Research on Evaluating Index System of the Applicability of Vehicle Used as Taxi

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Abstract—Under the background of the promoting policies of electric vehicles development, the electrification of taxi is imperative in China. This paper aims to build an evaluating index system for the suitability of taxi vehicles from the perspective of actual taxi users to support local cities to choose adaptive electric vehicle types. Based on the analysis of operating characteristics and technical needs of taxi, a three-level index system of target level, standard level and index level is proposed. Safety, convenience, efficiency, economy, and comfort are proposed in target layer; and 17 indicators are defined in index layer, such as operation cost, average daily operation mileage, vehicle failure rate. Using questionnaire survey data of taxi drivers, the weights of each indicators are assigned by the analytic hierarchy process. The research results will effectively support the taxi industry management departments and taxi operating companies to make scientific decision-making in the process of taxi electrification, then promote the sustainable development of the taxi industry.

1. INTRODUCTION

Taxi, a convenient and comfortable service, is still an important mode for passengers, and its proportions of urban passenger volume even exceeded 50% in some China’s provinces in 2018[1]. To implement the national strategies of development new energy vehicle and emission reduction in China, many cities are beginning to promote new energy vehicles in taxi industry. For example, Taiyuan has become the first city in China where all taxis have been replaced with electric vehicles; Beijing, Xiamen and some cities began to demonstrate the battery-swapping mode of electric taxis. Vehicle types of taxis can be classified as gasoline, LPG, natural gas, ethanol gasoline, hybrid, and battery electric by fuel type; and the battery electric vehicles are classified as fast charging mode, slow charging mode, and battery-swapping mode. In the energy conversion of taxi industry, how to select vehicle types that suit the characteristics of the taxi industry according to local circumstances is essential to maintain the taxi industry stability as well as emission reduction.

At present, most of the research on taxi applicability is just problem description, or quantitative analysis by separate indicators. It is urgent to carry out a comprehensive and systematic research. From the perspective of taxi users, this paper analyzes the operating characteristics and the technical needs of taxis, then builds an index system consisting of 17 indicators to evaluate the applicability of vehicles as taxis. Through questionnaire survey, the weights reflecting the importance of indicators are decided by
analytic hierarchy process. The research results provide ideas and methods for various cities to select vehicle types of taxi.

2. LITERATURE REVIEW
Applicability research methods can be divided into qualitative analysis and quantitative index evaluation. Peng Qingyan et al. [2] used qualitative analysis methods to study the application conditions of supercapacitor buses and battery electric buses. They analyze the problems encountered by the actual use cases in Shanghai, so as to directly infer the applicable line, station distance, departure frequency, traffic conditions of each bus type. Zhang Yulong et al. [3] used index evaluation methods to analyze the adaptability of hybrid taxis in the plateau area. Through the manual operation data collection of the hybrid taxis and gasoline taxis in Kunming, the economical efficiency and power system failures were analyzed by using simple indicators. Both qualitative and quantitative analysis methods have their own advantages. Qualitative analysis can conduct a more systematic analysis of the research object without being limited by digitalization, especially for the difficult to quantify aspects of the research object; and the quantitative indicator evaluation method can digitize the analysis angle and can better describe object differences. Establishing an evaluation index system including qualitative indicators and quantitative indicators will help to combine the advantages of both and conduct a more comprehensive evaluation of the applicability of each vehicle type in taxi industry.

There are many researches on taxi index evaluation. According to the research direction, it can be divided into index evaluation that reflects the characteristics of taxi operation, the application benefit and so on. LYU Zhenhua [4] and Hu Xiaowen et al. [5] proposed the average daily operation mileage, average daily operation time, average daily carrying time, average daily carrying times, deadhead kilometers, average daily load distance and other indicators, and described and analyzed the operation characteristics of taxi by the above indicators. Ge Xiaohua et al. [6] analyzed the carbon emission reduction benefits of electric taxis instead of oil-gas dual-fuel hybrid taxis, and compared the greenhouse gas emissions of the two vehicle types with the energy consumption data in Taiyuan.

There are few evaluation studies on the applicability indicators in taxi industry that comprehensively consider the qualitative and quantitative indicators. It is necessary to combine the operating characteristics and needs of the taxi industry itself, as well as consider the characteristics of the vehicle types and the coordination of related supporting infrastructures to obtain a comprehensive system of applicability evaluation index system. Through the comparison of index between different taxi types, the applicability of a certain vehicle types in taxi industry can be obtained.

3. OPERATION CHARACTERISTICS AND DEMAND ON VEHICLE OF TAXI INDUSTRY
Compared with other public transport modes such as bus and urban rail transit, taxi service has the advantages of door-to-door convenience, rapid and comfort. To keep those service advantages requests the taxi operation should have at least the following characteristics:

3.1. Safety and stable supply
The taxi industry belongs to the public service field. On the one hand, the safety of passengers, drivers must be guaranteed, and the "people-oriented" development concept of China should be implemented. This requires that the vehicles used in the taxi industry have higher safety and lower vehicle failures. On the other hand, it is necessary to ensure stable vehicle performance and high reliability, to ensure the safety of taxi operations, and to maintain the stable operation of the urban public transport system. It requires that vehicles used in the taxi industry should have higher stability, and the infrastructure construction must be planned in advance, reasonable layout and stable operation. For example, for electric taxis, it is necessary to ensure the normal use of the vehicle under heavy rain and cold weather. When the vehicle's power is insufficient, it can find charging equipment within a few kilometers.
3.2. Efficient operation and convenient use
Taxi is a tool to provide operational services for taxi drivers. The operational efficiency and convenience of taxis are directly related to the taxi driver’s operating income. The driver prefers the vehicle to be used for effective operation for a longer period, as much as possible to shorten the taxi's deadhead time and fuel filling time. At the same time, the difficulty of taxi’s maintenance and maintenance time are also aspects to be considered.

3.3. Competitive costs
Compared with family cars, taxis are more sensitive to cost performance. Firstly, the operators expect that the purchase cost will be kept at a low level, without the need for higher interior and appearance configurations, and taxi type can meet the needs of daily operations. Secondly, the costs in operation need to be in a controllable range, such as the cost of the vehicle's fuel price, maintenance cost and so on. In addition, it is necessary to consider factors such as the number of taxi orders and the income from passengers to ensure the better return of the operators and drivers.

3.4. Comfortable customer experience of riding
Taxi is one of the tools to provide high-quality urban public passenger transport services. The drivers spend 12-20 hours every day in the taxis, so the riding comfort and handling comfort of the vehicle directly affect the drivers’ happiness. At the same time, passengers also have a high demand for the riding comfort of vehicles. This requires that the vehicle types used in the taxi industry have the characteristics of low noise, convenient handling, and comfortable riding.

4. BUILDING EVALUATING INDEX SYSTEM

4.1. Principles of Index System Building
The building of the applicability index system needs to start from the problems and needs of the taxi industry, and comprehensively consider the impact of various vehicle types on the operation of the taxi industry, so as to obtain a comprehensive and comprehensive index system. Specifically, the building of the applicability index system of the vehicle type in taxi industry needs to follow these principles:

4.1.1. The principle of teleonomy. The index system building in this paper aims to evaluate the applicability of vehicle being used as taxi. It is necessary to start from the operation characteristics and actual needs of taxis and use the evaluation indicators to show the actual application effect of the vehicle types used in taxi industry. By matching the characteristics of the vehicle types with the needs of the taxi industry, the applicability conclusion is drawn.

4.1.2. The principle of hierarchy. The indicators that reflect the applicability of taxi types are complex and diverse. We adopt a hierarchical method to make the index system structure clear, logical, and comprehensible. According to the inherent logic of indicators, the index system proposed in this paper are divided into three levels: target layer, criterion layer and index layer.

4.1.3. The principle of comparability. The building of index system aims to reflect the applicability of vehicle types being used as taxi. It is necessary to compare various vehicle types used in taxi industry to verify which type can better meet the operation needs of taxis and have excellent performance in certain aspects. This requires that the same indicator can be compared horizontally between different vehicle types, and the indicator value of the same vehicle types in different cities can also be compared. Indicators that cannot be compared are not included in the index system in this paper or converted into comparable indicators. For example, the battery decay rate should not be used as an evaluation indicator because fuel taxis do not have batteries.
4.1.4. The principle of associativity. The building of index system should combine qualitative and quantitative indicators. Quantitative indicators can reduce the subjectivity of the evaluation process to a certain extent. For indicators that cannot be quantified, qualitative indicators can make up for the shortcomings of using only quantitative indicators, and can more comprehensively and objectively evaluate the applicability of vehicle being used as taxi.

4.2. Designing Evaluating Index System
From the perspective of actual taxi users, the paper considers the operation characteristics and actual needs of taxis, follows the index design principles mentioned above, and build an evaluating index system of vehicle’s applicability for taxi that covers five aspects of safety, convenience, efficiency, economy, and comfort. The index system is divided into three levels: target layer, criterion layer and index layer, as shown in Figure 1.

| Target Layer | Criterion Layer | Index Layer | Variate |
|--------------|-----------------|-------------|---------|
| Safety       | Vehicle Failure Rate | A1          |         |
|              | Handling Stability | A2          |         |
|              | Maintenance Response Speed | A3       |         |
|              | Average Maintenance Time | A4   |         |
|              | Average Daily Refueling Time | A5   |         |
|              | Average Refueling Time | A6       |         |
|              | Average Refueling Mileage Interval | A7    |         |
|              | Average Daily Operation Mileage | A8   |         |
|              | Proportion of Deadhead Time | A9    |         |
|              | Proportion of Deadhead Kilometers | A10  |         |
| Convenience  | Average Daily Carrying Time | A11  |         |
|              | Average Carrying Distance | A12  |         |
|              | Vehicle Purchase Cost | A13    |         |
|              | Operation Cost | A14       |         |
|              | Vehicle Contract Fee | A15    |         |
|              | Average Daily Income from Passengers | A16  |         |
|              | Comfort Level | A17       |         |

The applicability index system of vehicle for taxi

It can be seen from Fig. 1 that the criterion layer of the applicability index system of the vehicle for taxi is includes 5 indexes, and the index layer includes a total of 17 indicators. The index system can evaluate the applicability of taxis more scientifically and comprehensively on the premise of ensuring the appropriate layer and number of indicators.

The safety indexes include two indicators: vehicle failure rate and handling stability, reflecting the industry need for safe and stable operation. The convenience indexes include five indicators: maintenance response speed, average maintenance time, average daily refueling times, average refueling time, average refueling mileage interval, which are all quantitative indicators, reflecting the convenience in maintenance and refueling process. For electric taxis, the battery driving range, the layout of the charging and replacing infrastructure, and the service capacity of the maintenance service station will directly affect the value of the convenience indexes. The efficiency indexes include five indicators: average daily operation mileage, proportion of deadhead time, proportion of deadhead kilometers, average daily carrying times, and average carrying distance, all of which are quantitative. The economy indexes include four indicators: vehicle purchase cost, operation cost, vehicle contract fee, and average daily income from passengers, which involve various processes such as vehicle purchase, use right transfer, vehicle operation and maintenance, and are also the indicators that drivers are most
concerned about. The comfort index includes an indicator of comfort level, which is a qualitative indicator. The qualitative indicators above are scored by taxi drivers, and the score is the value of indicators.

4.3. Deciding Weights of Indicators

After obtaining the evaluating index system of the applicability of vehicle for taxi, the weight of each indicator is assigned by the analytic hierarchy process [7]. The importance of the indicators is reflected by the weight, which is convenient for the comparison and comprehensive analysis of various taxi types. Then the conclusions on the applicability of some a vehicle type in taxi industry are drawn.

4.3.1. Data collection and preprocess. Data collection was carried out using a questionnaire survey with taxi drivers. The questionnaire uses a five-point scale method to design a question that scores the importance of the applicability evaluation indicators of taxi types, and is distributed to taxi drivers in Shenzhen, Chongqing, and Xiamen. The vehicle types driven by taxi drivers cover various categories, such as fuel, gas, battery-swapping mode, fast charging mode and so on, so the results of the questionnaire are widely representative. A total of 1300 questionnaires were collected. The results of the questionnaire are shown in Table I.

The importance of indicators in the questionnaire is divided into very important, important, general important, unimportant, and very unimportant, which correspond to 5 points, 4 points, 3 points, 2 points, and 1 point respectively. The value of each indicator is obtained by eliminating invalid answers and using the weighted mean method.

| Subject                          | Very Unimportant | Unimportant | General Important | Important | Very Important | Average Score |
|----------------------------------|------------------|-------------|-------------------|-----------|----------------|---------------|
| Vehicle Failure Rate             | 420 (3.2%)       | 111 (0.8%)  | 150 (1.2%)        | 126 (1.0%)| 566 (4.3%)     | 4.48          |
| Handling Stability               | 327 (2.5%)       | 72 (0.5%)   | 117 (0.9%)        | 127 (1.0%)| 558 (4.2%)     | 4.51          |
| Maintenance Response Speed       | 291 (2.2%)       | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.52          |
| Average Maintenance Time         | 224 (1.7%)       | 97 (0.7%)   | 156 (1.3%)        | 127 (1.0%)| 567 (4.2%)     | 4.55          |
| Average Daily Refueling Time     | 291 (2.2%)       | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.56          |
| Average Refueling Miles          | 327 (2.5%)       | 72 (0.5%)   | 117 (0.9%)        | 127 (1.0%)| 558 (4.2%)     | 4.58          |
| Average Refueling Mileage Per Mile | 291 (2.2%)     | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.59          |
| Average Operation Time           | 291 (2.2%)       | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.60          |
| Average Daily Refueling Time     | 291 (2.2%)       | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.61          |
| Average Refueling Miles          | 327 (2.5%)       | 72 (0.5%)   | 117 (0.9%)        | 127 (1.0%)| 558 (4.2%)     | 4.62          |
| Average Operation Time           | 291 (2.2%)       | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.63          |
| Proportion of Deadhead Kilometers | 291 (2.2%)     | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.64          |
| Average Daily Carrying Times     | 291 (2.2%)       | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.65          |
| Average Carrying Distance        | 291 (2.2%)       | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.66          |
| Average Failure Rate             | 291 (2.2%)       | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.67          |
| Average Repair Cost              | 291 (2.2%)       | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.68          |
| Average Daily Income from Passenger | 291 (2.2%)     | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.69          |
| Comfort Level                    | 291 (2.2%)       | 181 (1.4%)  | 124 (1.0%)        | 127 (1.0%)| 563 (4.2%)     | 4.70          |

4.3.2. Constructing a judgment matrix. As a key step of the analytic hierarchy process, constructing a judgment matrix is very important. The judgment matrix is a matrix composed of the comparison results of indicators. In order to reduce the difficulty of comparing indicators of different types with each other and possible inconsistencies, we design a questionnaire using the principle of scoring each indicator, and then process the results of the questionnaire to obtain the judgment matrix. The element \( a_{ij} \) of the judgment matrix is the comparison result of the importance of the index \( i \) and the index \( j \). Table II is the scaling method of judgment matrix elements, and 9 importance levels and their assignments are given. Among them: \( \alpha = \frac{1}{2} \).

| \( i \ compare \ with \ j \) | quantized value |
|-----------------------------|-----------------|
| equally important           | 1               |
| weakly important            | 3               |
| normal important            | 5               |
| strongly important          | 7               |
| absolutely important        | 9               |
| the median of two adjacent judgments | 2,4,6,8 |
Standardize the final score of the importance of the indicators in the questionnaire, convert the data into integers in the range of 0–10, and quantify the value according to the scaling method of judgment matrix elements to obtain the judgment matrix, as shown in Table III.

TABLE III. JUDGMENT MATRIX OF EVALUATING INDICATORS OF VEHICLE’S APPLICABILITY FOR TAXI

| INDEX | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | A12 | A13 | A14 | A15 | A16 | A17 |
|-------|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|
| A1    | 1 | 1/2 | 1/2 | 2 | 2 | 1 | 2 | 4 | 2 | 1/2 | 1 | 2 | 2 | 1 | 2 | 1   |
| A2    | 2 | 1 | 1 | 4 | 4 | 3 | 4 | 6 | 4 | 2 | 1 | 2 | 2 | 1 | 2 | 1   |
| A3    | 1 | 1/2 | 1/2 | 1 | 1 | 1 | 1 | 2 | 1 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1   |
| A4    | 2 | 1/2 | 1/2 | 2 | 2 | 2 | 2 | 4 | 2 | 1/2 | 1 | 2 | 2 | 1 | 2 | 1   |
| A5    | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 4 | 2 | 1/2 | 1 | 2 | 2 | 1 | 2 | 1   |
| A6    | 1/2 | 1/2 | 1/2 | 1 | 1 | 1 | 1 | 2 | 1 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1   |
| A7    | 1 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1   |
| A8    | 1 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1   |
| A9    | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1   |
| A10   | 1 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1   |
| A11   | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1   |
| A12   | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1   |
| A13   | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1   |
| A14   | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1   |
| A15   | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1 | 1/2 | 1 | 1 | 1 | 1 | 1 | 1 | 1   |
| A16   | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 4 | 2 | 1/2 | 1 | 2 | 2 | 1 | 2 | 1   |
| A17   | 1/8 | 1/9 | 1/6 | 1/6 | 1/5 | 1/6 | 1/4 | 1/5 | 1/3 | 1/4 | 1/3 | 1/4 | 1/5 | 1/6 | 1/7 | 1/8 | 1 |

4.3.3. Calculating the index weight. The index weight representing the importance of each indicator is the eigenvectors corresponding to the largest feature root of the judgment matrix. After calculation, the index weight for the applicability of vehicle for taxi is shown in Table IV.

TABLE IV. THE WEIGHTS OF INDICATORS

| Indicator | Weight | Indicator | Weight |
|-----------|--------|-----------|--------|
| A1        | 10.5%  | A10       | 3.1%   |
| A2        | 14.8%  | A11       | 3.1%   |
| A3        | 5.8%   | A12       | 2.1%   |
| A4        | 5.8%   | A13       | 0.9%   |
| A5        | 4.2%   | A14       | 8.2%   |
| A6        | 5.8%   | A15       | 10.5%  |
| A7        | 3.1%   | A16       | 14.8%  |
| A8        | 4.2%   | A17       | 1.1%   |
| A9        | 2.1%   |           |        |

The weighs of four indicators, handling stability, average daily income from passengers, vehicle failure rate, and vehicle contract fees exceed 10%, which are more valued indicators for taxi drivers. The results of the research imply that ensuring the safety of vehicles is the basis of taxi operations. Meanwhile, ensuring the economic competitiveness of vehicles is the most important thing to introduce new energy vehicle type into taxi industry. In addition, when vehicle manufacturers design taxi types and taxi companies select vehicle types, it is necessary to focus on the indicators with larger weight, and to synthesize the results of various indicators to determine whether the vehicle types are applicable in taxi industry.

5. CONCLUSION AND SUGGESTION

The paper proposed an evaluating index system of vehicle applicability for taxi in terms of safety, convenience, efficiency, economy, and comfort. Among the proposed 17 indicators, handling stability, average daily income from passengers, vehicle failure rate, and vehicle contract fees are more important for taxi user. In the context of the large-scale promotion of new energy vehicles in the taxi industry in China, the applicability evaluating method can help the industry management departments and taxi operation companies in various cities to select suitable taxi types to better meet the local needs.

Because index system on evaluating applicability of vehicle for taxi is a complex system with multi-level and many factors, and the specific conditions and the user needs of each city are different and
changeable, the index system is expected to be supplemented and improved to further promote the renewal and iteration of taxi products and promote the sustainable development of the taxi industry.

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