APEM journal

Advances in Production Engineering & Management
Volume 14 | Number 1 | March 2019 | pp 65–79
https://doi.org/10.14743/apem2019.1.312

ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

Achieving sustainable transport through resource scheduling: A case study for electric vehicle charging stations

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A B S T R A C T

Electric vehicles support low-carbon emissions to revitalize sustainable transportation, and more charging stations are being built to meet the daily charging demand. Charging piles and service workers are the most important resources for electric vehicle charging stations, and the scheduling of these resources is an important factor affecting the charging stations' profits and sustainable industrial development. In this paper, we simulate the charging piles and service workers in charging station resource scheduling and analyze the impacts of the number of service workers, the charging pile replacement policy and the charging pile maintenance times on an electric vehicle charging station's profits. An orthogonal test can achieve the following optimal resource scheduling results when their range is known: (1) In the lifetime of the charging pile, seven maintenance times are needed; (2) Even if the charging pile is still in normal condition, it needs to be replaced in order to achieve the maximum profits for the charging station; (3) a comprehensive analysis of service efficiency and service costs indicates that 8 service workers are needed to achieve the optimal profits for the charging station. Therefore, the scientific contribution of this research is to establish one resource scheduling simulation model that can assess the effects of the number of service workers, the charging pile replacement policy and the charging pile maintenance times on charging station revenues and to obtain the optimal results. In addition, if the model parameters change, we can still obtain the optimal results.

A R T I C L E I N F O

Keywords:
Sustainable transport;
Resource scheduling;
Electric vehicle;
Charging station;
Simulation;
Profit

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Article history:
Received 8 September 2018
Revised 12 February 2019
Accepted 24 February 2019

1. Introduction

To revitalize sustainable transportation, China is vigorously developing electric vehicles (EVs). By virtue of clean energy and total emissions reductions, electric vehicles address low-carbon emissions regulations under the new requirements and new tasks in China's auto industry [1, 2]. The next decade or even decades will be a strategic opportunity for EVs. In addition to satisfying the need for sustainable transportation, more charging stations are being built to meet the daily charging demand. Charging piles and service workers are the most important resources for electric vehicle charging stations. Charging piles are distributed in different charging stations, and each pile has a certain income if it operates normally. If failure occurs, repair or replacement is necessary, and charging piles require maintenance over the lifetime of the machine; otherwise, there is a high probability of failure. Therefore, we need to allocate charging station resources to achieve optimal charging station profits and sustainable transportation.

Limited by the developmental phase of the EVs industry, resource scheduling for charging stations has not been paid adequate attention. If resource scheduling is not taken into consideration, the EV industry may not develop properly, which will hinder sustainable transportation. Simulation technology is used to model the relationships and behaviors between individuals in the whole system, and computer simulations are used to establish a model that can reproduce the real system in order to obtain an optimal solution. Therefore, based on the conception model, this paper obtains a resource scheduling mathematical model of a charging station and analyzes the model based on simulation theory using the AnyLogic tool. From the simulation point of view, this paper studies the effects of the number of service workers, the equipment replacement policy (equipment refers to the charging pile, and this is the same as follows) and the equipment maintenance times on charging station profits. Reasonable resource scheduling will result in proper electric vehicle industry development and achieve sustainable transportation.

This paper is organized as follows. We first conduct a comprehensive review, which forms the theoretical foundation of this study. In section 3, an analytical model is proposed that forms the base of the research problem. In section 4, we present the mathematical materials and methods. In section 5, we verify the simulation model through a case study. Finally, conclusive remarks are presented.

2. Literature review

EVs are environmentally friendly and are becoming increasingly popular in sustainable transportation. However, factors including the mileage (battery life), charging time, charging convenience, purchase price, and vehicle performance hinder the development of the EV industry [3-6]. An adequate charging infrastructure, rational national guidance and locally targeted construction planning, that is, reasonable resource scheduling, can be an effective way to solve these problems of the EV industry.

In the actual operations of EV charging stations, personnel time and effort are necessary, thus requiring the scheduling of a larger workload [7]. Therefore, theories and methods are needed to guide resource scheduling. Scholars have made many achievements in their research, including experience summarization, mathematical programming models, and artificial intelligence algorithms.

The initial research was basically a summary. Due to the lack of scheduling experience, Miller turned to the mathematical programming model [8], and Cook viewed the scheduling problem as essentially an NP (Non-deterministic Polynomial) problem [9]. Many scholars have studied specific problems. Xi *et al*. used a linear integer program to simulate the number of L1 (level 1) and L2 (level 2) EV charging stations required at work and public locations and predicted the EV travel flows in central Ohio as well as the number, type, and location of EVs charging stations [10]. Zhang *et al*. optimized direct current, fast EV charging station allocation and temporal utilization to maximize eVMTs (electric vehicle miles traveled) through a set-cover problem. This work showed that random and late charging will increase the grid demand in the afternoon, while early, inexpensive, and reserve strategies evenly distribute charging throughout the day [11]. Chen *et al*. developed a mixed-integer optimization program considering budgetary constraints, which limit the total number of EV charging stations to be deployed. The forecasted parking demand was used as an input to the mixed-integer optimization program, which strategically locates 80 public charging stations across 900 traffic analysis zones in the Seattle, Washington region [12]. Yi and Bauer formulated an optimal energy-aware charging infrastructure placement framework. The multi-objective decision model located the EV charging stations to maximize the number of reachable households under an energy constraint while minimizing the overall transportation energy consumption of charging actions [13].

For complex production scheduling, a simple mathematical model cannot cover all the factors, and the solution process is very complex. Therefore, people have developed artificial intelligence technology to solve scheduling problems; for example, in Mehar [14], a modified GA (genetic algorithm) that considers an objective function based on investments and transportation costs was used to optimize charging station locations. By contrast, Bendiabdellah *et al*. [15] and You and Hsieh [16] employed a hybrid GA to determine the optimal number and size of public charging stations, which found the optimal location by minimizing the investments and travel costs. Tang *et al*. [17] applied multi-phase particle swarm algorithm to solve resource scheduling problem. The main shortcomings of AI are its low precision and easy divergence, thus making AI solutions non-optimal.

By combing the literature, we find that the existing scheduling theories have a record of solving the resource scheduling problem for EV charging stations. However, EV charging stations have their own characteristics, and many specific factors can influence resource scheduling, such as different policies, policymakers, charging station planners, battery technologies and EV manufacturers [18-21]. On the other hand, some studies have discussed the layout of EV charging stations [22-26], but they paid minimal attention to the resource scheduling of EV charging stations. Based on the mathematical model and simulation method [27], this paper builds the resource scheduling agent model of the EV charging station and analyzes the effect of the number of service workers, the equipment replacement policy and the equipment maintenance times on charging station profits.

3. Problem description

The problem of resource scheduling in EV charging stations is as follows. The service workers are concentrated in a certain area. When they receive the message "equipment maintenance", "equipment repair" or "equipment replacement" sent by the message center, they go to a charging station location to complete the corresponding task. In the service process, if the equipment cannot be repaired, the worker can directly replace the equipment, and if the equipment can be repaired, the worker checks whether the equipment needs maintenance. Considering the overall profits of the charging station, the service worker can replace equipment that is in a working state.

There are three main situations related to resource scheduling in charging stations.

Single service worker and single equipment

In the model for "single service worker and single equipment", the status of the equipment determines the worker's working time (drive time) and agenda (equipment replacement, equipment repair or equipment maintenance) (Fig. 1). The worker checks whether there is demand (equipment failure) for the equipment. If there is demand, the service worker drives to the charging station location to complete the service and finally returns to the worker center.

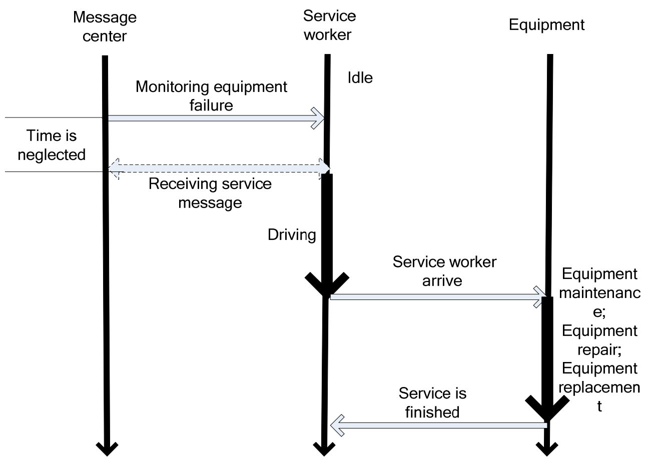

Fig 1 Situation 1

Single service worker and more equipment

In this case, there are two pieces of equipment and only one service worker (Fig. 2). When equipment 1 detects a fault and sends a service request to the message center, the message center immediately notifies the service worker, and the service worker quickly drives to the designated charging station location to finish the service. Equipment 2 also detects a fault, which also sends a service request to the message center; however, the request of equipment 2 cannot be answered until the service for equipment 1 is finished.

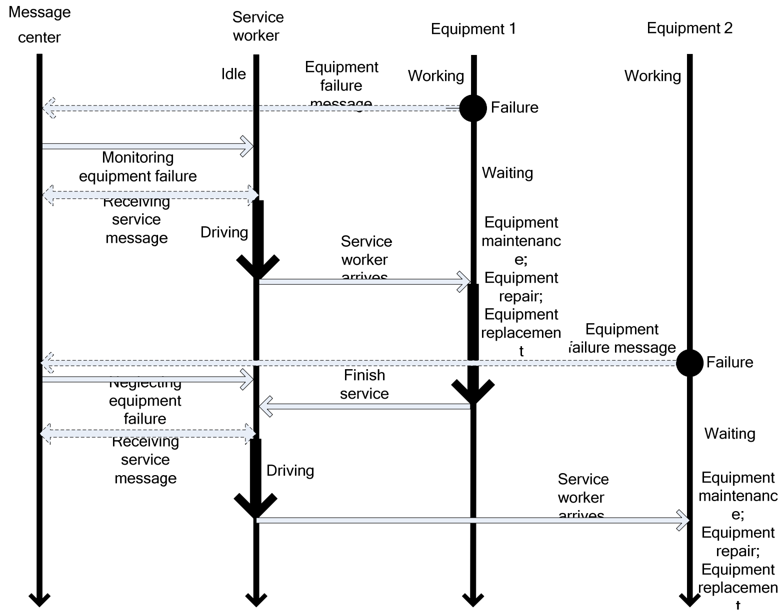

Fig 2 Situation 2

More service workers and single equipment

In this case, two workers can provide service for the same equipment (Fig. 3). The message center sends an equipment failure message to all service workers. At first, two service workers are idle, so they receive the messages and check their messages at the same time. Then, only one worker arrives at the designated charging station location to complete the service, and the other worker remains idle. In reality, it is a combination of the above three conditions.

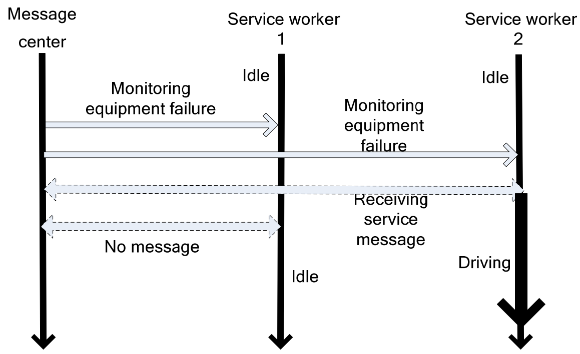

Fig. 3 Situation 3

The remainder of this paper will analyze the impacts of the number of service workers, the charging pile replacement policy and the charging pile maintenance times on the electric vehicle charging station's profits based on the mathematical model of resource scheduling and the idea of simulation modeling.

4. Materials and methods

4.1 Model definition

The assumptions in this paper are as follows:

- equipment needs maintenance, repair and replacement, and service workers can complete the above tasks,
- there are fixed costs in the process of equipment maintenance, repair and replacement,
- there is no specific running routine for the workers, and they move at a fixed rate,
- workers can provide service all day,

- workers can complete the task each time,
- workers can always arrive at the nearest charging station regardless of the running costs.

There are two types of worker-equipment constraints in the process of the worker reaching the demand point: the physical condition and the operational condition. These constraints are set as follows:

$$\begin{gathered}\sum_{i=1}^{n} v_i = V\ ,\ \sum_{j=1}^{m} b_j = B \\ \text{idle}(v_i) = V_{idle} \\ \sum V_{idle} = \sum B_{type} \\ V_{idle} = B_{type} = (B_0, B_1, B_2, B_3) \Rightarrow service(v_i) = b_j\end{gathered} \tag{1}$$

where v_i is the worker, b_j is the equipment demand (maintenance, repair and replacement), V is the worker set, B is the demand set, $\text{idle}(v_i)$ is the condition of the worker, V_{idle} is the worker condition set, B_{type} is the demand type set, and $service(v_i) = b_j$ means that worker i provides service for demand j. Only if the demand type matches the worker type can service start. Therefore, the matrix of worker -equipment constraints is set as follows:

$$A = \begin{bmatrix} y_{11} & y_{12} y_{13} & \cdots & y_{1n} \\ y_{21} & \ddots & & \vdots \\ y_{31} & \ddots\ \ddots & & \vdots \\ \vdots & y_{ij} & \ddots & \vdots \\ \vdots & & \ddots & \vdots \\ y_{m1} & \cdots\cdots & \cdots & y_{mn} \end{bmatrix} \tag{2}$$

where $0 < i < n$ and $0 < j < m$.

$$y_{ij} = \begin{cases} 1 & \text{worker } v_i \text{ provides service for demand } b_j \\ 0 & \text{worker } v_i \text{ cannot provide service for demand } b_j \end{cases} \tag{3}$$

With the worker-equipment constraints, we aim to optimize the profits of the charging station and ensure the satisfaction of demand. The initial setting of the parameters is shown in Table 1.

Table 1 Initial setting of parameters

Parameter	Memo
V_n	Number of service workers
B_n	Amount of equipment
$B_0 b_j, B_1 b_{j'}, B_2 b_{j''}, B_3 b_{j'''}$	Equipment in different states (working, repair, maintenance or replacement); j, j', j'', j'' = 1, 2,...,B_n
t_1	Daily revenues generated by the equipment
t_2	Daily payment for the workers
t_3	Equipment repair costs
t_4	Equipment maintenance costs
t_5	Equipment replacement costs
$t_{17}(B_3)_{jm}$	Battery replacement policy
$t_{16}(B_2)$	Equipment maintenance times
X_{ijk}	Equipment j is serviced by worker i in sequence k
y_i	Equipment-worker constraints

The objective function in the model gains the maximum profits for the EV charging station. The charging station's total costs include worker costs, equipment maintenance costs, equipment repair costs and equipment replacement costs.

Total worker costs: $t_2 V_n$

Total equipment repair costs:

$$t_3 \sum_{j'=1}^{B_n} (B_1 b_{j'})$$

Total equipment maintenance costs:

$$t_4 \sum_{j''=1}^{B_n} (B_2 b_{j''})$$

Total equipment replacement costs:

$$t_5 \sum_{j'''=1}^{B_n} (B_3 b_{j'''})$$

Total charging station costs:

$$t_3 \sum_{j'=1}^{B_n} (B_1 b_{j'}) + t_4 \sum_{j''=1}^{B_n} (B_2 b_{j''}) + t_5 \sum_{j'''=1}^{B_n} (B_3 b_{j'''}) + t_2 V_n$$

4.2 Model construction

The total revenues of the charging station, which are generated by the normal working equipment, are as follows:

$$t_1 \sum_{j=1}^{B_n} (B_0 b_j)$$

The following maximizes the profits for the charging station when considering $t_{16}(B_2)$:

$$\begin{aligned} \max_{\substack{t_{16}(B_2)\\ V_n}} t_1 \left\{ \sum_{m=1}^{t_{16}(B_2)} \sum_{j=1}^{B_n} (B_0 b_{m,j}) - \sum_{m=t_{16}(B_2)}^{\infty} \sum_{j=1}^{B_n} (B_2 b_{m,j''}) \right\} - t_3 \sum_{j'=1}^{B_n} (B_1 b_{j'}) \\ -t_4 \sum_{m=1}^{t_{16}(B_2)} \sum_{j''=1}^{B_n} (B_2 b_{m,j''}) - t_5 \sum_{j'''=1}^{B_n} (B_3 b_{j'''}) - t_2 V_n \end{aligned} \tag{4}$$

The following maximizes the profits for the charging station when considering $t_{17}(B_3)_{jm}$:

$$\begin{aligned} \max_{\substack{t_{16}(B_2)\\ V_n \\ t_{17}(B_3)_{jm}}} t_1 \left\{ \sum_{m=1}^{t_{16}(B_2)} \sum_{j=1}^{B_n} (B_0 b_{m,j}) - \sum_{m=t_{16}(B_2)}^{\infty} \sum_{j=1}^{B_n} (B_2 b_{m,j''}) \right\} \\ -t_3 \sum_{j'=1}^{B_n} (B_1 b_{j'}) - t_4 \sum_{m=1}^{t_{16}(B_2)} \sum_{j''=1}^{B_n} (B_2 b_{m,j''}) - t_5 \sum_{j'''=1}^{B_n} (B_3 b_{j'''}) \{\max(t_{17}(B_3)_{jm} + 1,0)\} - t_2 V_n \\ \text{if} \quad t_{17}(B_3)_{jm} = 0 \end{aligned} \tag{5}$$

$$\begin{aligned} \max_{\substack{t_{16}(B_2)\\ V_n \\ t_{17}(B_3)_{jm}}} t_1 \left\{ \sum_{m=1}^{t_{16}(B_2)} \sum_{j=1}^{B_n} (B_0 b_{m,j}) - \sum_{m=t_{16}(B_2)}^{\infty} \sum_{j=1}^{B_n} (B_2 b_{m,j''}) - \sum_{j''=1}^{B_n} (B_3 b_{j''}) \right\} - t_3 \sum_{j'=1}^{B_n} (B_1 b_{j'}) \\ -t_4 \sum_{m=1}^{t_{16}(B_2)} \sum_{j''=1}^{B_n} (B_2 b_{m,j''}) - t_5 \sum_{j'''=1}^{B_n} (B_3 b_{j'''}) \{\max(t_{17}(B_3)_{jm} - 1,0)\} - t_2 V_n \\ \text{if} \quad t_{17}(B_3)_{jm} = 1 \end{aligned} \tag{6}$$

Considering the equipment-worker constraints, the objective function is as follows:

$$\begin{aligned}\max_{\substack{t_{16}(B_2)\\ V_n\\ t_{17}(B_3)_{jm}}} X_{ijk} \Bigg[& t_1 \left\{ \sum_{m=1}^{t_{16}(B_2)} \sum_{j=1}^{B_n} \left(B_0 b_{m,j}\right) - \sum_{m=t_{16}(B_2)}^{\infty} \sum_{j=1}^{B_n} \left(B_2 b_{m,j}\right) \right\} \\ & - t_3 \sum_{j'=1}^{B_n} \left(B_1 b_{j'}\right) - t_4 \sum_{m=1}^{t_{16}(B_2)} \sum_{j''=1}^{B_n} \left(B_2 b_{m,j''}\right) \\ & - t_5 \sum_{j'''=1}^{B_n} \left(B_3 b_{j'''}\right) \left\{ \max\left(t_{17}(B_3)_{jm} + 1,0\right) \right\} - t_2 V_n \Bigg] \\ & \text{if} \quad t_{17}(B_3)_{jm} = 0 \end{aligned} \tag{7}$$

$$\begin{aligned}\max_{\substack{t_{16}(B_2)\\ V_n\\ t_{17}(B_3)_{jm}}} X_{ijk} \Bigg[& t_1 \left\{ \sum_{m=1}^{t_{16}(B_2)} \sum_{j=1}^{B_n} \left(B_0 b_{m,j}\right) - \sum_{m=t_{16}(B_2)}^{\infty} \sum_{j=1}^{B_n} \left(B_2 b_{m,j''}\right) - \sum_{j''=1}^{B_n} \left(B_3 b_{j''}\right) \right\} \\ & - t_3 \sum_{j'=1}^{B_n} \left(B_1 b_{j'}\right) - t_4 \sum_{m=1}^{t_{16}(B_2)} \sum_{j''=1}^{B_n} \left(B_2 b_{m,j''}\right) \\ & - t_5 \sum_{j'''=1}^{B_n} \left(B_3 b_{j'''}\right) \left\{ \max\left(t_{17}(B_3)_{jm} - 1,0\right) \right\} - t_2 Vn \Bigg] \\ & \text{if} \quad t_{17}(B_3)_{jm} = 1 \end{aligned} \tag{8}$$

Subject to

$$\sum_{i=0}^{V_n} \sum_{j=0}^{B_n} X_{ijk} \geq 1, \qquad \text{where} \quad i = 1,2 \ldots V_n \tag{9}$$

Eq. 9 indicates that each instance of equipment demand can be assigned to the worker more than two times.

$$\sum_{j=0}^{B_n} X_{ijk} = 1, \qquad \text{where} \quad j = 1,2, \ldots, B_n \tag{10}$$

Only one equipment demand can be served by the worker at a time (Eq. 10).

$$\sum_{type=0}^{3} B_{type} = 1 \tag{11}$$

Equipment failure (work, repair, maintenance or replacement) can occur only once at a time, and type = 0 means that the equipment is in normal working condition (B_0), (Eq. 11).

$$t_{16}(B_2) \in [1, M] \tag{12}$$

M is a positive number. Eq. 12 means that there is a certain limit for the equipment maintenance times according to the equipment operations and charging station profits.

$$X_{ijk} \leq y_{ij}\ , y_{ij} \in \{0,1\} \tag{13}$$

The equipment service must meet the equipment-worker constraints in Eq.13.

Matrix y_{ij} should consider the conditions below:

- whether the worker is in an idle state,
- whether the equipment is in a failure state,
- whether the equipment failure times reach the service limit.

$$\sum_{m=0}^{1} t_{17}(B_3)_{jm} = 1, j = 1,2 \dots B_n \tag{14}$$

To increase the total profits of the charging station, even equipment in a normal working state can be replaced. Therefore, $t_{17}(B_3)_{j0} = 1$ indicates that normal equipment needs to be replaced, and $t_{17}(B_3)_{j1} = 0$ indicates that normal equipment does not need to be replaced (Eq. 14).

We can obtain the feasible solution using the Cplex model if V_n = 1 and B_n = 2, while it will be difficult to calculate the solution if more agents (equipment and workers) are included in the model. Due to the relationship complexity of the two agents and the dynamic demand of resource scheduling in the charging station, this paper develops the simulation method to model and simulate the resource scheduling for EV charging stations using the AnyLogic platform (AnyLogic platform is the leading simulation software invented by AnyLogic Company).

5. Case study

The AnyLogic simulator is developed to build equipment and worker simulation models. Our settings are shown in Table 2.

The output mainly includes the amount of equipment in operation, the amount of equipment in maintenance, and the amount of equipment in replacement or repair when changing $t_{16}(B_2)$, $t_{17}(B_3)_{jo}$, and V_n so that we can calculate the profits of charging stations. With respect to the equipment and worker simulation model, their message models are involved in the resource scheduling of the EV charging station.

Table 2 The simulation settings

Model	Item and memo
Worker model	Equipment variable
	Daily payment for worker
	Number of service workers
Equipment model	Equipment replacement time
	Equipment maintenance time
	Equipment repair time
	Equipment replacement probability
	Equipment maintenance period
	Basic equipment failure rate
	Equipment failure rate
	Workers
	Last maintenance time for equipment
	Last replacement time for equipment
	Equipment age
	Time since last maintenance
	Equipment replacement policy
	Equipment maintenance times
	Daily revenue generated by equipment
	Equipment replacement costs
	Equipment repair costs
	Equipment maintenance costs
Message	Equipment replacement or repair queue
	Equipment maintenance queue
	Equipment sent request for replacement or repair
	Equipment sent request for maintenance
	Request for replacement or repair is activated
	Request for maintenance is activated

5.1 Equipment simulation model

There are many factors that can affect the use of charging station equipment, such as the equipment failure rate, the equipment maintenance times, the equipment replacement policy, and the equipment maintenance cycle. In this model, there are four rules for each equipment agent.

Equipment failure rate

Whether a piece of equipment needs service is determined by its failure rate. The failure rate is affected by three factors: the equipment maintenance delay, the equipment age and basic failures. In this case, equipment maintenance delay = max (1, timeSinceMaintenance / MaintenancePeriod), age = max(1, ages/Flifetime), and equipment failure rate = basic failure × equipment maintenance delay × equipment age, where timeSinceMaintenance is the period since the equipment maintenance was completed, MaintenancePeriod is the maintenance period of the equipment, Flifetime is the rated life span of the equipment, and Fliftime = 3 × MaintenancePeriod.

Equipment maintenance times

After the equipment maintenance cycle, the equipment cannot work until it is serviced. However, the maintenance times K is limited by M; that is, the equipment can receive maintenance only if K<M, or it is directly scrapped.

Equipment replacement policy

When the equipment breaks down, the worker replaces or repairs it. Equipment replacement is also affected by the equipment replacement policy, which refers to the fact that the worker can directly replace the equipment that is still in working condition.

Equipment maintenance cycle

When the equipment repair is finished, the worker also checks whether the equipment needs maintenance. When the equipment maintenance period comes (timeSinceMaintenance > MaintenancePeriod), the worker immediately starts the maintenance service on the equipment. The operation of the equipment simulation model in AnyLogic is shown in Fig. 4.

Graphic description: The equipment is working at first. Then, it breaks down (Fails) according to the failure rate and sends the required service message to the message center. When the worker receives the request information through the message center, he or she goes to the charging station location (SCArrivaldForRepair). In this case, there are two ways of handling the issue: repair or replacement. If it is in the condition of replacement, the worker replaces the equipment (StartReplacement) after the replacement time (FinishReplacement); otherwise, the worker repairs the equipment (StartRepair) after the repair time (FinishRepair). If timeSinceMaintenance > MaintenancePeriod, the equipment needs maintenance (MaintenanceDue) after the maintenance time (FinishMaintenance); otherwise, if the maintenance cycle (MaintenanceNotDue) is not reached, the equipment can begin to run after the completion of the repairs. In addition, considering the equipment replacement policy and the overall charging station profits, we can require workers to check the working equipment (SCArrivedForMtce) even if it is still in normal condition.If it meets the equipment replacement policy, the worker should replace the working equipment (PlannedReplacement); otherwise, equipment maintenance (JustMaintenance) should be performed.

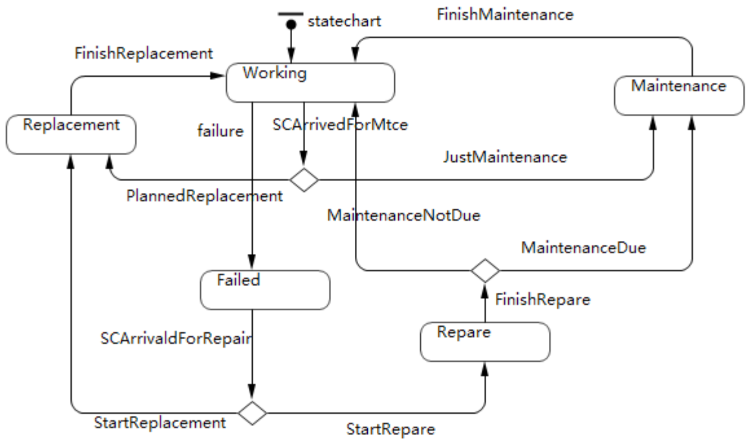

Fig. 4 Equipment agent operation

5.2 Worker simulation model

The workers will check the equipment service request from time to time. When the demand information is found and the worker is idle, the worker quickly drives to the designated charging station to complete the corresponding service. Thus, an eight-tuple is used to represent the level of worker service capability:

$$Cap\_servive(xloc, yloc, S_{number}, S_{idleornot}, S_{cost}, S_{worktime}, S_{miles}, S_{area})$$

The first two terms of the eight-tuple represent the geographical coordinates of the worker's location, S_{number} indicates the number of workers, $S_{idleornot}$ indicates the current status of the worker, $S_{idleornot} = 1$ indicates an idle state, $S_{idleornot} = 0$ indicates a busy state, S_{cost} is the payment for the worker, $S_{worktime}$ is the worker service time per day, S_{miles} is the maximum miles that a worker can drive every day, and S_{area} is the largest service area. The service process of the worker agent in AnyLogic is shown in Fig. 5.

Graphic description: At first, the worker is in the idle state $S_{idleornot} = 1$ and checks the service message from the message center (Check Request Queue). After receiving the equipment failure information (RequestsWaiting), the worker drives (DrivingtoWork) to the charging station (Arrived) and finishes the corresponding service (Working), which includes replacement, repair and maintenance. When the equipment sends out the "Finished" information, the equipment reenters the working state, and the worker is in an idle state again (IAmstillEmployed).If there are new requests for equipment service, the worker can be scheduled again, or the worker leaves the system (laidoff). If there is no equipment failure information (NoRequest), the worker returns (DrivingHome) to the original location (ArrivedHome) and assumes an idle state ($S_{idleornot} = 1$). Considering the overall profit of the charging station, we need to calculate the appropriate number of workers (checkiflaidoff).

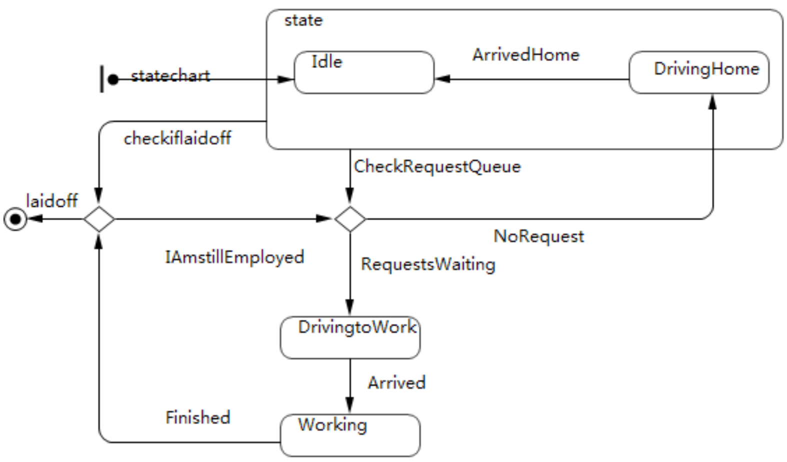

Fig 5 The service process of a worker

5.3 Message Center

Due to the "single service worker and more equipment" situation, the "first come, first service" mode is used to finish the corresponding service. The equipment failure information (replacement or repair) will be sent by the message center. The equipment failure information (maintenance) will also be sent by the message center. The worker checks the service message (replacement, repair, or maintenance) from the message center, and then the worker drives to the charging station and finishes the corresponding service.

In the simulator, we can obtain working equipment, in-service equipment, in-maintenance equipment and failed equipment.

6. Results and discussion

According to the mathematical model and simulation model, this paper can obtain the simulation results using the AnyLogic tool. The parameter setting and their values are shown in Table 3. Note: $t_{16}(B_2), t_{17}(B_3)_{j0}$ or $t_{17}(B_3)_{j1}, V_n$ are the decision variables, and the simulation time unit is years.

We need to analyze the number of service workers, the equipment replacement policy and the equipment maintenance times. When $t_{16}(B_2) = 5, t_{17}(B_3)_{j0} = 1$ and $V_n = 5$, the corresponding statistics of the worker and equipment are as shown in Fig. 6. In Fig. 6, most workers will be driving or working, and few workers are idle. In addition, most equipment are working, a few pieces are in the failed state, and a few pieces of equipment are in the maintenance state, repair state or replacement state. Based on the above statistical results, we can calculate the revenues of the charging station for years.

Table 3 Parametersettingand their values

Parameter	Memo	Distribution(value)
t_1	Daily revenues generated by equipment	$U[150,250]$
t_2	Daily payment for worker	$U[700,800]$
t_3	Equipment repair costs	$U[250,450]$
t_4	Equipment maintenance costs	$U[100,200]$
t_5	Equipment replacement costs	$U[3000,4000]$
t_6	Equipment repair time	$Tr_i[t_{51} \cdot 0.5, t_{51}, t_{51} \cdot 2.5], t_{51}n\ U[0.5,1.5]$
t_8	Equipment maintenance time	$Tr_i[t_7 \cdot 0.5, t_7, t_7 \cdot 1.5], t_7{\sim}U[0.3,0.7]$
t_{10}	Equipment replacement time	$Tr_i[t_9 \cdot 0.5, t_9, t_9 \cdot 1.5], t_9{\sim}U[1.5,2.5]$
t_{11}	Equipment replacement rate	$EXP[\lambda], \lambda = 10$
t_{12}	Equipment maintenance cycle	$U[80,100]$
t_{13}	Last maintenance time for equipment	$U[-t_{12},0]$
t_{14}	Last replacement time for equipment	$U[-3t_{12},0]$
t_{15}	Basic equipment failure rate	$EXP[\lambda_1], \lambda = 100/3$
$t_{16}(B_2)$	Equipment maintenance times	5
$t_{17}(B_3)_{j0}t_{17}(B_3)_{j1}$	Equipment replacement policy	$t_{17}(B_3)_{j0} = 1$ or $t_{17}(B_3)_{j1} = 0$
t_{18}	Worker driving miles per day	$U[400,600]$
V_n	Worker number	3
B_n	Equipment number	100
t_{21}	Service area	300000

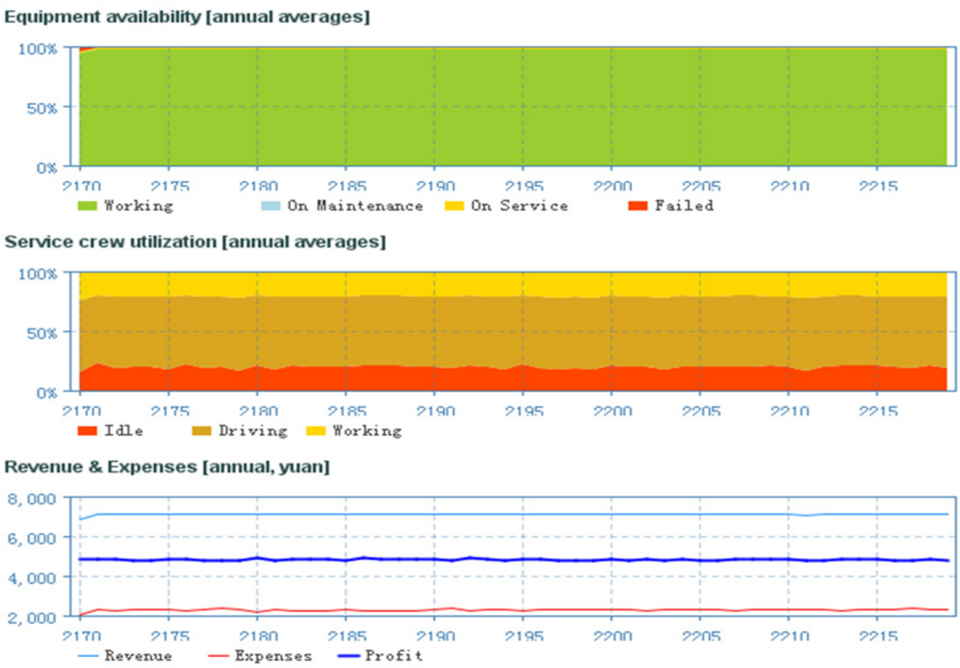

Fig. 6 Simulation results

It can be seen from Fig. 6 that the revenues, costs and profits of the charging station are held at a constant level when $t_{16}(B_2) = 5, t_{17}(B_3)_{j0} = 1$ and $V_n = 5$, and the profits are 4,800,000 yuan annually.

The goal of resource scheduling for EV charging stations is to achieve the maximum profits. Therefore, it is necessary to comprehensively consider the number of workers, equipment maintenance times and equipment replacement policy. Here, the number of workers is $V_n = 3 \in [1, \infty]$, the equipment maintenance times is $t_{16}(B_2) \in [1, \infty]$ and the equipment replacement policy is $t_{17}(B_3)_{j0} = 1$ or $t_{17}(B_3)_{j1} = 1$. Fig. 7 shows the different situations. When $t_{16}(B_2) = 6, t_{17}(B_3)_{j0} = 1$ and $V_n = 4$, the corresponding statistics of the worker and equipment can also be obtained, and the profits are 5,300,000 yuan annually (Fig. 7). When $t_{16}(B_2) = 7, t_{17}(B_3)_{j0} = 1$ and $V_n = 2$, the profits are approximately 3,200,000 yuan in one year (Fig. 8). Similarly, when $t_{16}(B_2) = 8, t_{17}(B_3)_{j0} = 1$ and $V_n = 3$, the profits are approximately 5,000,000 yuan in one year.

It is therefore impossible to calculate the optimal results through sensitivity analysis due to the infinite simulation results. An orthogonal test is developed to solve such a problem. In this paper, an orthogonal test is used to select some representative points in a nonstop way until the optimal situation is found. The parameter setting is given in Table 4.

The simulation time is 20 years, and the maximum number of iterations is 2000.The setting of the other parameters is shown in Table 2. The optimal results are obtained after 104 iterations (Table 5).

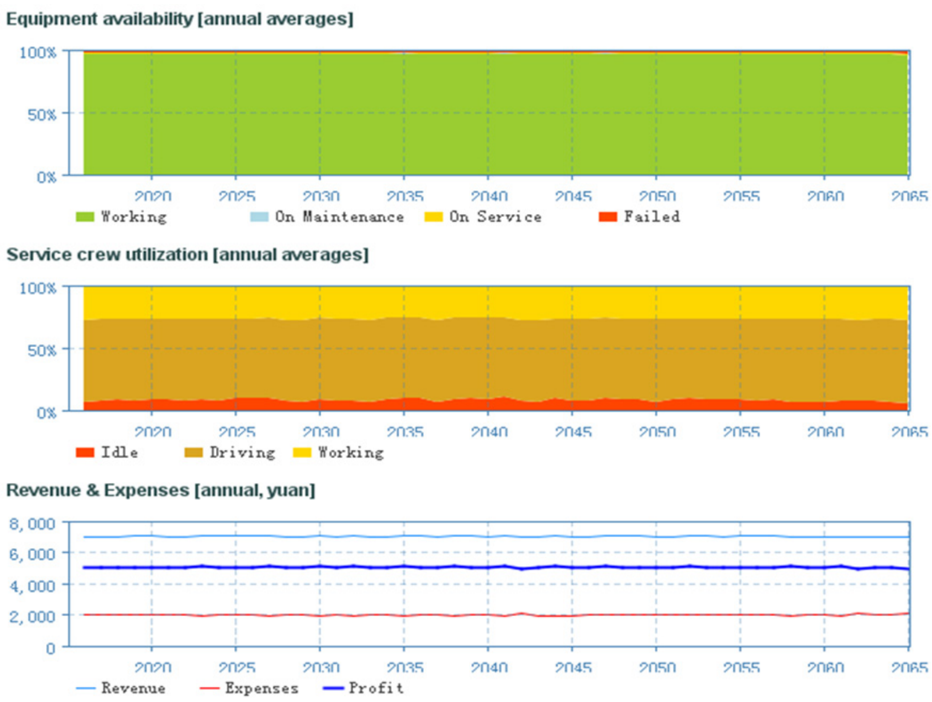

Fig. 7 Statistics of results 1

Table 4 Parameter setting in the orthogonal test

Parameter	Type	The minimum	The maximum	Step size
$t_{16}(B_2)$	Integer	2	8	1
$t_{17}(B_3)_{j0}$	Boolean	-	-	-
V_n	Integer	1	9	1

Table 5 The optimal results

Decision variables	Results
$t_{16}(B_2)$	7
$t_{17}(B_3)_{j0}$	$t_{17}(B_3)_{j0} = 0$ or $t_{17}(B_3)_{j1} = 1$
V_n	8

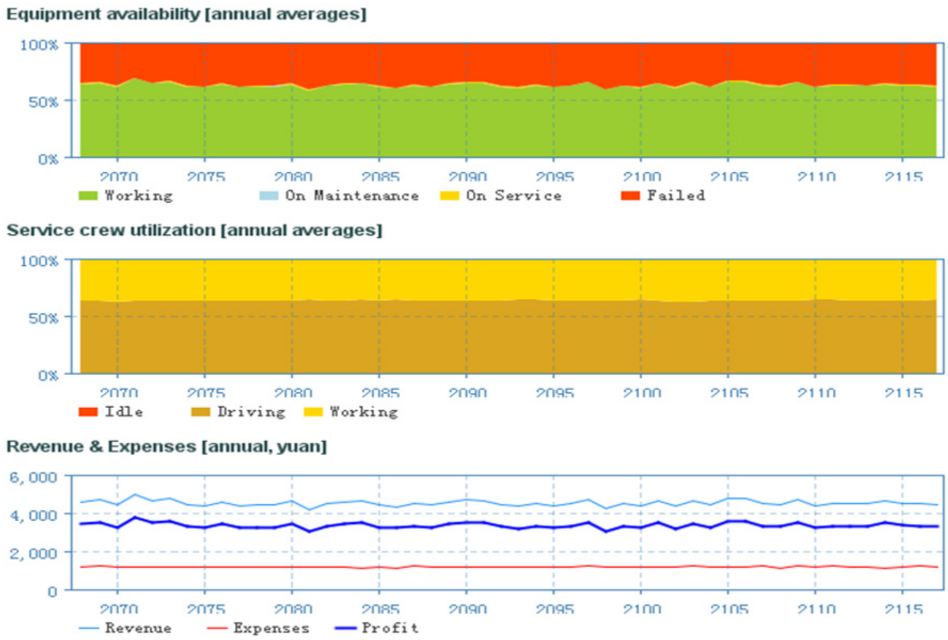

Fig 8 Statistics of results 2

Based on the results in Table 5, we can achieve additional profits of 5,928,336 yuan in one year. Therefore, we need to incorporate the following.

- Seven equipment maintenance instances. In Table 5, we known that the maximum number of maintenance instances is 8 and the minimum is 2, while it needs 7 maintenance instances for equipment during its life cycle. Therefore, it is not "the bigger, the better" for equipment maintenance. In this model, $t_{16}(B_2) = 7$.
- Replace equipment that is still in working condition. After a comprehensive analysis of labor costs, equipment maintenance costs, equipment replacement costs and equipment repair costs, equipment needs to be replaced even if it is working normally. In this model, $t_{17}(B_3)_{j0} = 0$ or $t_{17}(B_3)_{j1} = 1$.
- Eight workers are necessary for a charging station to achieve the optimal profits. Fewer workers will lead to a low service efficiency, and too many workers can create very large service costs. In the model, $V_n = 8$.

7. Conclusion

The development of EVs is an important way to improve sustainable transportation, energy security and the low-carbon economy. According to the statistics of the ISO in 2009, 25% of newly purchased vehicles (approximately 50 million) will be EVs by 2030. China has achieved a great deal in terms of the infrastructure, marketing and standardization of the EV industry. In particular, more charging stations will be built around central areas of cities. Investors or governments should optimize the resource scheduling in order to reduce investment costs due to the limited charging facilities. However, poor management, that is, unreasonable resource scheduling (including service workers and charging piles), will affect the revenues and the future development of the EV industry, thus hindering sustainable transportation; accordingly, resource scheduling for EV charging stations should be a top priority.

Therefore, this paper models and simulates the resource scheduling of an EV charging station. A mathematical resource scheduling model of a charging station is established. Due to the solution problem of the mathematical model, AnyLogic implements the communication mechanism of the multi-agent, including the worker agent, equipment agent and the message model, in order to acquire the model's results. For the simulation results, it is possible to know the effect of the number of service workers, the charging pile replacement policy and the charging pile maintenance times on charging station revenue. Our findings are mainly the following: (1) In the lifetime of the charging pile, seven maintenance times are needed; (2) Even if the charging pile is still in normal condition, it needs to be replaced in order to achieve the maximum profits for the charging station; (3) A comprehensive analysis of service efficiency and service costs indicates that 8 service workers are needed to achieve the optimal profit for the charging station; (4) We can still obtain the optimal results if the model parameters change.

Acknowledgement

This paper is supported by the Fundamental Funds for Humanities and Social Sciences of Beijing Jiaotong University (2018RCW005,2018YJS051). We appreciate their support very much.

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