DETERMINATION OF TRUCK MAINTENANCE ALLOCATION SCHEME BASED ON SA-GA

Jiandong QIU[1], Wei REN[2], Minan TANG[3], Panpan MA[4], Yang ZHANG[5]

[1, 2, 4, 5] *School of Mechanical Engineering, Lanzhou Jiaotong University, Lanzhou China*

[3] *School of Automation Electrical Engineering, Lanzhou Jiaotong University, Lanzhou China*

Abstract:

As an important department of railway transportation and production, large freight train depot is responsible for the regular overhaul and maintenance of railway trucks. The shunting operation of freight train depot covers the whole process of railway trucks entering, storing, overhauling and leaving the depot. It is an important step in the implementation of the maintenance operation. Usually, shunting personnel in the depot transport the trucks to be overhauled to the maintenance line by relying on the shunting operation plan, which is the key to determine the shunting operation plan according to the distribution relationship between vehicles and maintenance. Firstly, this paper analyzes the process of centralized shunting operation in the freight train depot and the factors affecting the time-consuming based on the research idea of flexible workshop scheduling problem. Then, on the premise that the proportion of the weight coefficient will have an impact on the time-consuming of truck busy and shunting in the shunting process, and with the goal of minimizing the time-consuming of truck maintenance busy and shunting, the allocation model between trucks and maintenance lines is established; In addition, an improved genetic algorithm is proposed to solve the established model; Finally, combined with the maintenance of railway trucks in a large freight train depot, an example analysis is carried out on this basis. The results demonstrate that using simulated annealing genetic algorithm to solve the model can obtain the allocation scheme between railway trucks and maintenance operation line. Under the influence of three different coefficients, compared with genetic algorithm, simulated annealing genetic algorithm can reduce the detention time of railway trucks in depot by 0.21%, 0.09% and 0.12% respectively, which is beneficial to reducing the detention time of maintenance vehicles in depot, It plays a positive role in improving the maintenance efficiency of trucks in the depot, and also provides new ideas for the research of railway truck shunting operation.

Keywords: railway truck shunting, train-line distribution scheme, SA-GA

Contact:
1) qiujd@mail.lzjtu.cn [https://orcid.org/0000-0001-9972-898X]; 2) 1170910995@qq.com [http://orcid.org/0000-0002-8143-8260];
3) tangminan@mail.lzjtu.cn [https://orcid.org/0000-0003-1424-2708] – corresponding author;
4) 210772234@qq.com [http://orcid.org/0000-0002-6876-2330]; 5) 563448563@qq.com [http://orcid.org/0000-0001-6995-293X];

1. Introduction

As an important department of railway transportation and production, the freight train depot mainly undertakes the repair task of railway trucks, and other maintenance operations can also be performed in conditional depot. Determining the shunting plan through the distribution relationship between trucks and maintenance lines is the key step for the depot to organize the truck maintenance, and it is the premise to ensure that the truck starts maintenance on time (Tong et al., 2020) For the trucks to be overhauled entering the depot, it can be regarded as an operation set, which includes the entry and departure operations specified in the maintenance plan and several operations specified in the plan (Ma et al., 2016; Per et al., 2011). Each batch of operations lasts for a certain time, the operation can be carried out on any track with maintenance conditions, and the transfer or stay must meet the connectivity and occupation conditions between the operation lines during maintenance (Brady et al., 2018).

The research on the determination of the distribution relationship between trucks and maintenance lines can be inspired by the research of domestic scholars on the maintenance process of EMUs in the EMU station. At present, Chinese scholars aim to mobilize the maintenance resources in the depot and EMU Operation Station to minimize the cost of maintenance. For example, Wang et al. (2013) transformed the vehicle maintenance problem into a workshop scheduling problem with space-time constraints, established the shunting optimization model with the goal of reducing the invalid occupation time of vehicles in the key maintenance line area and the shunting path cost, they solved the system with the improved max-min ant colony algorithm. Compared with the current manual scheduling method, the overall scheduling of equipment and resources is more perfect, but the vehicle cannot complete the maintenance within the expected time. Zhang et al. (2013) constructed a 0-1 programming model for the use of the storage line of the vehicle on the premise of giving the occupation time of them, with the optimization goal of improving the utilization rate of the storage line and reducing the running distance of the shunting operation. Considering that the number of vehicles arriving at the same time may exceed the capacity of the storage line and cannot arrange the storage of vehicles, a simulated annealing algorithm excluding neighborhood is designed to solve it. The

research results have been put into use then designed a simulated annealing algorithm in addition to the neighborhood to solve it. Guo et al. (2016) established the shunting operation plan optimization model of the EMU station with the goal of minimizing the total delay time of EMU in the station and taking the number of maintenance operation lines, the number of the train units, the execution sequence of train units and the time occupied by the maintenance operation line as constraints. The micro evolutionary algorithm and maintenance line allocation algorithm are used to solve the model, and the optimal solution of the problem is obtained step by step through iteration. Hu et al. (2022) established the optimization model of shunting operation planning considering the occupation of station position of maintenance line, and designed the simulated annealing algorithm based on the generation of shunting feasible path and the exchange of operation priority in order to reduce the number of track occupation model of dictionary sorting target planning on the premises in the shunting process. Shi Jintao et al. (2022) established a two-level that it is suitable for EMU stations with different depot layout types, focused on the problems of flexible vehicle storage and platform occupation, which is based on coordinating the actual conditions such as the sequence arrangement of various maintenance operations, route conflict and depot layout types. Lei et al. (2016) established a 0-1 integer programming model to formulate a track operation plan. By applying modern sequencing theory, this is transformed into a fixed sequencing model of special parallel machines, and then they design a heuristic algorithm to solve the model. The total number of times that the train occupies and the number of times that the train occupies unnecessarily in the train dispatching area can be reduced. Zheng et al. (2020)According to the characteristics of railway terminal stations with co-existence of traffic operation and shunting operation and various shunting operations, considering that the route selection of shunting operation has time continuity, that is, the completion of the previous operation directly affects the progress of subsequent operations, a multi-objective route selection and time arrangement model with minimum route conflict delay time and minimum running time is established, and a genetic algorithm is designed to solve it. The optimized route scheme can avoid some route conflicts and delays and maintain the time continuity of

shunting operation to the greatest extent. The relationship between the vehicles and the maintenance lines should also consider the flexible use of the shunting line in the technical station. (Zhao et al., 2020) According to the shunting operation process, the disassembly and rolling cost and marshalling and coupling cost caused by the use of the shunting line should be measured. Aiming at minimizing the total weighted shunting cost, the original problem is first constructed as a 0-1 nonlinear programming model, and then further transformed into a 0-1 linear model. The existing modeling methods of slip constraint and capacity constraint are improved by using graph based maximum clique technology.

During the maintenance period, the truck does not complete all the maintenance contents in a fixed maintenance operation line, and it needs to transfer between multiple maintenance operation lines. Therefore, in the research on the scheduling of truck maintenance in the freight train depot, we establish the objective function to minimize the sum of busy time and transfer time of the truck to be repaired in this paper to determine the distribution relationship between the trucks and the maintenance operation lines. It is expected that the distribution relationship between the trucks and the maintenance lines can be obtained within the limit of the maintenance time of the freight car depot, so that the dispatching resources in the depot can be more fully mobilized.

2. Problem description

Figure 1 shows the layout of a freight train depot in China. In the research on the vehicle line distribution relationship of the depot, all kinds of trucks participating in the maintenance are regarded as processed parts from the perspective of depot site layout, working mode and operation type of maintenance garage. Several maintenance items to be carried out in each maintenance line, such as, beam adjustment, shot blasting and other operation processes are regarded as the processing procedures of work pieces (Lv et al., 2015). Treat the track with maintenance capacity in the section as a machine that can perform a certain processing operation. Since there are one or more maintenance lines that can be selected when the truck is executing one project, which is not completely corresponding, the allocation problem between the trucks and the maintenance lines or maintenance station can be regarded as a special

kind of FJSP. Therefore, we can consider abstracting the problem into the latter and optimizing it.

When establishing the shunting operation model, it can be assumed that the trucks entering the section are parked on the storage lines. After picking up, the locomotive pushes the selected trucks to the corresponding workshop for maintenance (Wang et al., 2016). Since the trucks of the same type of items are pushed in and pulled out to the storage lines at one time after maintenance, these trucks can be regarded as a whole. Therefore, the following description is proposed for the shunting operation model.

(1) On the premise of meeting the requirements of operation time, arranging trucks to stay and transfer in the operation line area of different maintenance items (Zhang et al., 2020);

(2) Reasonably arrange the operation sequence of various maintenance contents of trucks to ensure the completion of various maintenance tasks;

(3) During the maintenance period, the conflict must be avoided when trucks enter or exiting the maintenance shed (Shi et al., 2019).

3. Distribution model of truck and line

The shunting operation plan of trucks basically includes the whole process of all trucks entering the depot, maintenance and storage. It is the key to connecting the maintenance tasks of the trucks with the maintenance resources of the depot. Before trucks are pushed to each station in the maintenance shed, there will be two states of arrangement of established order I and established order II on the storage line (Wang et al., 2012), as shown in Figure 2.

3.1. Model Establishment

According to the actual situation of the depot, the following shunting operation model is established on the premise that the operation in the depot meets the maintenance regulations, with the goal of minimizing the sum of the busy time occupied by the maintenance of trucks and the time spent on line switching:

$$\text{Min} Z = m_1 T + m_2 F \tag{1}$$

$$T = \sum_{e \in E} \sum_{d \in D} \sum_{l \in L_d} x_{del}(t_{edl}^e - t_{edl}^s) \tag{2}$$

$$F = \sum_{e \in E} \sum_{d \in D} \sum_{l \in L_d} \sum_{h \in L_{d+1}} \sum_{k \in W} y^k_{edlh} \, f^k_{(dl,d'h)} \qquad (3)$$

Where e refers to the overhaul truck in the depot; d is the number of the maintenance line area; l is the track number in the maintenance line area; T is the busy time occupied by the maintenance; F is the time spent by the trucks on the line switching in shunting operation; D is the collection of line areas; E is the collection of trucks; W is the set of transfer paths; L_d is the track set; m_1, m_2 are the coefficient representing T and F respectively, according to the configuration of shunting equipment in the depot,

the values of m_1 and m_2 are also different, but both satisfy that the sum of the two is 1; x_{del} is a variable of 0-1, when the truck e stops on track l in any line area d and carries out maintenance, it is 1, otherwise it is 0; y^k_{edlh} is a 0-1 variable, which indicates the transfer route selection of truck, when the truck e transfers from track l in line area d to track h in another maintenance line area d' according to its transfer order, and selects the k shunting path in W, y^k_{edlh} is 1, otherwise it is 0; t^e_{edl} is the time when the truck e enters track l of line area d; t^s_{edl} is the time when the truck e leaves track l of line area d.
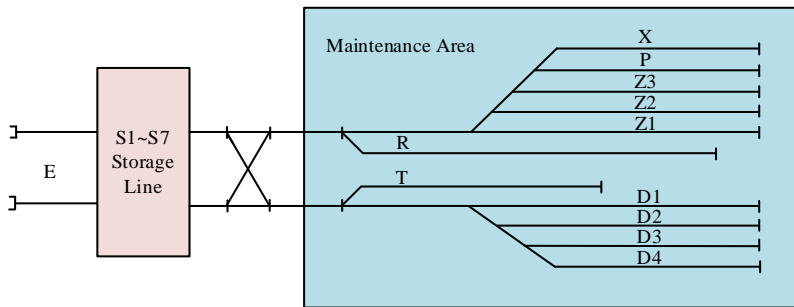

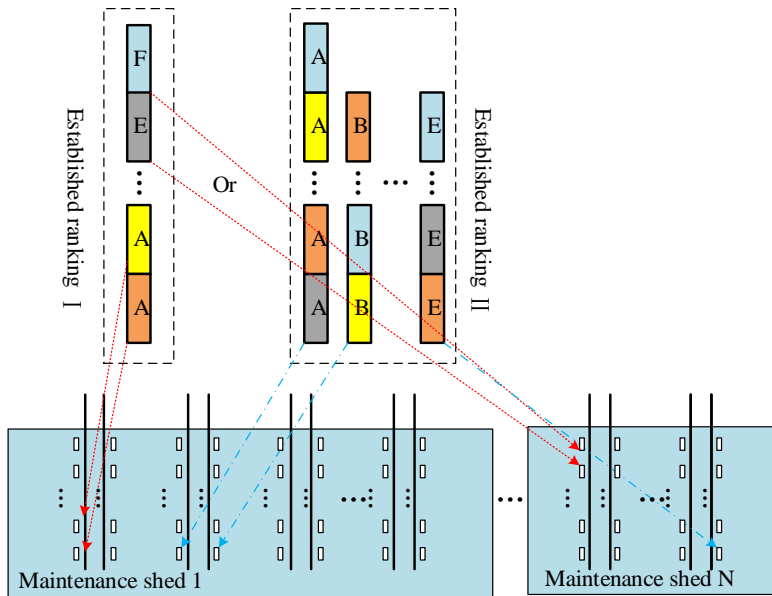Fig. 1. Track distribution of a freight train depot.

Fig. 2. Schematic diagram of established sequence of trucks (Note: A, B, E, F, etc. indicates that the trucks to be overhauled in the depot shall be numbered according to the overhauled items).

3.2. Initial Condition Setting

(1) Maintenance operation constraints: If the truck needs to be carried out operation in a certain line area, the designated vehicle must select a station track in the designated line area to stop and complete it.

$$\sum_{l \in L_d} x_{edl} = \begin{cases} 1 & \forall_e \in E, d \in D \\ 0 & \forall_e \in E, d \notin D \end{cases} \quad (4)$$

(2) Path constraint: Only one path can be selected when the truck turning between two line areas.

$$\sum_{h \in L_{d'}} \sum_{k \in W} y_{edlh}^k = \begin{cases} 1 & \forall_e \in E, d \in D, l \in L_d \\ 0 & \forall_e \in E, d \notin D, l \in L_d \end{cases} \quad (5)$$

(3) Maintenance time constraint: When trucks performing maintenance on a designated track, it must be completed within the specified time, otherwise it is deemed that it cannot be repaired and must leave the track.

$$\begin{aligned} &x_{edl} = 1, t_{edl}^e - t_{edl}^s \leq T_e \\ &\forall_e \in E, d \in D, l \in L_d \end{aligned} \quad (6)$$

Where T_e is the minimum maintenance time of the overhaul truck.

(4) Track compatibility constraint: When there are trucks on a track for maintenance or occupation, the track cannot park two or more trucks.

$$\begin{aligned} &2z_{delc} \leq x_{edl} + x_{cdl} \\ &\forall_e \in E, d \in D, l \in L_d \end{aligned} \quad (7)$$

Where y_{edlh}^k is a 0-1 variable, which indicates the occupation order of trucks in the track, when any truck e gives priority to truck c to track l, z_{delc} is 1, otherwise it is 0; x_{cdl} is a 0-1 variable, which indicates that any truck c stops on track l of any line area d and carries out maintenance, which is 1, otherwise it is 0.

(5) Maintenance accommodation constraint: For one truck, only one track in the maintenance area of the depot can be occupied when one item is carried out; similarly, the maximum number of vehicles that can be accommodated at the same time for a certain station track is limited by the maintenance station.

$$\begin{cases} x_{edl} = 1, & \forall_e \in E, d \in D, l \in L_d \\ \sum_{l \in L_d} x_{edl} \leq n, & n = 1,2,3 \dots \end{cases} \quad (8)$$

4. Model solving

Genetic algorithm (GA) is a general optimization algorithm. Its most remarkable feature is the implicit parallelism and the ability to search the global solution space, but it also has the disadvantage of easy premature convergence to the local optimal solution (Lewczuk, 2015). With the evolution of the population, the fitness value of a few individuals in the population is much higher than the other individuals. These individuals have strong advantages in selecting, which will lead to a loss of diversity in the population (Ma et al., 2012). In this paper, simulated annealing algorithm (SA) and GA are combined to overcome this disadvantage. SA-GA combines the respective characteristics of SA and GA in terms of optimal operation and principle, enhances the ability of global search and local search, which can control the phenomenon of rapid convergence effectively. SA-GA can better solve the scheduling problem of vehicles to be repaired in the depot.

4.1. Design of an Improved Genetic Algorithm

Genetic algorithm is mainly composed of five parts: coding, initial population generation, fitness value evaluation, basic genetic operation and termination condition judgment (Zheng et al., 2022). The following settings are made for model solving in this paper.

4.1.1. Coding Design

Trucks with several maintenance items are considered chromosomes with genetic properties and assigned to different tracks. Binary coding method is used to combine and arrange the maintenance items to be carried out by trucks. The vector $\bar{\tau} = [r_1 \quad r_2 \quad \cdots \quad r_n]$ represents a complete maintenance operation, from r_1 to $r_2 \dots r_{n-1}$ to r_n, and then back to r_1. The specific gene coding method is shown in Figure 3

"0101" in the first gene (0001 0001 0101 0011 0000 0010) indicates that open wagon is on track 3 when performing the fifth maintenance procedure, "0011" indicates that open wagon is on track 4 when performing the third maintenance procedure, and "0000" indicates that this type of vehicle does not perform this maintenance operation. The sequence of coded characters on each chromosome from left

to right indicates the track number arrangement where the truck maintenance project is located. The character itself represents the sequence number of the next process of each maintenance project. Accordingly the second, third and fourth genes represent platform wagon, covered truck and tank truck in turn, the meaning of the string is the same as that of the first gene.

4.1.2. Fitness Function

The value of fitness function is used to measure the ability of individuals in the population to adapt to the environment, it is usually converted from the objective function. The higher the function value, the opportunity for the greater the individual to obtain greater opportunities to reproduce the next generation. According to the shunting model, the longer the truck is busy and turns, the less ideal the scheme is and the greater the possibility of being eliminated. The problem of GA is that its fitness function has poor convergence and it is easy to converge prematurely. To improve this situation and improve the maximum fitness of individuals, the fitness function based on exponential transformation is adopted. The fitness function is:

$$Fit\big(f(x)\big) = e^{-Z} = e^{-(m_1 T_i + m_2 F_i)} \qquad (9)$$

Where T_i represents the minimum maintenance time for the process i; F_i represents the minimum time from line transfer to the track where the process i is located.

4.1.3. Genetic Selection

In order to avoid causing the algorithm to fall into "local optimization", we adopt the selection method of roulette random competition in this paper. Assuming that the population size is N_i, selecting a pair of individuals i and j from the population at first, then the fitness of any individual i is f_i, and the fitness of j is f_j, then competing between the two individuals, also sorting all individual fitness values in the population according to the size, those with high fitness values are selected and executed repeatedly until the selection is full, then the probability of any individual being selected first is:

$$P_{ij} = f_{ij} \Big/ \sum_{i=1, j=1}^{N} f_{ij} \qquad (10)$$

4.1.4. Crossover and Variation

(1) The crossover operation distinguishes the genetic algorithm from other heuristic algorithms. It is a key step in genetic algorithm and the main method to generate new individuals. In this paper, the two-point intersection based on maintenance items and maintenance operation lines is adopted, as shown in Figure 4.

Casting the generated new individual into the next generation and judging the scale of the next generation. If the scale cannot reach the scale of the initial population, repeat the crossover operation until it meets the requirements and terminate the crossover operation. In this paper, the crossover probability P_c is proposed to be 0.9.

(2) The variation method of genes based on maintenance items is adopted. Generating two mutation positions i and j randomly, and exchange the genes at two locations, as shown in Figure 5. In this paper, the mutation probability P_m is proposed to be 0.08.

4.1.5. Simulated annealing Parameter Setting

In simulated annealing, the setting of initial temperature T_0 is one of the important factors affecting the global search performance of the algorithm. If the initial temperature is high, it is more likely to find the global optimal solution, but it takes a lot of calculation time; On the contrary, the calculation time can be saved, but the global search performance may be affected.

Similarly, the global search performance of the algorithm is also closely related to the annealing rate P_Δ. Generally speaking, a full search at the same temperature is quite necessary, but it requires calculation time.

4.1.6. Algorithm Operation Termination

The number of iterations setting. When the maximum number is reached, the operation ends and the result is output.

4.1.7. Operation flow

The specific operation flow chart is shown in Figure 6. Solution steps:
Step I: Analyzing the fault types of trucks and formulate a reasonable maintenance plan according to the parameter information of them;

Step II: Taking the initial conditions of the truck shunting operation as constraints, and the initial population is formed randomly;

Step III: GA parameter setting;

Step IV: Establishing the objective function based on the sum of the busy time occupied by the maintenance of trucks and the time spent on line switching;

Step V: The fitness function is established to evaluate the individual fitness value, select the individual with the maximum fitness value to pass on to the next generation, and perform crossover and variation;

Step VI: Keeping the current better scheme as the initial population of SA;

Step VII: Setting of initial temperature T_0 and annealing rate P_Δ of SA;

Step VIII: Executing the annealing operation and returning to step V.

5. Case analysis

Taking the actual maintenance operation of a freight train depot as an example, this paper analyzes its shunting operation, takes four types of open wagon, platform wagon, covered truck and tank truck in the daily maintenance of the depot as maintenance examples, and solves the model according to the actual operation data (Note: In the actual production operation, there will be very few special models in the freight train depot. Since there are only the above four types of trucks for maintenance in daily operation, other very few special models will not be considered.).

5.1. Data Input

(1) When the freight trains of all models in the freight train depot are performing maintenance operations. The time of the maintenance trucks on the maintenance platform is shown in Table 1.

(2) Table 2 shows the time taken when the trucks of all models in the freight train depot are changing lanes when carrying out maintenance operations.

In Table 1 and Table 2, "Type" refers to the type of truck to be repaired, "Items" refers to the maintenance items that need to be performed by the truck, including Pre repair (P-repair), Temporary repair (T-repair), Shed repair (S-repair), Beam repair (B-repair), Shot blast and Rain test ."Shot blast" refers to shot blasting of the truck body for repainting, and "Rain test" refers to waterproof test after finishing repainting. "T1~T4" are respectively the time spent by this type of truck on these four maintenance operation lines. L1-L2, L1-L3 ... L3-L4 respectively represent the time spent by the truck when it is transferred to each maintenance operation line during maintenance.

(3) Based on the idea of solving a shunting operation model by SA-GA, the initial parameter setting of this method is shown in Table 3.

(4) Simulation environment: The CPU is Intel Core i5 1.19 GHz, the memory is 16.0 GB, and the heuristic algorithm solving software is Matlab 2019.
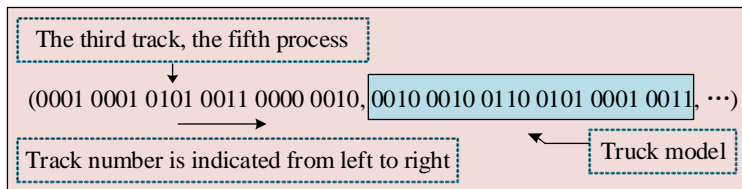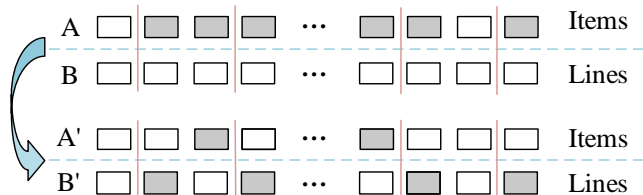

Fig. 3. Schematic diagram of the coding design
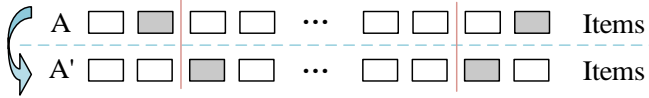

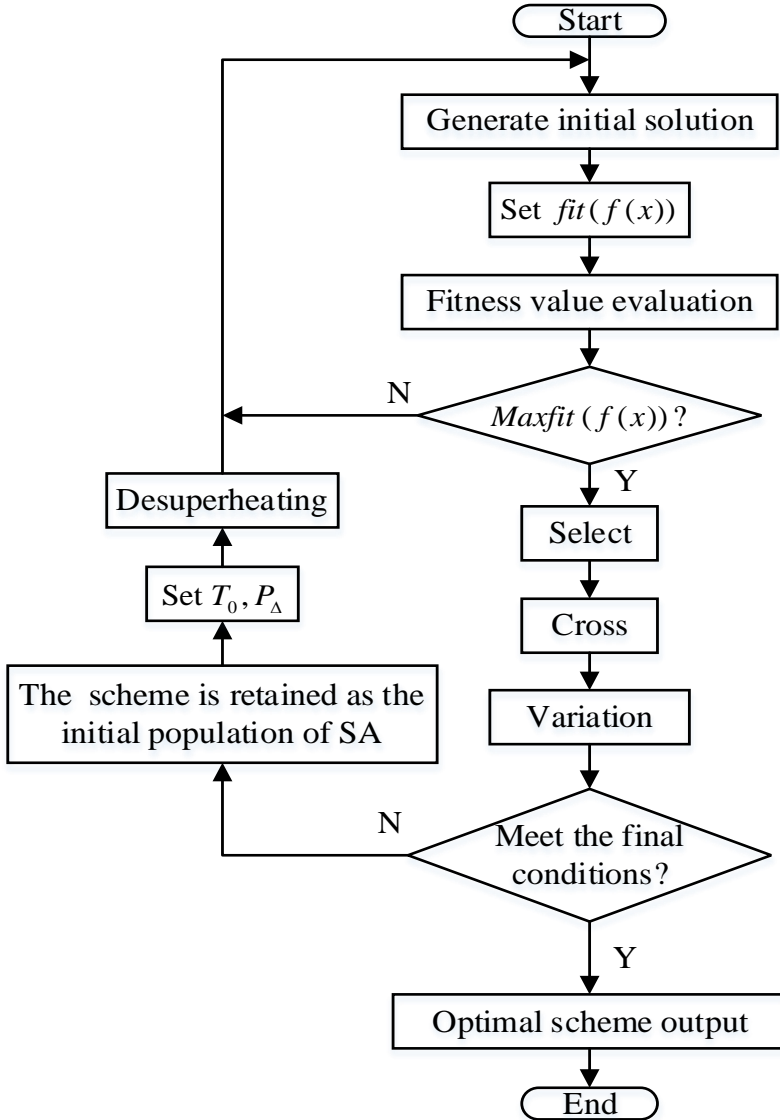Fig. 4. Genetic crossover diagram

Fig. 5. Genetic variation diagram

Fig. 6. SA-GA operation flow chart

Table 1 Busy time of truck maintenance

Type	N0.	Items	T1	T2	T3	T4
C70 **C70A**	1	P-repair	3	3	2	3
	2	T-repair	4	4	3	3
	3	S-repair	6	6	7	7
	4	B-repair	1	2	2	2
	5	Shot blast	3	2	3	2
	6	Rain test	1.5	2.5	2.5	2.5
NX70 **X70H**	1	P-repair	1	2	2	2
	2	T-repair	3	2	2	3
	3	S-repair	5	7	6	5
	4	B-repair	0	0	0	0
	5	Shot blast	2	1	2	2
	6	Rain test	1	2	1	1
P70 **P64GK**	1	P-repair	2.5	2.5	2.5	3.5
	2	T-repair	3.5	4.5	4.5	5.5
	3	S-repair	6	6	8	7
	4	B-repair	1	2	1	1
	5	Shot blast	3	4	3	2
	6	Rain test	1	1	1	1
GQ70 **GF70**	1	P-repair	3	4	3	4
	2	T-repair	5	6	6	5
	3	S-repair	7	7	8	7
	4	B-repair	0	0	0	0
	5	Shot blast	3	3	4	3
	6	Rain test	1	2	2	1

Table 2 Time consuming for truck to change lanes

Type	N0.	Items	L1-L2	L1-L3	L1-L4	L2-L3	L2-L4	L3-L4
C70 **C70A**	1	P-repair	0.3	0.2	0.4	0.3	0.2	0.2
	2	T-repair	0.3	0.5	0.6	0.3	0.5	0.3
	3	S-repair	0.2	0.1	0.1	0.2	0.2	0.1
	4	B-repair	0.1	0.2	0.2	0.2	0.1	0.1
	5	Shot blast	0.4	0.5	0.2	0.4	0.3	0.5
	6	Rain test	0.2	0.1	0.1	0.3	0.1	0.2
NX70 **NX70H**	1	P-repair	0.3	0.2	0.4	0.3	0.2	0.3
	2	T-repair	0.3	0.5	0.5	0.3	0.5	0.3
	3	S-repair	0.2	0.1	0.1	0.3	0.1	0.2
	4	B-repair	0	0	0	0	0	0
	5	Shot blast	0.3	0.2	0.4	0.3	0.2	0.2
	6	Rain test	0.2	0.2	0.3	0.2	0.3	0.1
P70 **P64GK**	1	P-repair	0.3	0.2	0.4	0.3	0.2	0.2
	2	T-repair	0.4	0.6	0.7	0.4	0.5	0.4
	3	S-repair	0.2	0.2	0.2	0.2	0.1	0.2
	4	B-repair	0.1	0.1	0.2	0.1	0.1	0.1
	5	Shot blast	0.5	0.4	0.3	0.5	0.4	0.5
	6	Rain test	0.3	0.2	0.2	0.3	0.2	0.2
GQ70 **GF70**	1	P-repair	0.3	0.2	0.4	0.3	0.2	0.3
	2	T-repair	0.3	0.5	0.6	0.5	0.4	0.3
	3	S-repair	0.3	0.3	0.4	0.4	0.2	0.2
	4	B-repair	0	0	0	0	0	0
	5	Shot blast	0.2	0.1	0.1	0.2	0.1	0.2
	6	Rain test	0.1	0.1	0.2	0.2	0.1	0.1

Table 3 Initial parameter setting of SA-GA

Initial Population	Number of Iterations	P_c	P_m	T_0	P_Δ
200	500	0.9	0.08	100	0.99

5.2. Result Analysis

According to the value of coefficients m_1 and m_2 in the objective function, it will have different effects on the solution of the model. At the same time, in the actual production, the proportion of truck maintenance busy time and transfer time will change. Therefore, the function values are analyzed and compared in three different states.

(1) When $m_1 = 0.6$, $m_2 = 0.4$, after the operation, the objective function curves is shown in Figure 7. For the results of GA operation, when the function is iterated 48 times, the function solution tends to a stable state, and when the function is iterated to more than 350 times, an approximate optimal solution will be obtained, the corresponding objective function value is 48.68h; Compared to GA, the objective function curve of SA-GA converges more slowly and produces a lower objective function value of 48.58 h when iterating to the convergence state.

After the calculation is completed, the truck allocation scheme is given in the form of a Gantt diagram, as shown in (a) and (b) of Figure 8

(Note: different colors indicate that different types of truck are overhauled on the maintenance lines, for example, "1" of "1.3" in the figure indicates that the vehicle type is open wagon, "3" indicates that the third process is performed, and "1.3" is located on track 2, indicating that the maintenance operation is performed on track 2). Compared to the scheme (a) solved by GA and the scheme (b) solved by SA-GA, the distribution of processes is more uniform, which can avoid multiple trucks performing operations on one maintenance line and alleviate the operation pressure of each maintenance line.

(2) When $m_1 = 0.7$, $m_2 = 0.3$, the objective function curve is shown in Figure 9. For the result of the GA operation, when the function is iterated nearly 200 times, an approximate optimal solution with a value of 42.8 h is obtained; Compared with GA, the convergence speed of SA-GA is slower, showing a convergence state when iterating nearly 210 times, and the output function value is 42.76h.

The Gantt chart of the operation of each process of the truck to be overhauled on the corresponding track is obtained, as shown in (a) and (b) of Figure 10, the truck to be overhauled is mainly allocated to track 1 and track 4, while track 2 and track 3 are relatively less allocated, but the overall distribution is uniform.
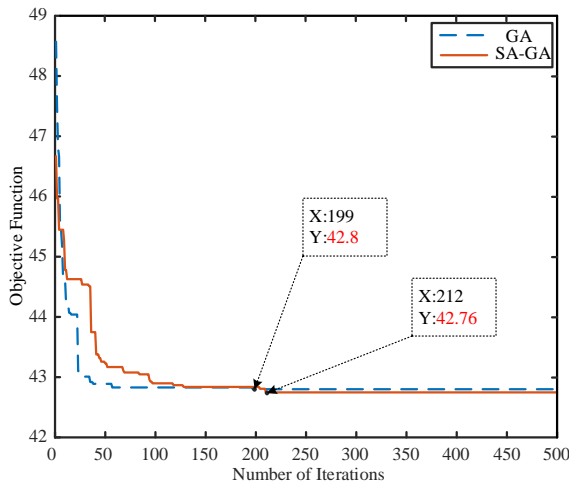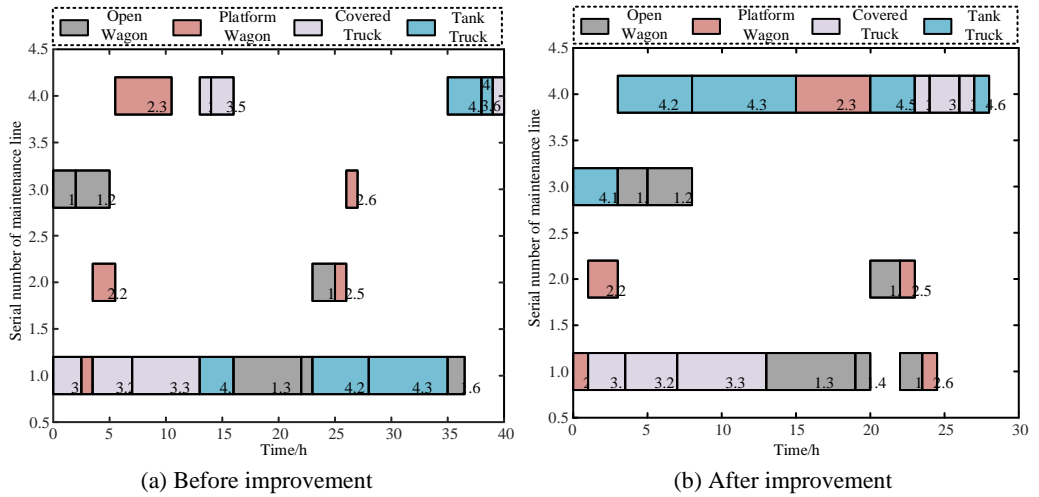

Fig. 9. Objective function curve

(a) Before improvement   (b) After improvement

Fig. 10. Gantt chart of distribution scheme

(3) When $m_1 = 0.8$, $m_2 = 0.2$, the objective function curve is shown in Figure 11. For the operation result of GA, when the function is iterated to 300 times, an approximate optimal solution with a value of 48.64h is obtained. Compared to GA and SA-GA, the function shows convergence when iterating nearly 190 times, and the output objective function value is 48.7h. The Gantt chart of each truck maintenance process

to be repaired in the corresponding track is obtained, as shown in (a) and (b) of Figure 12.

Similarly, compared with GA, the distribution scheme obtained by SA-GA is more reasonable. Although the truck to be repaired is mostly distributed on track 1 and track 4, and track 2 and track 3 are relatively less distributed, the overall distribution is uniform.
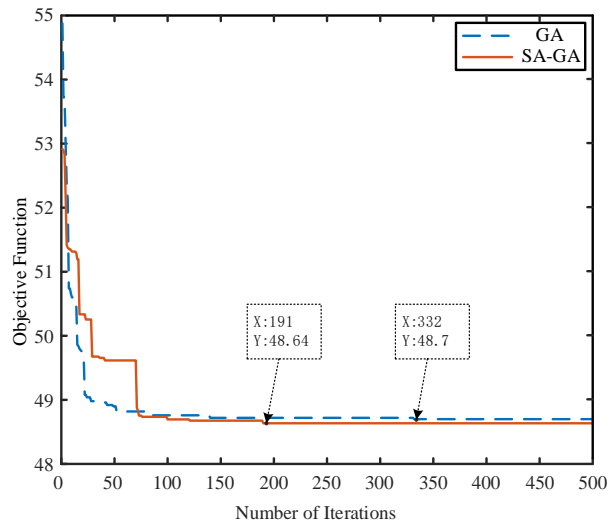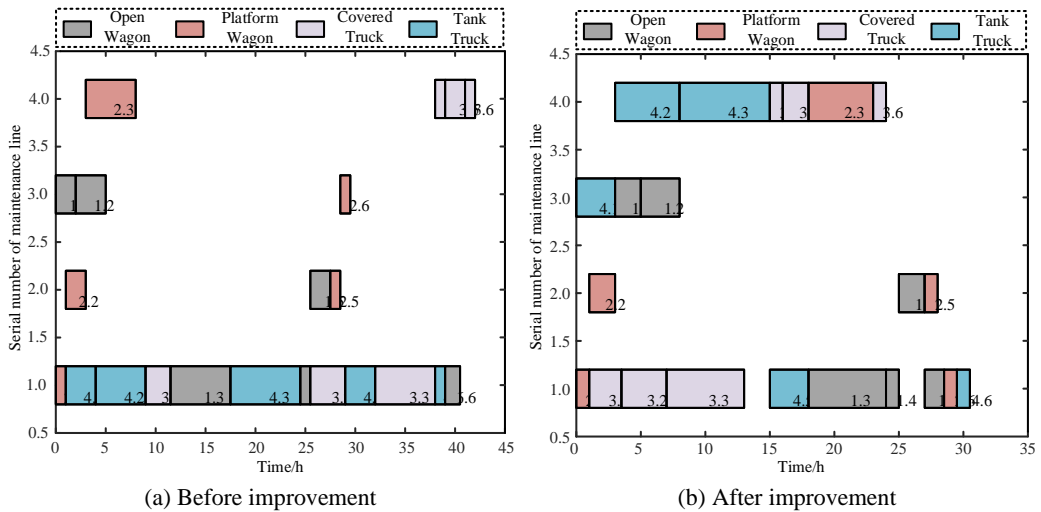

Fig. 11. Objective function curve

(a) Before improvement

(b) After improvement

Fig. 12. Gantt chart of the distribution scheme

6. Conclusion

According to the above solution of shunting operation model in the freight train depot, the objective function values obtained by SA and SA-GA under different parameters are compared, as shown in Table 4. Overall analysis SA and SA-GA get better satisfactory solutions to the shunting operation model. Compared with GA, SA-GA achieves the purpose of optimization and reduces the value of objective function under the same parameters; According to the 72 hours retention time limit specified in the freight train depot, the vehicle line allocation scheme can complete the maintenance operation within the specified time.

Table 4 Comparison of results

Parameter		MinZ(Unit：h)		Comparison of Results
m_1	m_2	GA	SA-GA	
0.6	0.4	48.68	48.58	-0.21%
0.7	0.3	42.80	42.76	-0.09%
0.8	0.2	48.64	48.70	-0.12%

In summary, we use the improved genetic algorithm to reduce the sum of the maintenance busy time and transfer time of the trucks to be repaired, and can produce the matching scheme between the trucks and the maintenance lines suitable for the shunting plan of the truck, which provides theoretical help for the automation of shunting operation.

References

[1] Tong, J. N., Nie, L., He, Z. H. (2016) Optimization of first level maintenance operation plan of EMU Operation Station Based on genetic algorithm. *Railway Transport and Economy*, 38(08): 59-65.

[2] Ma, L., Zhang, X. X., Guo, J. (2016). Research on track utilization of railway marshalling yard shunting yard based on heuristic backtracking algorithm. *Journal of the China Railway Society*, 38(08), 16-22.

[3] Per, Munk. Jacobsen., David, Pisinger. (2011) Train shunting at a workshop area. *Flexible Services and Manufacturing Journal*, 23(02) 156-180.

[4] Brady, Gilg., Torsten, Klug., Joseph, Paat., et al. (2018) Conflict-free railway track assignment at depots. *Journal of Rail Transport Planning & Management*, 08(01) 16-28.

[5] Wang, Z. K., Shi, T. Y., Zhang, W. J, & Wang, H. (2013) Optimization model and algorithm of shunting operation plan in EMU Operation Station. *Journal of the China Railway Society*, 35(08), 1-9.

[6] Zhang, W. J., Shi, T. Y., Chen, Y.(2013) Optimization model and algorithm of train line operation scheme in EMU Operation. *China Railway Science*, 34(01), 121-125.

[7] Guo, X. L., Song, R., Li, H. D. (2016) Preparation and optimization of shunting operation plan in EMU Operation Station. *China Railway Science*, 37(01), 117-123.

[8] Hu, Z. A., Zheng, L., Zhou, S. (2022) Optimization of shunting operation plan of EMU station considering reasonable occupation of train positions. *Journal of Southwest Jiaotong University*, 57(01), 65-73.

[9] Shi, J T., Li, H. D., Cao, H. et al.(2022) Preparation of shunting operation plan of EMU station considering flexible storage and occupation of train positions. *China Railway Science*, 43(01) 152-162.

[10] Lei, D. Y., Guo, C., Zhang, Y. (2016) Reasonable scheduling for arrival-departure track operations in railway stations. *Transportation Planning & Technology*, 39(06), 1-16.

[11] Zheng, K. D., Cha, W. X., Wang, M. et al. (2020) Route selection optimization of enterprise hub stations based on time continuity. *Journal of the China Railway Society*, 42(10): 1-8.

[12] Zhao, J., Zhang, S. Y., Peng, Q. Y. (2020). Application Optimization of Shunting Line in Railway Technical Station Considering Shunting Cost. *Journal of the China Railway Society*, 42(08), 10-22.

[13] Lv, X. X., Ni, S. Q., Cheng, D. J. (2015) Research on optimization model of shunting operation in positioning operation passenger station. *Journal of the China Railway Society*, 37(12), 1-7.

[14] Wang, J. X., Lin, B. L., Wang, Z. K., & Li, J. (2016) Optimization model and solution algorithm of shunting operation plan in EMU station. *Transportation System Engineering and Information*, 16(06), 122-127+141.

[15] Zhang, B. J., Pen, Q.Y., Li, L. et al. (2020) Shunting operation planning method of pick-up and coupling train for optimizing the number of shunting vehicles. *Journal of the China Railway Society*, 42(03) 11-20.

[16] Shi, J. T., Li, H. D., Giulio, E. Cantarella. (2019) Optimization of the shunting operation plan at electric multiple units depots[J]. *Journal of Advanced Transportation*, 12(06), 1-16.

[17] Wang, Y. L., Xiao, Y., Lei, Y. C., et al. (2012) Automatic preparation method of marshalling hook plan of uncoupling train based on sorted binary tree. *China Railway Science*, 33(03), 116-122.

[18] Konrad, Lewczuk. (2015) The concept of genetic programming in organizing internal transport processes. *Archives of Transport*, 34(02), 61-74.

[19] Ma, Y. J., Yun, W. X. (2012) Research progress of genetic algorithm. *Journal of computer application research*, 29(04), 1201-1206+1210.

[20] Zheng, X. H., Bao, J. S., Ma, Q. W., & Zhang, L. S. (2022) Spinning workshop scheduling system based on simulated annealing genetic algorithm. *Journal of Textile Research*, 41(06), 36-41.