program [16]. Additionally, it won the honorary title of 'National Demonstration City for Transit Metropolis' [17], which is awarded by the Ministry of Transport of the People's Republic of China.

A commercial bus company focuses on profitability in addition to the social benefits that it offers. On the basis of guaranteeing a certain quality of service, the company is required to reduce costs to increase economic efficiency as much as possible. For this purpose, a road operation test was proposed by the Nanjing Bus Company, to determine the most cost-effective vehicles among several bus manufacturers.

The road operation test is a common method used to perform an all-around evaluation of vehicle performance. These tests replicate actual driving conditions and by doing so, differences between tests and reality are minimized. In addition to the characteristics of the vehicle itself, test results can also be influenced by the pavement conditions, traffic conditions, weather, driver behaviors, etc.

2.2. Organizational Structure for the Test

A reasonable organizational structure was designed to define clear duties and labor divisions to further enhance work efficiency. The road test process is generally designed in accordance with the actual operation of buses. Besides the internal work processes of bus companies, road tests require pre-planned arrangements and well-defined organization and coordination of all parts to lay the foundation for efficient testing and accurate results. Based on the operation and evaluation function, the organization structure was divided into three modules—the leadership group, work group, and review group.

2.2.1. Leadership Group

The leadership group was composed of the people overseeing the program and belonged to the Nanjing Bus Company and its subsidiaries and other companies in support roles. The main duties of this group were:

- To monitor and guide the overall operation of the road test;
- To check and approve the implementation plan, and to deal with any possible problem;
- To organize the final review conference and to make a final report, submitted to Nanjing Transportation Bureau.

2.2.2. Working Group

The working group was composed of the various parties involved in road operation, such as operation management, security, maintenance and logistics support sector. The main duties of this group were:

- To conduct the preliminary information survey about electric buses and to determine the outline of operational testing;
- To formulate an implementation plan and the relevant details;
- To supervise subcontractor companies such as Jiangnan and Yangzi to conduct basic data collection and data analysis;
- To make arrangements and to assign vehicles and staff during the road test work;
- To keep track of the progress of the project and to report it to the leadership group on time.

2.2.3. Review Group

The review group was composed of people from the government transport management department, traffic police department, and experts from university and the private sector. The main duties of this group were:

- To comprehensively analyze the relevant data and test results, including investigation of vehicle performance, appearance, and passengers' perceptions and opinions (not reported in this paper);
- To make suggestions after the test and to write a special report on performance difference of buses, to be discussed with all participants.

Every member worked independently but communicated in a detailed manner, sharing feedback and opinions to ensure the successful completion of the test.

2.3. Test Content

2.3.1. Test Vehicle Selection

The Nanjing Bus Company selected four common brands of pure electric bus available in the market, each offering two types of buses, whose lengths are approximately 8 m and 10 m. This was done to ensure an equivalent size for the test vehicles.

The test vehicles were divided into two groups based on vehicle length. The first group, Group A, contained buses that were approximately 8 m in length, while Group B contained those that were approximately 10 m in length. All the vehicles were newly manufactured, and they met national standards requirements such as JT/T1026-2016 titled "The general technical conditions of pure electric city buses". The vehicle details are listed in Table 1, and Figures 1–4 show the four brands of buses.

Table 1. Vehicle Brand Involved in the Test.

Type	Brand Name	Model Number	Vehicle Quantity	Length (m)	Electrical Rating (kwh)	Charging Mode
Group A (8 m)	BYD	BYD6810LZEV4	4	8.06	172.8	Slow charge
	Skywell	NJL6859BEV40	4	8.5	93.3	Fast charge
	Yinlong	GTQ6801BEVBT9	4	8.05	46.4	
	Jiankang	NJC6850GBEV2	4	8.5	93.3	
Group B (10 m)	BYD	BYD6100LGEV3	4	10.49	255.4	Slow charge
	Skywell	NJL6100BEV30	2	10.5	221	
		NJL6100BEV37	2		258	
	Yinlong	GTQ6105BEVBT8	4	10.48	81.2	Fast charge
	Jiankang	NJC6105GBEV5	4	10.5	230.4	Slow charge

Figure 1. BYD brand.

Figure 2. Yinlong brand.

Figure 3. Skywell brand.

Figure 4. Jiankang brand.

2.3.2. Test Environment Selection

The buses were tested on the same route, under the same working conditions, at the same outdoor temperature (adjacent dates), and for days having equivalent humidity, that is, all the tests were conducted during either sunny or rainy days, but not both.

Four representative routes were selected of varying congestion levels, from open and clear to congested, to reflect conditions experienced in normal daily operation. The routes are shown in Figure 5 and the respective details are summarized in Table 2.

Table 2. Routes Involved in the Test.

	Route 1	**Route 2**	**Route 3**	**Route 4**
Bus No.	134W	302W	638W	646W
Length (km)	15.5	15.7	11.6	14.8
Bus stop number	30	33	25	30
Characteristic	No congestion	Congestion	Medium-level congestion	
Description	Traffic conditions are good.	(1) Has over fifty signal lights. (2) Crowded downtown.	Road is narrow.	Far away from the main city.

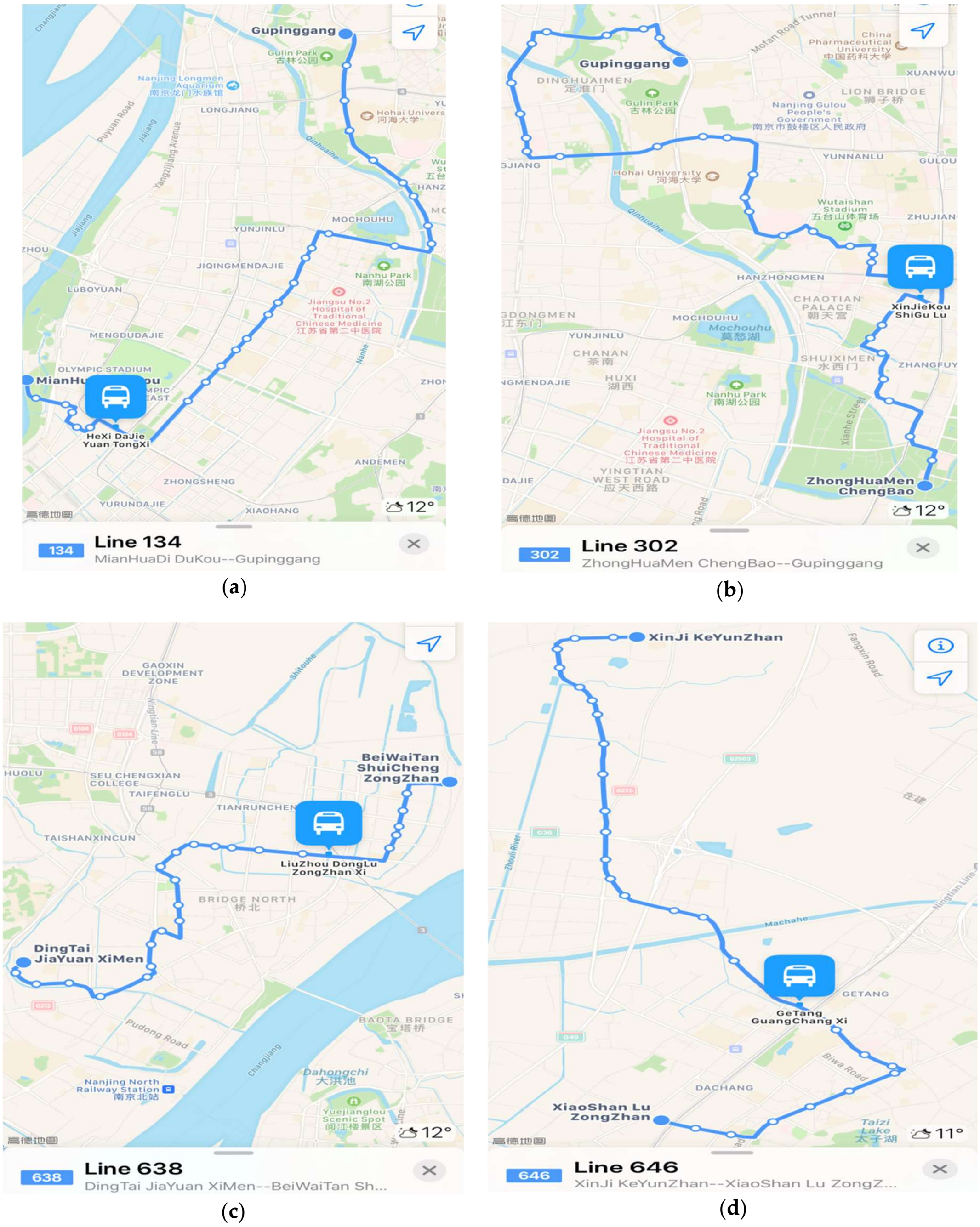

Figure 5. (**a**) Route 134W; (**b**) Route 302W; (**c**) Route 638W; (**d**) Route 646W.

2.3.3. Staff Selection

The participants, in particular, the drivers, were selected from a group of drivers with a certain level of experience (average driving age = 8–10 years) and no record of accidents to maximize safety. A total of 65 drivers participated in the test, one of whom was on standby. Two drivers were used for each bus. All personnel received the same training at the same time to standardize operational procedures. In addition, these drivers are professional, driving the same route and work a shift every five days, and they are assigned to the their daily driving routes, which can ensure the familiarity with their course of driving and thus reduce the error impact of drivers' behavior caused by the external factors such as the unfamiliarity with different vehicles on the test data.

2.3.4. Road Operation Procedure

Test date: During August and September 2017
Test area: Nanjing, Jiangsu Province, China
Step 1: Establish the organization structure and clarify the duty of the groups.
Step 2: Determine the test conditions and formulate the test process. Vehicle groups A and B were tested during the same period. For both groups, the specific serial number of each brand was assigned to specific test route, though for varying dates and numbers of days, as shown in Table 3.
Step 3: Record data before and after operation for each day.
Step 4: Summarize and analyze data to determine evaluation indexes.
Step 5: Have the experts from the review group evaluate the buses and make a selection.

The road operation test procedure is illustrated in Figure 6.

Table 3. Operation Arrangement.

Type	Brand Name and Model Number	Serial Number	Test Route	Test Date
Group A (8 m)	BYD BYD6810LZEV4	4011	134W	12th Aug. to 30th Sep. Total 50 days
		4012	302W	
		4013	638W	14th Aug. to 30th Sep. Total 48 days
		4014		13th Aug. to 30th Sep. Total 49 days
	Skywell NJL6859BEV40	3801	134W	8th Aug. to 30th Sep. Total 54 days
		3803	302W	
		3800	638	8th Aug. to 7th Sep. and 27th Sep. to 30th Sep. Total 30 days
		3802		8th Aug. to 30th Sep. Total 54 days
	Yinlong GTQ6801BEVBT9	3721	134W	18th Aug. to 21st Sep. and 30th Sep. Total 36 days
		3722	302W	18th Aug. to 28th Sep. Total 42 days
		3723	638W	19th Aug. to 30th Sep. Total 43 days
		3724		19th Aug. to 22nd Aug., 27th Aug. to 9th Sep., 11th Sep. to 25th Sep. and 28th Sep. to 30th Sep. Total 36 days
Group B (10 m)	Jiankang NJC6850GBEV2	3806	134W	31st Aug. to 30th Sep. Total 31 days
		3807	302W	
		3804	638W	29th Aug. to 30th Sep. Total 33 days
		3805		29th Aug. to 1st Sep., 3rd Sep. to 15th Sep. and 17th Sep. to 30th Sep. Total 31 days
	BYD BYD6100LGEV3	4015	134W	12th Aug. to 30th Sep. Total 50 days
		4016	302W	
		4017	646W	14th Aug. to 30th Sep. Total 48 days
		4018		13th Aug. to 30th Sep. Total 49 days
	Skywell NJL6100BEV30 NJL6100BEV37	3809	134W	6th Aug. to 30th Sep. Total 56 days
		3808	646W	
		3810		
		3811	302W	
	Yinlong GTQ6105BEVBT8	3725	134W	18th Aug. to 21st Sep. and 30th Sep. Total 36 days
		3726	302W	18th Aug. to 18th Sep. and 22nd Sep. to 28th Sep. Total 39 days
		3727	646W	19th Aug. to 23rd Sep. and 25th Sep. to 30th Sep. Total 42 days
		3728		19th Aug. to 30th Sep. Total 43 days
	Jiankang NJC6105GBEV5	3813	134W	31st Aug. to 30th Sep. Total 31 days
		3815	302W	
		3812	646W	29th Aug. to 30th Sep. Total 33 days
		3814		29th Aug. to 25th Sep. and 30th Sep. Total 29 days

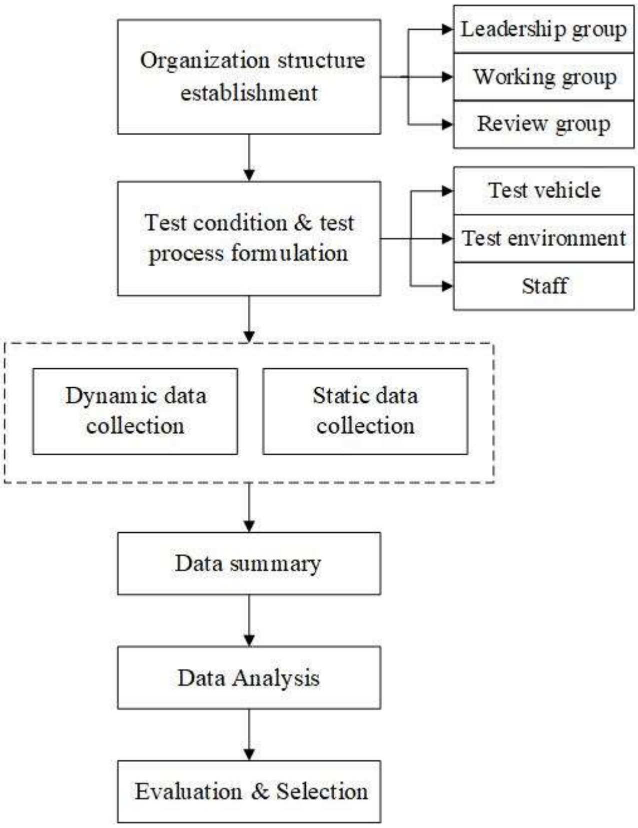

Figure 6. Flow chart of road test operation.

3. Data Collection and Analysis

3.1. Data Collection

Data collection, which had two steps, was performed for the objective data from the vehicle data collectors (vehicle sensors, the equipment installed in the vehicle to collect the data), for charging records and for other car parameters. The steps were as follows:

(1) The first stage of the test was mainly concerned with dynamic data (and various indicators of the vehicle) collected by the vehicle data collectors or determined from dashboard readings while the vehicle was in motion. The dynamic data included driving distance and power consumption.

(2) The second stage of operation test was concerned with static data collection. This included charging and maintenance records, which themselves included charging duration, charging frequency, failure frequency and failure duration.

A data table was completed by the drivers every day they participated in the test and recorded for each bus separately. Table 4 shows an example.

Table 4. Example of Data Collection Table.

Model Number: Skywell-NJL6859BEV40 Serial Number:3801						
Date	**Charging Frequency**	**Charging Duration (min)**	**Power Consumption (kwh)**	**Driving Distance (km)**	**Failure Frequency**	**Failure Duration (s)**
8th Aug.	3	39	140	206	0	0
9th Aug.	1	15	95	143	0	0
1st Sep	3	36	185	275	0	0
2nd Sep	3	40	168	274	0	0

After two months of testing, the data was summarized as shown in Table 5. Because of the confidential business information involved, code names are used for the buses. For example, the code name "V8-1" refers to buses from brand 1 in Group A (about 8 m long) and "V10-1" refers to buses from brand 1 in Group B (about 10 m long).

Table 5. Data Summary Table.

Bus and Route		Charging Frequency	Power Consumption (kwh)	Charging Duration (min)	Driving Distance (km)	Failure Frequency	Failure Duration (s)
V10-1	Total	464	40,061	11,325	40,031	4	8700
	134W	99	10,737	2939	10,793	0	0
	302W	51	8707	1703	7725	0	0
	646W	314	20,617	6683	21,512	4	8700
V8-1	Total	230	31,823	10,987	38,167	6	7800
	134W	75	8817	3124	11,131	2	600
	302W	67	7142	1944	8325	3	0
	638W	88	15,864	5919	18,711	1	7200
V10-2	Total	443	43,391	7506	46,838	1	320
	134W	67	11,195	1466	12,509	0	0
	302W	77	9596	1516	9083	1	320
	646W	299	22,600	4524	25,246	0	0
V8-2	Total	562	29,597	6572	40,284	1	14,400
	134W	147	8655	1839	12,954	0	0
	302W	127	7706	1557	9588	0	0
	638W	288	13,236	3176	17,742	1	14,400
V10-3	Total	829	30,840	8000	29,101	14	148,800
	134W	163	7172	1582	6034	7	48,960
	302W	135	6158	1403	4999	3	4200
	646W	531	17,510	5015	18,068	4	95,640
V8-3	Total	827	23,509	7051	25,051	18	124,380
	134W	196	5747	1713	6795	4	22,140
	302W	164	5945	1595	5810	3	1800
	638W	467	11,817	3743	12,446	11	100,440
V10-4	Total	348	25,389	5834	24,979	5	9900
	134W	60	6440	1217	6610	3	1500
	302W	39	5805	827	5064	2	8400
	646W	249	13,144	3790	13,305	0	0
V8-4	Total	332	17,043	4313	21,294	5	138,120
	134W	78	4445	1118	5958	2	7200
	302W	72	4439	1078	5475	0	0
	638W	182	8159	2117	9861	3	130,920

The various indicators and their data for the road test operation are summarized in Tables 6 and 7.

Table 6. Indicator Data Collected for Group A.

Indicator	V8-1	V8-2	V8-3	V8-4
Total driving distance (km)	38,167	40,284	25,051	21,294
Failure frequency	6	1	18	5
Failure duration (s)	7800	14,400	124,380	138,120
Power consumption (kwh)	31,823	29,597	23,509	17,043
Charging frequency	230	562	827	332
Charging duration (min)	10,987	6572	7051	4313
Average days of operation	49	51	43	32

Table 7. Indicator Data Collected for Group B.

Indicator	V10-1	V10-2	V10-3	V10-4
Total driving distance (km)	40,031	46,838	29,101	24,979
Failure frequency	4	1	14	5
Failure duration (s)	8700	320	148,800	9900
Power consumption (kwh)	40,061	43,391	30,840	25,389
Charging frequency	464	443	829	348
Charging duration (min)	11,325	7506	8000	5834
Average days of operation	49	56	43	32

3.2. Data Analysis

From the perspective of the bus company, economic benefits that can be gained from reducing energy consumption and reducing the time spent on activities or operations are priorities. When use of electric buses first commenced, the utilization rate of pure electric buses was only 50% of that of traditional fuel buses. To maximize the benefits, scheduling and charging mode innovations were implemented, achieving the same utilization rate as a traditional fuel bus. Based on these, the Nanjing Bus Company has processed the indicators in Section 3.1 to indicate four factors that contribute most to electric bus selection:

- *Factor 1: Power consumption per 100 km*

This factor is similar to the 'liters of fuel per hundred kilometers' concept in traditional fuel vehicles. It is the energy consumed by vehicles for a travel distance of 100 km, and it is one of the key economic indicators of pure electric buses. This factor is equal to the power consumption divided by the total driving distance, then multiplied by 100.

- *Factor 2: Charging duration per 100 km*

Factor 2 serves to establish a relationship between battery performance and driving performance. It indicates the battery efficiency and the pros and cons of the charging model used.

- *Factor 3: Daily average driving distance*

This is a basic and necessary index to show vehicle utilization rate, which bus companies value the most, and it is related to operation cost.

- *Factor 4: Failure time per 100 km*

This factor is related to reliability of a vehicle. This factor takes into account frequency and severity of failure, both of which contribute to maintenance costs directly and utilization costs indirectly.

These factors after calculation are given in Tables 8 and 9.

Table 8. Selection Factor Data for Group A.

Indicator	V8-1	V8-2	V8-3	V8-4
Power consumption per 100 km (kwh)	83	73	94	80
Charging duration per 100 km (min)	29	16	28	20
Failure duration per 100 km (s)	20	36	497	649
Daily average driving distance (km)	194	196	146	168

Table 9. Selection Factor Data for Group B.

Indicator	V10-1	V10-2	V10-3	V10-4
Power consumption per 100 km (kwh)	100	93	106	102
Charging duration per 100 km (min)	28	16	27	23
Failure duration per 100 km (s)	22	1	511	40
Daily average driving distance (km)	203	210	170	195

4. Discussion

Based on the analysis of the current situation of domestic pure electric bus, the road operation test is selected as the test method, the composition and responsibility of the road operation test organization are clarified, the test process with the outline of "determine the test conditions—data Collection—data collection" is determined, and the format of relevant record forms is given. According to the evaluation and the discussions of experts and the opinion of the bus company, on the basis of direct and indirect test data, and through observing Tables 8 and 9, it is evident that V8-1 and V8-2 are equally matched in Group A and that V10-2 is the best choice in all aspects, and V10-1 is considered good choice in Group B.

It was confirmed that the manufacturers who provided the V8-1, V8-2, V10-1and the V10-2 were ready to adjust to the conditions in Nanjing regarding the transition to fully electric bus fleets. As a result, the bus company has purchased a batch of pure electric buses of these brands. They have achieved positive operation effects as of the date of this paper.

Also, it should be noted that some limitations still exist in the current study. First, the selection indicators used are primarily objective. The subjective feelings of the drivers and passengers are not considered in the analysis. Second, the differences in battery attenuation and in other aspects of battery performance are ignored for this paper because they meet national standards. Third, the selection process was performed through observation and expert opinion only. Therefore, using different weighting methods, such as an analytic hierarchy process, is suggested to facilitate the selection of more acceptable and justifiable weighting methods [18] and to make the selection method more scientific. Besides, since the buses being completely new, their future performance is uncertain. It would be useful to analyze the performance of the bus throughout its operation life-cycle.

5. Conclusions

The promotion of the bus electrification is in full swing in China, among which pure electric bus, with its advantages of high driving stability, zero emission and outstanding economic performance, has become the focus of many cities. However, it can't be denied that electric buses still have some limitations, e.g., short driving range and long charging time, which are tough to overcome in a short time. Besides, compared with traditional bus, pure electric bus is a relatively new concept, with a more complicated process of its selection, deserving more attention and research.

In this article, a test organized by the Nanjing Bus Company that is based on actual road tests to aid in bus selection was illustrated. Compared with other test methods, road tests were used because they are direct and reliable and they take into account actual transport conditions. The process of the tests can be categorized into three steps: (1) To structure the organization of the testing and selection processes, three groups were introduced: a leadership group, working group, and review group. (2) The test process and test conditions, including bus, route, staff and environmental information were provided for data collection. (3) As for the indicator processing, power consumption per 100 km, charging duration per 100 km, daily average driving distance and failure time per 100 km were determined to be key factors in the selection of a suitable bus.

In general, it is critical for the bus companies to decide to purchase the buses, and thus, the performance, cost, safety, environment and other indicators of electric buses with the support of operation data and the goal of normal operation service are of great significance to be quantified, the method proposed in this paper the bus company applied to make progress in electric bus selection thereby proves the application value, in terms of both process and indicators. In addition, since the test is based on the new buses, it is worth exploring the subsequent performance in the practical operation in the future research.

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