A Model Based Method for Capacity Allocation in the Bus Transportation Industry

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Abstract. With the implementation of the dual carbon goal, electric vehicles have been rapidly promoted. However, in extreme conditions such as natural disasters, especially when power supply is insufficient, the widespread use of electric buses and the delisting of fuel powered buses may lead to insufficient transportation capacity in the region. This article establishes a calculation model for the allocation of buses of various power types to address this issue. Based on population size, the paper comprehensively considers the charging time and range of pure electric buses during use, and calculates the transportation capacity of pure electric buses and fuel buses respectively. Then, based on the rule of prioritizing the use of electric vehicles for transportation, when the capacity of electric buses is insufficient, fuel powered buses are used for replenishment. Calculate the minimum number of fuel buses required to ensure the basic transportation capacity for personnel transfer.

1. Introduction

With the continuous development of new energy vehicle technology, the requirements for energy conservation and carbon reduction are becoming higher and higher[1]. Proposals from countries around the world to ban the sale of fuel vehicles are constantly being heard. In June of this year, the environment ministers of the 27 EU countries held a meeting in Luxembourg to reach a consensus on a proposal to stop the sale of fuel vehicles in Europe by 2035, which had previously been passed by the European Parliament[2]. In the report of the 20th National Congress of the Communist Party of China, issues related to national security and energy security were mentioned, and a comprehensive emergency framework was established to strengthen the construction of regional emergency forces. Specifically, in the transportation industry, a comprehensive ban on the sale of fuel vehicles and the application of new energy vehicles will face special situations such as wars, large-scale natural disasters (earthquakes, typhoons, ice and snow, epidemics), special geographical environments, and special climatic conditions (plateau, high-altitude regions), causing a lack or shortage of electricity may result in insufficient basic transportation capacity.

An emergency condition with a large scale of extreme conditions that pose a threat to life and health, leading to a series of significant impacts such as property damage. Mainly including natural disasters such as earthquakes and typhoons; public health events such as epidemics and social security events such as wars[3].

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Domestic and foreign scholars have conducted certain research on personnel scheduling problems under extreme conditions. In refs[4], consider the time satisfaction of emergency rescue teams located at different rescue points to perform different rescue tasks at the demand points, as well as the competence of rescue teams for different rescue tasks. Establish an optimization model for assigning earthquake emergency rescue teams with the goal of maximizing satisfaction with rescue time and enhancing team competence. In refs[5], by considering the collaboration between rescue units, the rescue unit scheduling problem is described as a binary linear minimization problem, and a branch and price algorithm is designed to solve it. In refs[6-7], by introducing prospect theory and considering the characteristics of reference dependence and risk preference of people in reality, the bounded rational behaviour of decision-makers is truly described, and the psychological perception of disaster victims on rescue time and demand satisfaction rate under priority rational conditions is depicted.

The above literature mainly considers the scheduling problem of rescue personnel, and does not consider the transportation problem of residents in disaster areas. In refs[8], based on a flexible scheduling model, this paper explores the scheduling mode of large-scale infectious disease shelter hospitals in short-term high-volume transportation. In refs[9], based on the theory and method of geographical district division, using multi-source data containing spatiotemporal big data will enrich the theory of transportation geography, expand the application of geography in China's national transportation strategy, and provide a geographical scientific basis for national and regional comprehensive transportation planning.

The above methods are mainly used for the allocation and scheduling of emergency rescue personnel under extreme conditions, as well as the transportation of personnel. The allocation of vehicle types for emergency rescue and personnel transfer did not take into account various types of power vehicles. Based on the above analysis, this article constructs a bus capacity allocation model with the goal of personnel transfer. The model takes into account the problems of electric vehicles in the transportation process, and calculates the minimum number of fuel buses that each city needs to retain to ensure personnel transportation under extreme conditions.

2. Calculation model for bus capacity

The bus capacity indicates how many people can be transported to the disaster area within the specified time. The passenger car capacity is mainly influenced by factors such as the number of passengers (n) and the number of transportation times. The expression for passenger car capacity is shown in (1).

$$Bus\ capacity = Number\ of\ approved\ passengers \times Round\ trips \tag{1}$$

Electric buses need to be charged during operation, but in extreme cases, they may not be able to be charged due to grid damage. Therefore, when calculating the capacity of electric buses, there are two situations: charging stations available and unavailable, as shown in figure 1. When the charging stations is available (Yes), the latest delivery time is divided by the round-trip time to obtain the round trips. When the charging stations is unavailable (No), the range of the electric bus is divided by the round-trip distance to obtain the round trips. The number of passengers on the bus is a fixed 55, and the number of round trips is determined by factors such as vehicle travel time and charging time of electric buses. Below are the calculation methods for the capacity of electric buses and fuel buses, respectively.

2.1. Electric Bus Capacity

When calculating the capacity of electric buses, the most important thing is to calculate the number of round-trip trips for electric buses, which are mainly determined by factors such as the transportation time and range of the buses. Therefore, it is necessary to consider the calculation methods of transportation capacity separately when there is a charging station and when there is no charging station.

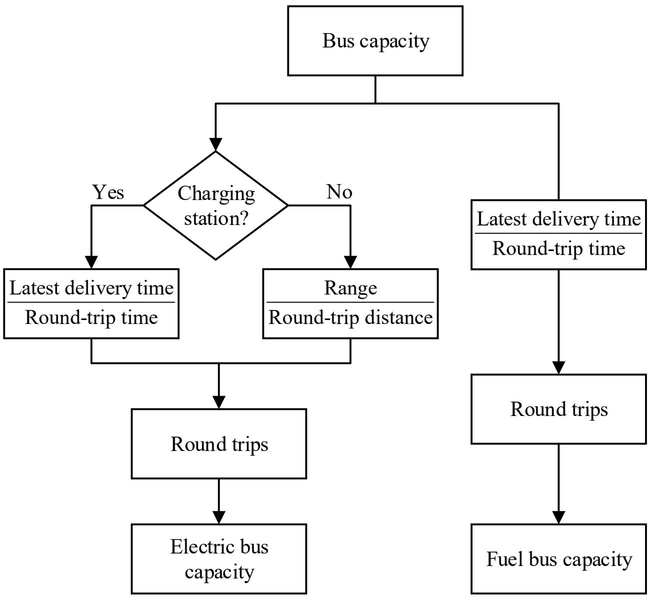

Figure 1. Calculation process for capacity of electric and fuel buses

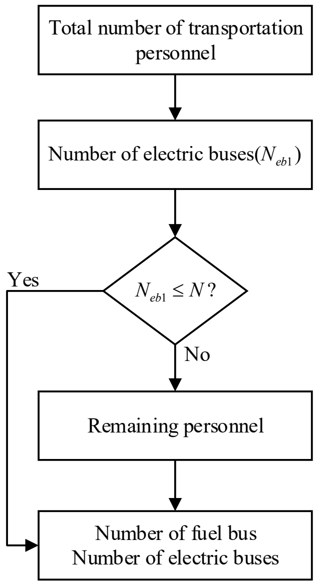

Figure 2. Allocation process of personnel transportation capacity

2.1.1. When charging station is available

When charging station is available, the time required for a round trip of electric bus consists of charging time and driving time. The charging time for a round trip is calculated by dividing the distance travelled by electric bus, and obtaining the average charging time for a round trip. The driving time is the average speed of electric bus, excluding the round-trip distance. Therefore, the calculation expression for the time required for a round trip of electric bus is shown in (2).

$$T = \frac{L}{R}T_c + \frac{L}{v} \tag{2}$$

Where, T indicates the round-trip time, L indicates the round-trip distance, R indicates the range of electric vehicles, T_c indicates the charging time of electric buses, v indicates average speed of electric buses.

In order to evaluate the impact of temperature on the range of electric buses, interpolation method was used to calculate the range of electric trucks. Calculate the attenuation rate of the battery through interpolation and then multiply it by the rated range to obtain the actual range. The interpolation data is shown in table 1. When the battery decay rate is less than 0.5, it is considered that pure electric vehicles cannot be used and the transportation capacity is zero.

Table 1. The data of temperature and battery attenuation rate.

Temperature (℃)	Attenuation rate
35	0.8
25	1
0	0.7
-10	0.6
-20	0.4

The calculation method for the number of round-trip times of electric buses (F_{eb}) is to divide the latest arrival time of personnel (T_d) by the round-trip time, and the specific expression is shown in (3).

$$F_{eb} = \frac{T_d}{T} = \frac{T_d Rv}{LT_c v + LR} \tag{3}$$

Therefore, the expression for the transportation capacity of pure electric buses with charging stations is shown in (4).

$$T_{eb} = nF_{eb} = \frac{nT_d Rv}{LT_c v + LR} \tag{4}$$

2.1.2. When charging station is unavailable

When charging station is unavailable, the number of round-trip trips for electric bus is mainly determined by the range of the electric bus. The number of round-trip trips for electric bus is equal to the range of the electric bus divided by the round-trip distance. The expression for the number of round-trip trips for electric bus is shown in (5).

$$F_{eb} = \frac{R}{L} \tag{5}$$

Therefore, when charging station is unavailable, the expression for the transportation capacity of electric buses is shown in (6).

$$T_{\text{eb}} = nF_{eb} = \frac{nR}{L} \tag{6}$$

2.2. Fuel Bus Capacity

When calculating the capacity of fuel powered passenger cars, only the travel time needs to be considered. The travel time of fuel buses is the distance divided by the average vehicle speed. The number of round-trip trips for fuel buses is equal to the latest delivery time divided by the travel time. The expression for the number of round-trip trips for fuel powered buses is shown in (7).

$$F_b = \frac{vT_d}{L} \tag{7}$$

Where, F_{eb} is the number of round-trip trips for fuel powered buses.

The expression for the transportation capacity of fuel powered passenger cars is shown in (8).

$$T_b = nF_b = \frac{nvT_d}{L} \tag{8}$$

3. Personnel capacity allocation

The research scenario for passenger car transportation is to reserve at least a certain number of fuel powered passenger cars in order to ensure the basic transportation capacity of the city in the event of extreme conditions such as disasters, epidemics, or wars, without changing the total number of passenger cars (N) in the city. The basic capacity allocation concept for personnel transportation is shown in figure 2, based on the rule of prioritizing the use of pure electric buses for transportation. When electric buses cannot be used for transportation within the specified time, a certain number of fuel powered buses are used to replace pure electric buses for transportation. The steps for personnel capacity allocation are as follows:

(1) Assuming that all personnel are transported by electric buses, the total number of transportation personnel (N_{p}) is divided by the capacity of electric buses to obtain the number of electric buses (N_{eb1}). The specific expression is shown in (9).

$$N_{\text{eb1}} = \frac{N_p}{T_{eb}} \tag{9}$$

(2) When $N_{eb1} \le N$, only using electric buses can complete the transportation of personnel, without the need for additional fuel buses to ensure your basic transportation capacity. The expressions for the number of fuel buses (N_b) and the number of electric passenger cars (N_{eb}) are shown in (10).

$$N_b = 0, \quad N_{eb} = \frac{N_p}{T_{eb}} \tag{10}$$

(3) When $N_{eb1} > N$, the use of electric buses alone cannot complete the transportation of personnel and cannot meet the demand for basic transportation capacity. A certain number of fuel powered buses are needed to fill the gap in basic transportation capacity. The calculation method for the number of fuel powered buses is to first calculate the remaining number of people when all vehicles are transported using pure electric buses, and then divide the remaining number of people by the difference in transportation capacity between fuel powered buses and electric buses to obtain the number of fuel powered buses. The remaining number of people (N_r) is the product of the total number of people minus the total number of vehicles and the capacity of pure

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electric buses. The expression for the remaining number of people is shown in (11).

$$N_r = N_p - NT_{eb} \tag{11}$$

The expressions for the number of fuel powered bus (N_b) and the number of electric bus (N_{eb}) are shown in equations (12) and (13), respectively.

$$N_b = \frac{N_r}{T_b - T_{eb}} = \frac{N_p - NT_{eb}}{T_b - T_{eb}} \tag{12}$$

$$N_{eb} = N - N_b \tag{13}$$

4. Results and discussion

In order to verify the effectiveness of the model proposed in this article, four cities in different regions of China were selected as case studies to analyse the results of bus capacity allocation. The distribution results of buses capacity are shown in table 2. The total number of passenger cars is obtained from inquiries by transportation bureaus in various regions. The number of people transferred is calculated by subtracting the number of private cars that can be transported from the local population. The transportation distance is the average round-trip distance from the city centre to the suburbs.

City A is located in the central region of China, with densely populated areas and moderate temperatures. With charging stations available, more electric buses can be used, but a small amount of fuel buses are needed to supplement transportation capacity. In cases where the charging station is not available, more fuel powered buses are needed to supplement the transportation capacity. City B is located in the northwest region of China, with a vast area and sparse population. Most transportation can be completed using electric buses when charging stations are available. However, when charging stations are not available, electric buses cannot complete transportation due to their range being less than the transportation distance, and can only be transported using fuel powered buses. City C is located in the northeast region with cold weather. Low winter temperatures have led to a severe decline in the range of electric buses, so it is considered that the capacity of electric buses is zero and only fuel powered buses are used for transportation. City D is located in the warm southern region, with dense population, developed economy, and good public transportation construction. Therefore, regardless of whether charging stations are available or not, electric buses can complete personnel transportation.

Table 2. Allocation results of buses capacity in different cities.

City	N	N_p	L (km)	Temperature (°C)	Number of electric buses		Number of fuel buses	
					Yes	No	Yes	No
A	4592	1300000	130	-8	4240	1690	350	2900
B	1770	100000	380	-12	1720	0	50	910
C	10539	1000000	250	-20	0	0	6070	6070
D	20000	2500000	100	21	7580	11370	0	0

5. Conclusion

This article matches electric buses and fuel buses based on the population in the region. In the calculation process, factors such as the number of people to be transported, the charging time of electric buses, and the variation of the driving range of electric buses with temperature were mainly considered to calculate the transportation capacity of pure electric vehicles and fuel vehicles. Then, based on the rule of prioritizing the use of pure electric buses for transportation, priority is given to the use of pure electric buses for transportation. When using electric buses cannot complete personnel transfer, using fuel powered buses can compensate for the insufficient transportation capacity of electric buses. Finally, the minimum number of fuel buses that need to be retained is obtained. Through this calculation method, a matching scheme for the basic transportation capacity within the region can be provided to ensure the personnel transportation capacity within the region when the road is not blocked under extreme conditions. This study also provides scientific guidance for the healthy development of the transportation industry, especially in the context of the continuous development of new energy vehicle technology, the rational use of transportation tools, the establishment of a basic time limited transportation capacity for emergency supplies transportation, to ensure disaster relief and social stability.

There are also some shortcomings in the article, such as not considering the impact of terrain and road congestion on passenger transport capacity in the model. And the relevant parameters need to be refined to make the model calculation results more accurate. The next step is to add factors to be considered in the model and refine existing parameters to ensure the accuracy of model calculations.

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