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Optimization of overhaul of EMU Based on Planning Model

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ABSTRACT

With the speed increase of the railway and the construction of the passenger dedi-cated line, the application efficiency and maintenance quality of the EMU, as the main means of transport of the passenger dedicated line, are directly related to the safe opera-tion of the passenger dedicated line. Therefore, it is very necessary to carry out high-efficiency and high-quality maintenance work for EMU. In this paper, the mainte-nance problem of EMU is studied. According to the different maintenance process of EMU under different conditions, a mixed nonlinear programming model is established, and the software is used to solve the shortest total time of maintenance of all EMU is 541min. The model provides a reference for the optimization of maintenance of EMU in actual production and life, and is helpful to improve the maintenance efficiency of EMU.

Keywords: Overhaul of EMU; Mixed nonlinear programming model; Genetic algorithm

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1. Introduction

According to *China's Medium-and long-term Railway Network Planning (2016 Adjustment)*, During the period from 2016 to 2025 (long-term to 2030), we plan to build a well-developed high-speed railway network with eight vertical lines and eight horizontal lines as the skeleton, regional connection lines and inter-city railway supplement. With the gradual improvement of China's high-speed railway network and the increasing range of radiation, the demand for passenger transport will continue to be stimulated, and the operation and retention of EMU is bound to increase, which puts forward higher requirements for the transportation and inspection capacity of bullet train sections and bullet train operation stations. Therefore, the research on the maintenance optimization of EMU is of great practical significance. [1]

The motor train unit inspection and repair maintenance base mainly includes: complete maintenance depot, electrical test device, wheelset tread diagnosis device, non-falling wheel rotation equipment, wheelset and bogie replacement center, axle flaw detection device, internal cleaning and finishing equipment of EMU, external cleaning equipment of EMU, all maintenance work is carried out in the building in order not to be affected by climatic conditions and night work. In addition to the maintenance base, it is also necessary to set up a maintenance factory to carry out comprehensive inspection and maintenance of the EMU.

More than 50 bullet train stations have been built across the country. The EMU operation station is a place for maintenance and maintenance of motor cars, which is divided into different maintenance levels according to driving conditions, and different levels correspond to different processes

(1) The basic procedure of maintenance: the first inspection and repair of EMU includes three processes: a, b, c. The EMU overhauls the motor cars in the order of a→ b→ c.

Tab.1 Basic data of inspection and repair of CRH2 bullet train

Process category	a	b	c
Number of workshops (unit)	3	8	5
Time spent (hours)	1	2	1.5

(2) It is known that each process of different types of motor cars takes time data, as shown in the following table:

Tab.2 Time data table for each process of each type of bullet train

	a	b	c
CRH2	1	2	1.5
CRH3	0.8	2.4	0.5
CRH5	1.3	2.5	1.5
CRH6	1	2.7	0.3

2. Problems to be solved

The corresponding processes of different types of EMU take different time. Given the arrival time of various types of bullet trains, it is required to calculate the total time to complete the maintenance of these trains.

3. Model assumptions

Assumption 1: It is assumed that the workload of each maintenance personnel is evenly distributed.

Assumption 2: It is assumed that the maintenance machine will not break down suddenly during the maintenance process.

Assumption 3: It is assumed that all the maintenance workers can work normally, that is, there will be no accidents in the course of maintenance.

4. Problem Analysis

Considering that each process of different types of EMU takes different time, under the principle of "first come, first served", the total overhaul time and average waiting time may not be minimized, and the total time required to repair these cars is required to be minimum, that is, the type of motor car that takes the longest time to finish maintenance is required to be minimized. In this paper, whether the EMU enters a workshop of each process and whether it occupies the workshop at a certain time and the time when the EMU starts each process are taken as decision variables. Taking the priority relation of each process, the uniqueness of inspection and repair workshop in each process, the number of maintenance workshop in each process less than the number of available rooms, queuing relation, the starting time of the first process, the time of leaving the system and the maintenance process as constraints, and minimizing the maximum completion time as the objective function, a hybrid nonlinear programming model is established comprehensively.[2]

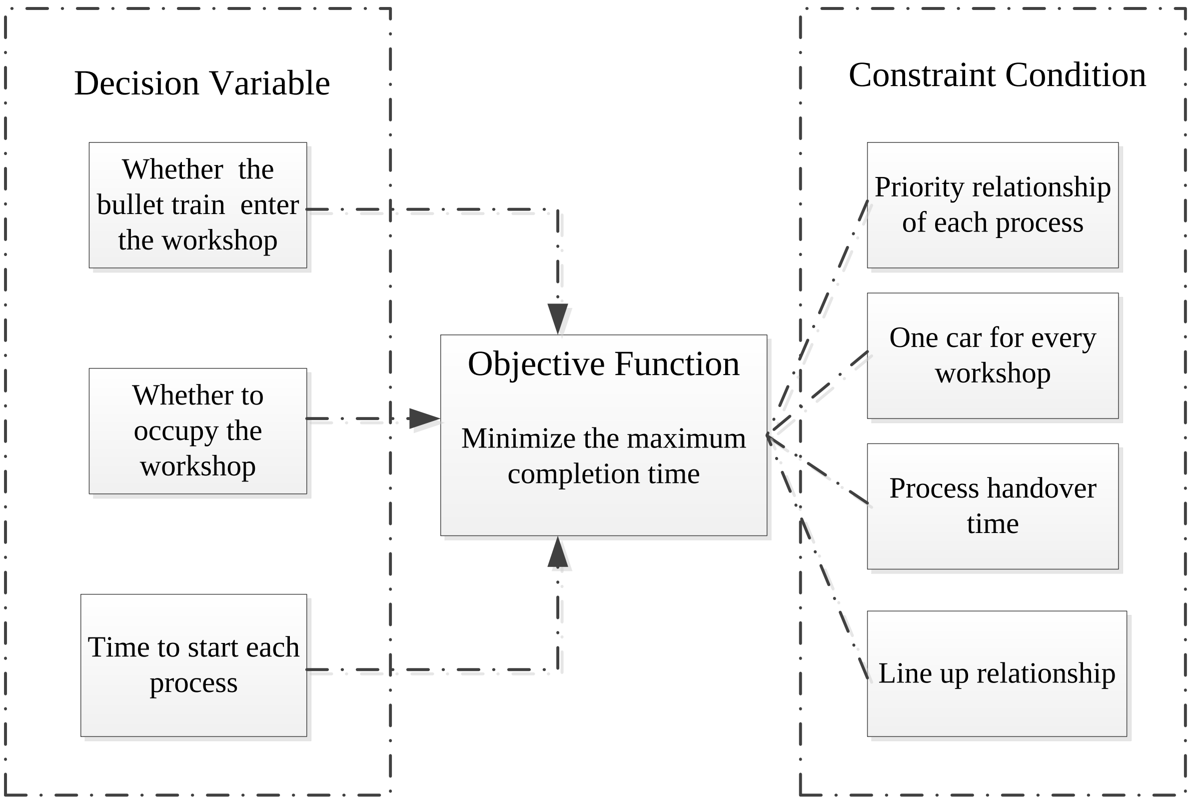

Fig.1: Idea Flowchart

5. Analysis of data

5.1 Analysis of basic data of maintenance

As the number of workshops and the time spent on bullet train maintenance will affect the maintenance time, the basic data chart of maintenance is drawn according to the basic data table of CRH2 EMU given in the question, as shown below:

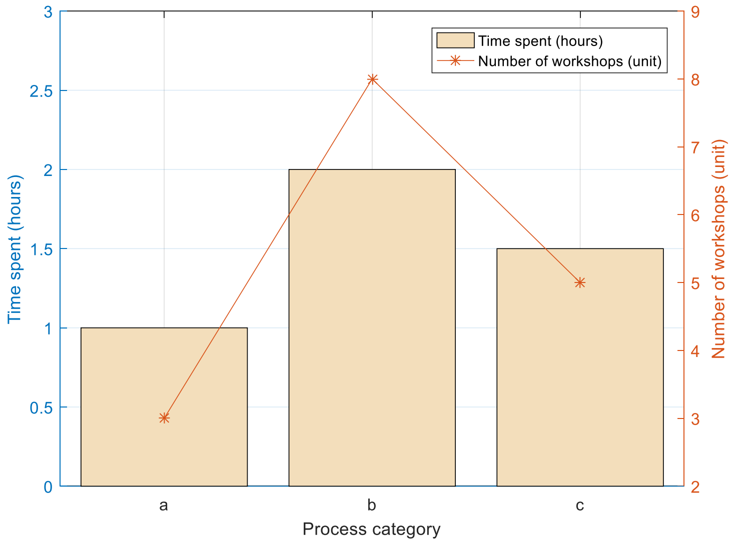

Fig.2 CRH2 EMU maintenance basic data chart

According to the observation chart, it is found that the time consuming of process b is the longest and the number of workshops is the largest, and that of process a is the shortest and the fewest. In order to observe the corresponding number of workshops allocated to the time consumed by each process, a table of the number of workshops corresponding to the time consumed by each process is listed as follows:

Tab.3 The number of workshops corresponding to the time-consuming process

Process category	a	b	c
Number of workshops (unit)	3	8	5
Time spent (hours)	1	2	1.5
Number of workshops per unit time	3	4	3.3

The observation table shows that the number of workshops in each process is proportional to the time spent, that is, the longer the time is, the more workshops are allocated to the process. At the same time, it can be seen from the table that the number of workshops is proportional to the number of workshops per unit time.

To observe the number of workshops per unit time, the number of units corresponding to process a is the least, and process a is the first process, so there may be a situation in which there is no spare workshop in process a and cars are waiting in the arrangement. on the other hand, there are more workshops corresponding to process b, so it is possible that the workshop of process b is not fully used. While the number of workshops in process c is in the middle, there may be a spare number of workshops or a motor car waiting at process b.

5.2 Analysis of basic process data

As the basic data table of the process is given in the questions of different motor cars, the working hours of each process of the four motor cars are drawn as follows:

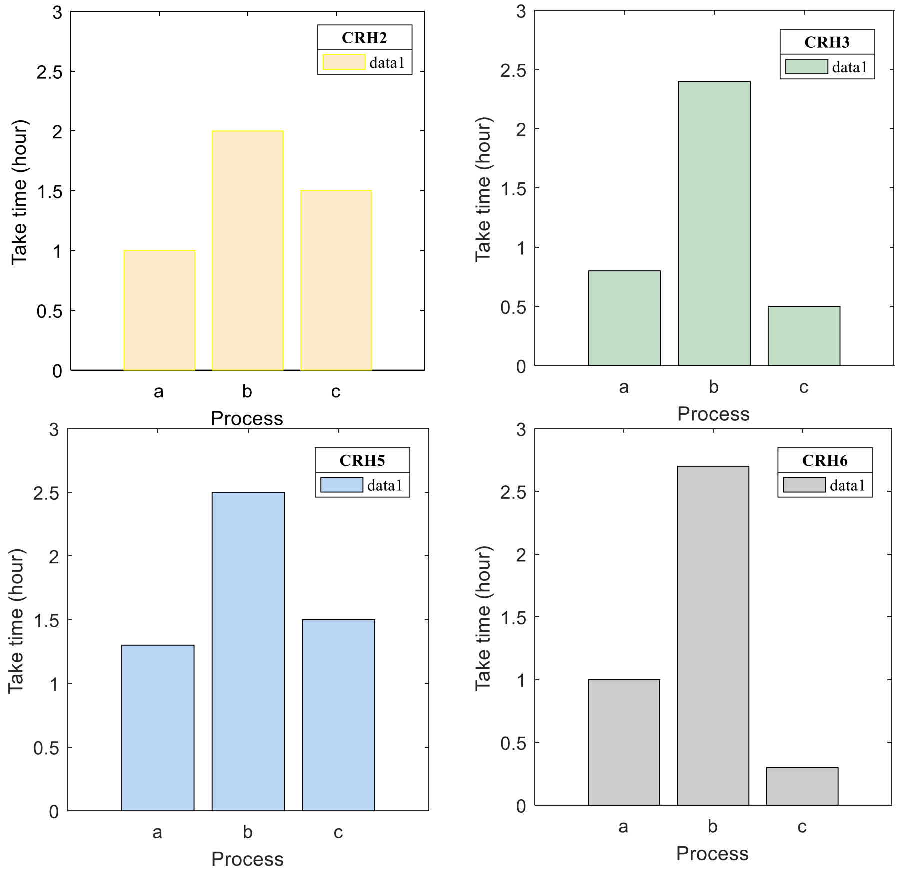

Fig.3 Working procedure time diagram of each bullet train

According to the above picture, the time distribution of each process of the four bullet trains is similar. The working hours of CHR2 and CHR5 are roughly the same, but the duration of process a is similar to that of process c, and that of process a is slightly less than that of process c, while that of bullet train CHR3 and CHR6 is roughly the same, with the least time of process c and the longest time of process b.

Since the factors determining the maintenance of motor cars are the duration of the process and the number of workshops corresponding to the process, the number of workshops for each process is listed as follows:

Tab.4 Table of the number of workshops in each process

Working procedure	a	b	c
Number of workshops	3	8	5

From the above table, it can be found that the number of workshops corresponding to process b is the largest, and the number of workshops corresponding to process a is the fewest. Based on the analysis of the number of workshops in each process and the time length diagram of each train process, it is found that the process b of different types of motor cars takes the longest time, but the number of workshops is the most, with 8, while process c takes a relatively long time, and there are 5 workshops. From this, it can be inferred that when the traffic flow is large, many cars will be stuck in the workshop of process b and process c.

6. Establishment and solution of the model

6.1 Establishment of the model

As the time required for each process of different types of EMU is different, it may occur that the bullet train will be repaired later to first, that is, the time-consuming type of EMU will be repaired first, so that all EMU will take the least time after overhauling. Therefore, the following hybrid non-linear programming model is established in this paper. [3]

(1) Establish the objective function

In this paper, we consider the maximum completion time minimum as the objective function, so we establish the following objective function:

$$\min T = T_{\max}$$

Where T^f represents the maintenance completion time of the f bullet train, and the maximum completion time of all motor cars is the maximum maintenance completion time of each motor car, that is, the maximum maintenance completion time.

$$T_{\max} = \max\left\{T^1, T^2, \cdots, T^{11}\right\}$$

(2) Establishing constraints

① The priority relationship between the processes of the same motor car, that is, in the maintenance process of the same motor car, the completion time of a process should be equal to the time of entering process b, and the completion time of process b should be equal to the time of entering process c, so the following constraints are met:

$$I_b^f \geq O_a^f\,;\quad I_c^f \geq O_b^f$$

Where I_a^f , I_b^f and I_c^f represent the time when the f bullet train enters the process a, b and c respectively, and O_a^f , O_b^f and O_c^f represent the time when the f bullet train completes the process a, b and c respectively.

② Ensure that the motor car can only be overhauled in one workshop in any process, that is, any motor car can only enter the only workshop in the same process for maintenance, so the following constraints are met:

$$\sum_{i=1}^{3} X_{a_i}^f = 1\,;\quad \sum_{j=1}^{8} X_{b_j}^f = 1\,;\quad \sum_{k=1}^{5} X_{c_k}^f = 1$$

Among them, $X_{a_i}^f$, $X_{b_j}^f$ and $X_{c_k}^f$ respectively indicate whether the f bullet train enters the i , j and k workshops of a, b and c processes for maintenance.

③ Each process should not be interrupted during maintenance.

$$O_a^f = I_a^f + P_{a_i}^f - 1; O_b^f = I_b^f + P_{b_j}^f - 1; O_c^f = I_c^f + P_{c_k}^f - 1$$

Where I_a^f , I_b^f and I_c^f represent the time when the f bullet train enters the process a, b and c respectively, and O_a^f , O_b^f and O_c^f represent the time when the f bullet train completes the process a, b and c respectively. $P_{a_i}^f$, $P_{b_j}^f$ and $P_{c_k}^f$ respectively represent the maintenance time of the f bullet train in the i , j and k workshops of the a, b and c processes, and the sum of the maintenance time of each process is equal to the completion time of the motor car maintenance:

$$P_{a_i}^f + P_{b_j}^f + P_{c_k}^f = T^f$$

Where T^f represents the completion time of the f bullet train maintenance.

④ The number of motor cars overhauled at any time in any stage shall not exceed the number of workshops available at that stage.

$$\sum_T Y_{a_i}^f(T) \le 3; \sum_T Y_{b_j}^f(T) \le 8; \sum_T Y_{c_k}^f(T) \le 5$$

Where $Y_{a_i}^f(T)$ 、 $Y_{b_j}^f(T)$ 、 $Y_{c_k}^f(T)$ indicate whether the f bullet train occupies the i 、 j 、 k workshop of a, b, c process at the moment, $Y_{a_i}^f(T)=1$ means that the f bullet train occupies the i workshop of a process at the T moment, $Y_{a_i}^f(T)=0$ means that the f bullet train does not occupy the i workshop of a process at the T moment. (b and c processes are the same)

⑤ The inspection and repair of process a can be carried out only after the bullet train arrives at the operation station, so the following constraints are met:

$$t^f \le I_a^f, f=1,2,\cdots,11$$

Where t^f represents the time when the f bullet train arrives at process a, and I_a^f represents the time when the f bullet train enters process a.

⑥ After completing the inspection and repair of process c, the motor car can leave the motor car operation station, so the following constraints are met:

$$\sum_T Y_{c_k}^f(T) = P_{c_k}^f, f=1,2,\cdots,11$$

Among them, $Y_{c_k}^f(T)$ indicates whether the f bullet train occupies the k workshop of the c process at the T moment, and $P_{c_k}^f$ represents the maintenance time of the f bullet train in the k workshop of the c process.

To sum up, a mixed nonlinear programming model for the problem is obtained.

$$\min T = T_{\max}$$

$$\text{s.t}\begin{cases} O_a^f = I_a^f + P_{a_i}^f - 1; O_b^f = I_b^f + P_{b_j}^f - 1; O_c^f = I_c^f + P_{c_k}^f - 1 \\ \sum_{i=1}^{3} X_{a_i}^f = 1; \sum_{j=1}^{8} X_{b_j}^f = 1; \sum_{k=1}^{5} X_{c_k}^f = 1 \\ P_{a_i}^f + P_{b_j}^f + P_{c_k}^f = T^f \\ \sum_T Y_{a_i}^f(T) \le 3; \sum_T Y_{b_j}^f(T) \le 8; \sum_T Y_{c_k}^f(T) \le 5 \\ I_b^f \ge O_a^f; I_c^f \ge O_b^f \\ t^f \le I_a^f, f=1,2,\cdots,11 \\ \sum_T Y_{c_k}^f(T) = P_{c_k}^f, f=1,2,\cdots,11 \end{cases}$$

6.2 Solution of the model

In this paper, we consider the time as a time axis, that is, it increases gradually from the zero time, and thinks that 00:00 is the zero time, the serial number of the bullet train coming in at 00:16 is 1, and the time of the bullet train is 16 minutes, and so on. [4]

According to the established mixed nonlinear programming model, the data are solved by using MATLAB software (see appendix for the source program). The time of each bullet train going in and out of process a, b and c is shown in the table below.

Tab.5 Timetable for each bullet train in and out of working procedures a, b and c

Train serial number	Arrival time	Enter the time of process a	Time to leave process a	Enter the time of process b	Time to leave process b	Enter the time of process c	Time to leave process c
1	16	16	76	76	196	196	286
2	47	47	125	125	275	275	365
3	82	82	142	142	262	262	352
4	120	120	180	180	342	342	360
5	141	141	189	189	333	333	363
6	182	182	242	242	404	404	409
7	211	211	271	271	391	391	494
8	239	239	317	317	467	467	466
9	241	242	290	290	434	434	493
10	267	271	319	319	463	463	**557**
11	309	309	369	369	531	531	549

It can be seen from the table that the time when each motor car leaves the c process, and the earliest to complete the whole maintenance process is the serial number 1 motor car, and the total maintenance time is the serial number 8 motor car, and the total maintenance time is 8, so the total time to complete the maintenance of these motor cars is 541min.

7. Results and error analysis

7.1 Analysis of process time

The above table can get the time of each bullet train in and out of process a, b and c. In order to show the time change more clearly, draw the time diagram of each motor car in and out of process a, b and c according to the timetable of each motor car in and out of process a, b and c, as shown below:

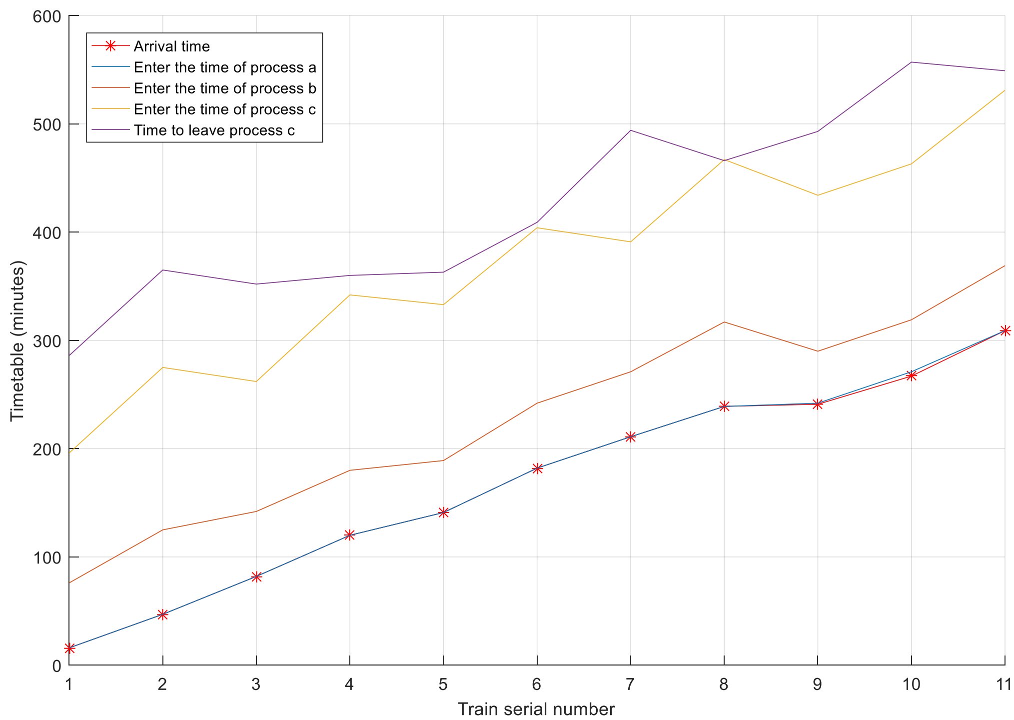

Fig.4 Time diagram of each bullet train going in and out of process a, b and c

Observing the time diagram of each bullet train going in and out of working procedures a, b, c, it is found that:

(1) By comparing the progress time and the time when entering process a, it is found that there is a jam when the 9th and 10th motor cars enter process a, that is, there is no spare workshop when the two motor cars enter process A. it is calculated that the blocking time of the two cars is 1 minute and 4 minutes respectively.

(2) The first train to leave the whole maintenance system is 286 minutes, and the latest train to leave the whole system is 557 minutes, and the train that leaves the whole system last is not the last train to arrive a.

7.2 Analysis of maintenance sequence

According to the maintenance results, the maintenance sequence table is listed as follows:

Tab.6 Maintenance sequence list

Working procedure	Maintenance sequence
Process a	a1-a2-a1-a2-a3-a1-a2-a3-a1-a2-a1
Process b	b1-b2-b3-b4-b5-b1-b2-b3-b4-5b-b6
Process c	c1-c2-c3-c1-c2-c1-c2-c1-c3-c3-c2

According to the observation of the above table, it is found that the workshops in process b have not been fully used, and only 6 workshops have been used at most, and because the arrival time of the train is different, and the process time of different trains is different, the workshops in the process are not used smoothly, so for the workshops in process a, the order is a1-a2-a1-a2-a3-a1-a2-a3-a1-a2-a1.

As the process time of each train is different, the proportion of the time of process a, b and c is drawn according to the total time of the four bullet train processes a, b and c, as shown below:

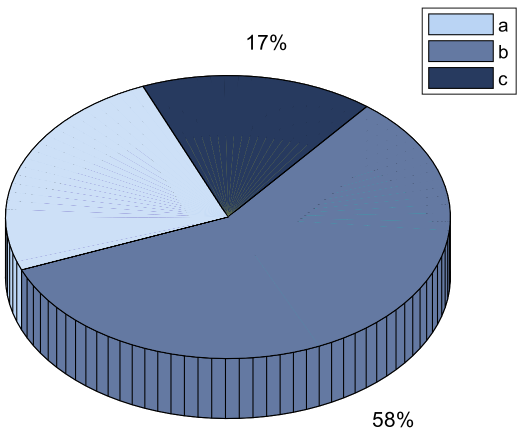

Fig.5 The proportion chart of the duration of processes a, b, c

From the diagram, it is found that process b accounts for the most time, accounting for 58% of the total process time, while process c accounts for the least, accounting for 17% of the total process time. Through analysis, it is found that the process a in which the workshop vacan- cy occurs. The workshop of the latter process has room and the lack of the workshop of process a will affect the overall maintenance time and maintenance efficiency. Therefore, in connection with practice, the maintenance station can appropriately increase the workshop of process a.

So as to improve the efficiency of the maintenance chain.

7.3 Analysis of errors

Although the problem requires ignoring the transfer time between workshops, it is impossible to maintain the train transfer workshop without time-consuming in real life, and the time spent on workshop transfer will change the queuing rules so as to change the results.

8. Evaluation, improvement and popularization of the model

8.1 Advantages of the model

(1) The model is closely related to the actual situation, combined with the actual situation to solve the problems and solve, so that the model is closer to the reality, versatility and generalization. [5]

(2) genetic algorithm is used in this paper. Genetic algorithm does not have too many mathematical requirements for the optimization problem solved, and it has good global search ability, it can search areas that have nothing to do with the problem, and multiple individuals can be compared at the same time. And it has strong expansibility, and it is easy to combine with other algorithms. And by making use of its inherent parallelism, it is very convenient to carry out distributed computing and accelerate the speed of solution.

8.2 Model Disadvantages

(1) The programming of genetic algorithm is more complex, a large number of functions will be applied in the programming process, and the amount of calculation of genetic algorithm is very large, so the search speed of the algorithm is relatively slow. and the algorithm needs more training time to get a more accurate solution.

(2) Genetic algorithm is difficult to deal with nonlinear constraints, requires multiple operations, and the reliability of the results is poor, cannot get a stable solution, at the same time, it is difficult to deal with or optimize the problem with relatively high dimension.

8.3 Model improvements

This paper applies the genetic algorithm, although the genetic algorithm is relatively superior, but there are still some problems in the genetic algorithm, so this paper can consider to further optimize the genetic algorithm and sort all the individuals in the population once. These individuals are listed in descending order according to their fitness, so as to improve the accuracy of the solution and reduce the running time of the algorithm.

8.4 Generalization of the model

Genetic algorithm (GA) is an optimal algorithm of global optimization probability, which does not depend on the specific field of the problem and has strong robustness to the types of problems, so it is widely used in many sciences and is suitable for function optimization, combinatorial optimization and job shop scheduling.

In addition, genetic algorithm has also been widely used in production scheduling problems, robotics, image processing, automatic control, genetic coding, artificial life and machine learning.

9. Conclusion

With the development of urban modernization and the further development of high-speed rail emus and intelligent detection technology, the application and maintenance industry of EMU develops, and the requirement of train maintenance of high-speed EMU in our country is higher. There are some problems in the process of maintenance, such as high standby rate of EMU, long maintenance and shutdown time, insufficient maintenance capacity and uneven configuration [6]. In this paper, the maintenance problem of EMU is discussed, and a mixed nonlinear programming model is established. The genetic algorithm is used to solve the problem, and it is found that the shortest total time of all EMU maintenance is 541min. Through the model established in this paper, the design of the shortest maintenance time in the process of EMU maintenance is realized more forcefully and theoretically, which provides a reference for the optimization of EMU maintenance in actual production and life, and is helpful to improve the maintenance efficiency of EMU.

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