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Research on site selection and vehicle scheduling of electric material vehicle swapping station

Longbao Xiang[1, #,*], Jianan Zhao[1,#], Li Yang[2,#]

[1]*College of Science, China Three Gorges University, Yichang, China*
[2]*College of Electrical Engineering & New Energy, China Three Gorges University, Yichang, China*
[*]*Corresponding author: xlb_6362_12@163.com*
[#]*These authors contributed equally.*

Abstract: *With the rise of electric material vehicles, transportation enterprises pay more and more attention to the location of battery swapping stations, the number of vehicles and battery packs. This paper analyzes the two cases of maximum material quantity and minimum cost. By establishing a mathematical programming model, the optimal scheduling scheme of station construction and battery pack is obtained under the conditions of maximum material quantity and minimum cost. In this study, by analyzing the known data, it is obtained that when the vehicle is fully loaded, the vehicle returns to the battery swapping station three times, and the remaining power is just 10 %. After analysis and comparison, the vehicle chooses to change the battery each time when the battery swapping station needs to change the battery to save time to meet the requirements of maximizing the amount of material transported. The battery pack is charged as a cycle. Firstly, the 1260 units of material, vehicles and battery packs transported in a cycle are analyzed, and then the maximum value of material transported within 240 hours is 274690 units by establishing a goal programming model. The station is located at station A, and the number of electric material vehicles and battery packs used is 47 and 534 respectively.*

Keywords: *Electric material vehicle; Battery pack; Goal programming model; Optimal scheduling scheme*

1. Introduction

1.1 Environment of problems

In recent years, great progress has been made in the field of batteries. Electric vehicles driven by electric energy, which will not produce polluting gases, have become the development trend under the theme of contemporary "environmental protection. " At the same time, China 's " carbon peak " by 2030 and " carbon neutrality " by 2060. The realization of the goal investment of clean autonomous electric vehicles in material transportation are contemporary development trends. In terms of economy and time, in the process of electric material vehicle operation, we should consider the location of the battery swapping station, the time cost and economic cost of charging and battery swapping of the battery swapping station, the scheduling scheme of the vehicle or battery pack, and make the location and scheduling plan of environmental protection and economy according to the actual situation[1].

1.2 Questions raised

In this paper, the following data are calculated according to the survey (Table 1). If the electric material vehicle transports the material from point A to point B, and then returns with no load, the material is transported in circulation. This problem requires us to establish a mathematical programming model to determine a two-way co-site location of the battery swapping station between point A and point B, and to find the corresponding vehicle and battery scheduling scheme. Under the constraints of resource constraints and battery operation mode, the maximum amount of material is transported within a specified time period. According to the given data, the model is solved, and the location of the power station, the amount of material transported in 240 hours, the number of vehicles and battery packs used in this period, and the optimal scheduling scheme of vehicles and battery packs are obtained.

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Table 1 Vehicle and battery data

Point A - Point B	The mileage is 10 km, two-way bicycle (rail) lane, the distance between the front and rear vehicles is not less than 500 m.
Vehicle	There are 120 vehicles in total, with a rate of 60km / h. Each vehicle is rated to be equipped with 6 battery packs, which are initially in the no-load state of the battery swapping station. The SoC (state of charge) of each vehicle battery pack is 100 %, and the maximum load capacity of each vehicle is 10 units.
Cell	A total of 900 groups are measured independently by a single battery pack. The six battery packs on the vehicle consume the same amount of electricity. The SoC of each battery pack is reduced by 1 % for every 4 minutes of no-load vehicle driving. Compared with no-load vehicle, the SoC of each battery pack is increased by 1 % for every 4 minutes of vehicle loading. The SoC of the vehicle battery pack can be replaced when it is in the interval [10 %, 30 %], and the SoC of the replacement battery pack is 100 %.
Time-consuming	Each replacement of a battery pack takes 30 seconds. After each battery pack is replaced, it takes 3 hours to charge and detect the standby state, and it takes 1 minute to load and unload each time.
Price	Including peak-valley electricity price, land price of battery swapping station, charging rate and charging pile cost, price of automatic battery swapping station equipment, battery price and vehicle price.

2. Problem analysis

There are three tasks. The first is to obtain the ' maximum ' transport material quantity within the specified time under the condition of vehicle constraints and battery pack constraints. The second is to determine the specific location of the bidirectional co-located power station on the AB road; the third is to obtain the number of vehicles and battery packs used and their scheduling[2].

For the first task, we first need to determine how many units of material are transported by each vehicle. ' Maximization ' means that the amount of material transported per unit time is the largest. Taking a vehicle as an example, the ratio of the amount of material transported to the transportation time is maximized to determine the amount of material transported by each vehicle. Then we calculate the amount of material. We regard one change (or change battery pack) to the next change (or change battery pack) as a cycle, and calculate the amount of material in one cycle of an electric material vehicle. The time limit has been given in the problem. In the process of transporting goods, the inevitable time consumption includes the loading and unloading time, the time consumed by transporting materials in two places, and these two time consumptions cannot be changed. For the time required to replace the battery pack, we should consider to minimize (previously assumed that the change does not consume time). Due to the requirement of ' maximization ', we compress the time to a minimum. Therefore, we only consider changing the car in each cycle. The amount of material in the objective function can be calculated by subsection. We first calculate the amount of material transported by all the cycles that can be completed in front of us, which is the product of the number of vehicles, the number of cycles and the amount of material in a single cycle of a vehicle. The number of vehicles we need to make the road between the two points as much as possible. There are electric material vehicles for transportation, which can try to transport more material in a short time. Under the time limit, there will be a cycle that cannot be completed. We consider the cycle separately and calculate the maximum amount of material that can be completed. Therefore, we sum the total amount of materials that complete the cycle and the amount of materials that fail to complete the cycle in the last paragraph to find the total maximum amount of materials transported.

On the second task, in the case of obtaining the maximum amount of material transported by the electric material vehicle, its position is obtained, that is, the method of goal planning [1] is used to solve it.

For the third task, we consider that in the case of maximizing the amount of material transported, the number of electric material vehicles used and the number of battery packs used are the smallest. For the number of vehicles used, we have compressed the time to the minimum, so we only need to avoid the replacement of the battery pack. For the number of battery packs used, we make the vehicle charge the battery pack at the battery swapping station when the power consumption is the lowest. As long as the battery pack is charged immediately after power consumption, and is put into use immediately after full power, the minimum number of battery packs can be obtained[3].

3. Data analysis

3.1 Searching electricity price data within a day

In a day, due to the different electricity consumption in each period, it can be divided into peak period, normal period and trough period, and the unit price of electricity in each period is different, as shown in table 2.

Table 2: One-day electricity price table

Electric power consumption state	**Time interval**	**Unit price**
fastigium	8:00-11:00，18:00-23:00	1.1992 yuan / kWh
Ping period	7:00-8:00，11:00-18:00	0.9120 yuan / kWh
low tide period	23:00-7:00	0.3376 yuan / kWh

Taking the 24-hour abscissa and the unit price of electricity as the ordinate, a one-day electricity price change map can be drawn (Figure 1).

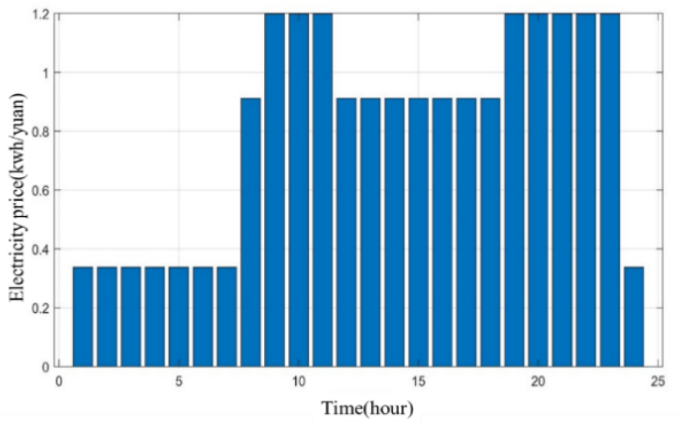

Figure 1 One-day electricity price change chart

3.2 Search for the cost data of the power station

In the calculation of the third question, we need to use the various costs of the battery swapping station, including: the land price of the battery swapping station, the cost of the charging pile, the price of the automatic battery swapping station equipment, the price of the battery pack, the price of the vehicle, the price of the DC charging equipment, and the price of the electricity. We display the data used above, as shown in table 3.

Table 3 Reference data

Land price for power station *Lc*	10000 yuan/m^2
Charging pile cost *PLc*	30000 yuan /piece
Battery price *Bac*	10000 yuan / piece
Electric material vehicle price *Cac*	200000 yuan /vehicle
Automatic power station equipment price *Ec*	500000 yuan / series
DC charging equipment *Dc*	300000 yuan / station
Charging ratec_r	65 ~ 70 min Filled with 6 battery packs
The area of the power station is occupied *S*	200m^2

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4. Establishment and solution of the model

4.1 Establishment of the model

4.1.1 Determination of the objective function

We set the location of the swapping station at point C, and set each time to meet the constraints to find the maximum value of the amount of material mq transported within 240 hours. Since each vehicle travels between points A and B, our objective function is:

$$\max mq \tag{1}$$

At the same time, we need to minimize the number of electric material vehicles and battery packs based on the calculated maximum material quantity, and specifically divide the use scheduling of vehicles and battery packs.

4.1.2 Modeling process

step1. **Determine the delivery volume of a vehicle**

We set m as the amount of material transported by an electric material vehicle (m = 0, 1, 2,..., 10). When m is 10, the electric material vehicle is fully loaded, and when m is 0, the electric material vehicle is empty. Each electric material vehicle has 6 battery packs, which consume the same amount of electricity. The SoC of each battery pack decreases by 1 % for every 4 minutes of no-load vehicle driving. Compared with no-load vehicle, the SoC of each battery pack increases by 1 % for every 4 minutes of cargo vehicle loading. The SoC of the vehicle battery pack can be replaced when it is located in the interval [10 %, 30 %], and the SoC of the battery pack is 100 %.

Considering the limitation of battery consumption, the amount of material transported by a single electric material vehicle m is obtained. Since the battery needs to be charged for three hours each time regardless of the amount of remaining power, without wasting the battery power and charging time, the remaining power is 10 %, so that the vehicle meets the requirement of ' when the vehicle travels back and forth for multiple times, the power is consumed to 10 %, and at this time, it is driven to the battery swapping station for battery swapping ', so that the amount of material transported is ' maximized '.

We have a total of 900 battery packs and 120 electric material vehicles. Through rough calculation, during the round trip between point A and point B, since the minimum distance between the vehicles is 500 meters, the road can accommodate up to 42 vehicles. The vehicle and the battery pack are sufficient to use. When the power consumption of each vehicle reaches 10 %, the electric material vehicle returns to the battery swapping station to meet the requirement that ' when the battery pack and the vehicle are sufficient, we enter the battery swapping station to directly replace the vehicle and continue to transport the material, saving its battery swapping time '.

The speed of the electric material vehicle is 60km / h, and the mileage between point A and point B is 10km.At the beginning, the SoC of each battery pack is 100 %, and both loading and unloading take 1 minute. Because the vehicle is traveling at a constant speed, the time of each trip is fixed. When an electric material vehicle consumes 100 % from SoC to 10 %, we set it to go a complete round trip. According to the above analysis, we do not calculate the time required to change the battery. Then the time required for an electric material vehicle to transport a round trip is 22 minutes, and the time required for a complete round trip is T.

$$T = 22 \cdot a \tag{2}$$

Similarly, when the power consumption of an electric material vehicle is from 100 % to 10 %, the amount of material transported in T time is

$$mq_T = m \cdot a \tag{3}$$

In order to meet the ' maximization ' of the amount of transportation materials required by the topic, we can maximize the amount of material transported per unit, that is, the ratio of the amount of material transported mqT to the required time T is the maximum value, that is, the maximum value of the amount of material transported per unit of a material carrier mqt.

$$\max mq_t = \frac{mq_T}{T} \tag{4}$$

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It is not difficult to conclude that the maximum value of mqt is only related to the amount of material transported by the vehicle. Therefore, we take m as the maximum value of 10. Through simple calculation, we can also find that when m = 10, starting from point A for round-trip, and the car with 100 % power consumption is consumed to 10 %, the electric material car just travels between point A and point B for 3 times, that is, a = 3. According to the above conclusions, the electric material vehicle starts from point C of the power station three times. When it reaches point C for the third time, the remaining power is 10 %. The total time T spent on the three times is:

$$T = 22 \times 3 = 66\,\text{min} \tag{5}$$

Then let the maximum number of changes be n, then n is

$$n = \left[\frac{240 \times 60}{66} \right] = 218 \tag{6}$$

The [x] symbol indicates that the number x in the brackets is rounded down.

Each time the electric material vehicle changes at point C, and the change is no-load driving back to point A. The change does not increase the time of loading and unloading, so the above time analysis is reasonable. Setting the distance between point A and point C as x, starting from 100 % of the electricity, and going back and forth three times according to figure 2, the route and electricity of the electric material vehicle are analyzed as follows:

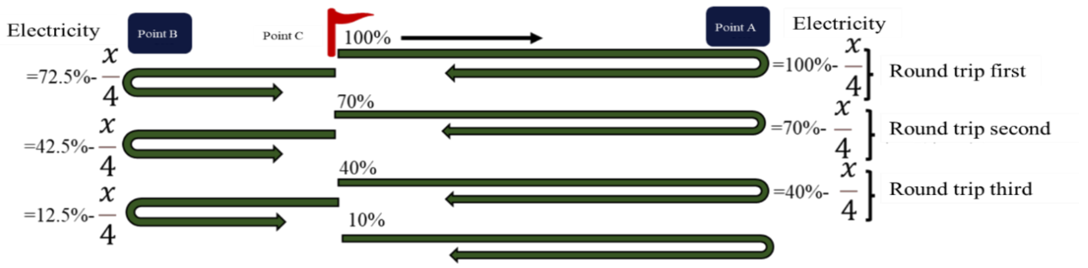

Figure 2 Vehicle cycle diagram

***step2.* Calculation of total time and determination of station location**

The electric material vehicle goes back and forth three times for a change. We will go back and forth three times for a change as a cycle. The maximum number of changes is n times. After the nth change, the vehicle's power is full. Due to time constraints, the n + 1 cycle of the amount of material transported by the electric material vehicle within 240 hours will not be fully carried out. It is assumed that during the period from the nth change to the n + 1 change, the number of times that the first vehicle passes through point B is k0, k0 = 1,2,3. Within the specified time, the electric material vehicle cannot return to the C point of the power station[4-5].

Let t be the total time spent on transporting materials in the above way, and x is the distance between point C and point A of the station. In the first n times of changing process, we calculate the electric material vehicle from station C to station C, and from the nth to the n + 1 times of changing period, we calculate the electric material vehicle from station B to station B. In the calculation of time, we calculate the time of a period of electric material vehicle passing through BC. The simple calculation shows that the BC section takes (10-x) min, and the total consumption time is

$$t = n \cdot T + 22 \cdot (k_0 - 1) + t_0 + (10 + x), \quad k_0 \in \{1,2,3\}, x \in [0,10]\; t \le 14400\,\text{min} \tag{7}$$

***step3.* Calculation of the amount of material transported**

In the transportation process from the nth to the n + 1st, after the first vehicle arrived at station B for the last time, the first vehicle could not return to station C during the remaining time of t0, and 41 electric material vehicles did not arrive at station C. At this time, there are $\left(\frac{t_0 - 2}{0.5} + 1 \right)$ electric material vehicles that can transport materials to station B and can be unloaded completely.

The amount of material transported in the first n times is different from that in the nth to n + 1 times. We assume that the amount of material transported in the nth to n + 1 times is mq0, and the maximum amount of material transported in this section is

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$$\max mq_0 = 42 \times m \cdot \left(k_0 - 1\right) + m \cdot \left(\frac{t_0 - 2}{0.5} + 1\right) \tag{8}$$

The total maximum amount of material transported is

$$\max mq = m \cdot n \cdot a \times 42 + mq_0 \tag{9}$$

***step4.* Vehicles, number of battery packs used**

Regarding the number of vehicles and battery packs used, we should minimize the number of vehicles and battery packs used during the ' maximization ' of the transport material.

Regarding the minimum number of vehicles used, we set the number of vehicles used in the process of maximizing the amount of transportation materials as V, numbering the vehicles 1, 2,..., 120, and numbering i as the ith vehicle ($1 \le i \le V$). In the first cycle, we use up to 42 vehicles for transportation to maximize the amount of materials transported, and then each time we enter the battery swapping station in the cycle. In order to minimize its time, we adopt a direct car swapping method. In addition to these 42 vehicles, in order to maintain the cycle, we used an additional V0 vehicle.

Considering that the station C is built at point A, the vehicle needs to stay for 1min to load at station A (C). Assuming that the i-th vehicle just arrives at the station, the i + 1th vehicle will arrive at the station after 0.5min, the i-1th vehicle has stayed at station A for 0.5min, and the i-2th vehicle has stayed at station A (C) for 1min to complete the loading and prepare to start.

As long as we ensure that after the first cycle, the electric material car is equipped with a battery pack, it can be recycled without consuming time to wait, and the number of vehicles used in the whole material transportation process can be guaranteed to be the smallest. Pi is the battery power of the i th vehicle ($1 \le Pi \le 6$). At the time of the i th electric material vehicle arriving at station A (C), the vehicle 's power is 10 %. At the end of one cycle, the replacement vehicle is loaded, and the i th vehicle has replaced two battery packs, i.e. Pi = 2.

$$\sum_{k=1}^{V_0} \left(P_i + 1\right) = 6 \tag{10}$$

We can easily calculate V0 = 5, that is, we add 5 vehicles to the cycle. At this time, the number of vehicles we use is the smallest, then the total number of vehicles used is $V = 42 + V_0 = 47$.

For the minimum number of battery packs used, we use 180 min as a cycle. When entering the next cycle, the battery pack consumed in the previous cycle has been recharged for use. According to the above ideas, all the battery packs used are the number of battery packs used by 42 vehicles and the number of battery packs needed to maintain the cycle. In the first change, 42 electric material vehicles all use battery packs. In the second change, because the battery packs are not fully charged, it takes 3 hours to detect the standby state. When the third change is just started, the battery is not fully charged. At this time, we need to use new additional battery packs, which have been loaded into the car and can be changed directly. In the third change process, the battery pack used in the first round is fully charged, and we can change the car directly. We do not need to use a new battery pack, so as to achieve the minimum value of the battery pack. Through simple calculation, the number of battery packs used in the first two car changes is 504. When the third car change starts from the sixth car of the current round, we can use the battery that has been fully charged replaced by the first car change. Therefore, the number of additional battery packs we use in the third car change is 30. Add them together to calculate the minimum number of battery packs we use in a cycle b.

4.2 Solution of the model

Using MATLAB to solve the above model, table 4.

Table 4 The maximum amount of material transported and other parameters results

Maximum material quantity	Switching station location	the minimum number of the buses	Minimum number of battery packs
274690 units	A station	47 vehicles	534 groups

Based on the above modeling, we can find the maximum value of 274,690 units of transported material delivered in 240 hours with the constraint of the number of vehicles and the number of batteries, and the location of the switching station is at station A. Under the condition of the maximum number of transported materials, the minimum number of vehicles used is 47, and the number of batteries used is 534.

The specific scheduling scheme for the vehicles and their individual batteries is shown in Table 5.

Table 5 Vehicle, battery pack specific scheduling

Car exchange		Vehicle Dispatch (Vehicle number)	Battery Pack Dispatch (battery pack number)	Shipping volume
The 1st time to change the car		1~42	1~252	1260
The 2nd car change		43~47,1~38	253~504	1260
The 3rd car change		39~47,1~33	505~534,1~222~	1260
The 4th car change		34~47,1~28	223~474	1260
The 5th car change		29~47,1~23	474~534,1~192	1260
…		…	…	1260
The 218th car change		1~42	1~252	1260
The 219th time did not change the car	First trip	1	253~258	10
	Second trip	0	0	0
	Third trip	0	0	0
Total number		47 vehicles	Group 534	274690 units

The specific scheduling scheme for the vehicles and their individual battery packs: the first 42 trams depart from station C. When they return to station C after 3 round trips, a tram change is made and the run continues. At the end of the 218th round trip, only the first vehicle is allowed to continue running and the other vehicles stay at station B.

4.3 Analysis of results

With the above results, we can know that this solution is to compress the time to the extreme, and change the vehicle directly at the change station instead of waiting to change the battery. We can know that the amount of material transported in this solution is the largest, but the number of its vehicles and battery packs required is not the smallest.

5. Conclusion

With the rise of electric material vehicles, transportation enterprises pay more and more attention to the location of battery swapping stations, the number of vehicles and battery packs. This paper analyzes the two cases of maximum material quantity and minimum cost. By establishing a mathematical programming model, the optimal scheduling scheme of station construction and battery pack is obtained under the conditions of maximum material quantity and minimum cost. In this study, by analyzing the known data, it is obtained that when the vehicle is fully loaded, the vehicle returns to the battery swapping station three times, and the remaining power is just 10 %. After analysis and comparison, the vehicle chooses to change the battery each time when the battery swapping station needs to change the battery to save time to meet the requirements of maximizing the amount of material transported. The battery pack is charged as a cycle. Firstly, the 1260 units of material, vehicles and battery packs transported in a cycle are analyzed, and then the maximum value of material transported within 240 hours is 274690 units by establishing a goal programming model. The station is located at station A, and the number of electric material vehicles and battery packs used is 47 and 534 respectively.

References

[1] Qiyuan Jiang, Jinxing Xie, Jun Ye. Mathematical models 5th edition [M]. Higher Education Press, 2018.
[2] Chen Guangkai, Qu Dapeng, Hu Xiaojing, Zhang Hongcai, Hu Zechun, Wang Ke. Cost-benefit assessment of electric vehicle charging and switching stations based on whole life cycle analysis [J]. Power Construction, 2016, 37(01): 30-37.

ISSN 2522-3488 Vol. 7, Issue 4: 37-44, DOI: 10.25236/IJNDES.2023.070407

[3] Fang Liujia. Research on Electric Bus Charging and Switching Station Layout Planning [D]. South China University of Technology, 2015.
[4] Guan Haoliang, Wang Jin-Hua, Qiu Wei-Yu. Control of electric vehicle charging rate in smart grid using multi-objective optimization method [J]. Electrical Technology, 2017(12): 76-80.
[5] Chen Q, Wei JP, Liu Y, Han N, Wu T, Liu MEQ, Wang X, Qiao SH. Scheduling method for infectious disease sample collection drones based on taboo search algorithm [J]. Radio Engineering, 2022, 52(07): 1238-1249.