Research Article

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Optimizing model and algorithm for railway freight loading problem

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Abstract: This paper constructed an optimizing model on multiple vehicles and multiple goods, which is used in a study on the loading problem for railway freight. We take the maximum utilization coefficient of car loading capacity, volume capacity and layout optimal degree as objective functions. Several major factors in railway transportation have been cited as constraints: center of gravity, non-overlapping freight, transportation circumscription, car marked loading capacity and volume capacity. In order to increase the car utilization coefficient and obtain flat layers in the loading scheme, an improved genetic annealing algorithm is proposed to solve this optimizing model. The proposed algorithm can efficiently obtain a satisfactory loading scheme in railway transportation. At the end, a numerical example shows that the proposed model and algorithm are better than First Fit Algorithm and Neural Network Algorithm in goods loading capacity and volume capacity, the new loading schemes are more flat on each layer.

Keywords: Railway transportation, freight loading problem, genetic annealing, layout optimal degree, Optimizing model

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1 Introduction

The railway freight loading problem is a common problem in the process of goods transportation. A reasonable loading scheme can reduce the unit costs and enhance the working efficiency, but also increase the safety of the transportation to a certain extent.

The loading problem means arranging multiple goods on several different cars, which aims to obtain the optimum and reasonable loading scheme. Moreover, the similar optimizing algorithm holds for highway, aviation, container and other modes of transportation [1]. In the actual transportation, there are a lot of constraints in the railway freight loading problem, so the heuristic approach is more used to obtain a satisfactory solution in solving this kind of NP-hard problem [2].

Lots of studies for loading problem have been done by domestic and international scholars. Researches abroad in this aspect have an early start. In this paper, a systematic review of the current state of research in loading problem is presented. The G&R algorithm with a concept of "layers" proposed by [3], is the foundation of current stratification algorithms. [4] Constructed a space matrix that can describe the free space and the loaded space simply and intuitively. A new approximation algorithm presented by [5] for the bin-packing problem, which has a linear running time and an absolute approximation factor: 3/2. The algorithm performs well even the number of bins is small and has a low complexity and a short computation time.

There are few reports concerning about this research in domestic, which pay more attention to the algorithm (*e.g.*, heuristic algorithm or artificial intelligence algorithm) [6]. Took the maximum loading capacity and volume capacity as optimizing targets. An optimizing model of freight loading problem for one car with multiple goods and multiple cars with multiple goods was proposed. [7] used the approach of spatial merging and small block reservation, the freight loading optimizing algorithm was built on the basis of central skeleton and the moving strategy. According to the characteristics of the container, [8] and [9] solved the optimal layout problem of rectangular objects in three-dimensional space. Although the algorithm has a low optimizing rate, the calculation process is simple and the loading efficiency is higher [10]. Further studied the loading problem of irregular goods, performed the combinatorial optimization on L, T and U shape goods, and combined irregular shape goods into regular shapes, such that the research results are more suitable for the actual situation.

In summary, the existing researches on the freight loading problem are mostly focus on the maximum loading capacity and volume capacity, which lead to the lack of further studies on loading scheme and Layout optimal degree. Besides, how to combine the two objective functions loading capacity and volume capacity better, they have not yet involved. In this paper, an optimizing model for railway freight is proposed, we take the maximum utilization coefficient of car volume and loading capacity and layout optimal degree as objective functions, and the goods gravity central shift, non-overlapping freight and transportation circumscription are cited as constraints. Reconfiguring and optimizing a group of goods in numerical example. To obtain the optimized scheme of railway freight loading problem, an improved genetic annealing algorithm is discussed by the characteristics of the proposed model.

2 Freight loading model

We first build the model of car body and goods by the vertexes coordinate sets, and further present the freight loading model. Specific definitions are as follows.

2.1 Car coordinate system

The car coordinate system (shown in Figure 1) is denoted by $V_i = (O_0, D_i^+)$, $O_0 = (0,0,0)$ and $D_i^+ = (X_i, Y_i, Z_i)$ are the start-point and end-point of the car coordinate set, respectively.

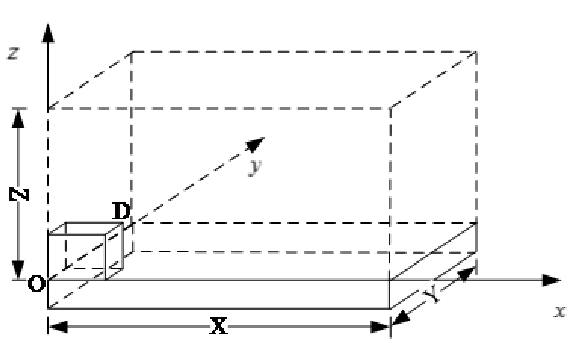

Figure 1: Car coordinate system

2.2 Freight layout parameters

We define that $H = (H_1, H_2, \cdots, H_n)$ as a good set. for H_j, it has a vertex set $H_j = (O_j, D_j)$, where O_j $(O_j = (x_j, y_j, z_j))$ is the closest point to the car starting point O_0. By the same token, $D_j = ({x'}_j, {y'}_j, {z'}_j)$. Then H_j can be denoted by the combination of x_j,y_j,z_j,x'_j,y'_j,z'_j. However, considering that the shape of the goods are mostly regular rectangles, we can obtain the only spatial location of the goods by the coordinates of O_j and D_j, which is recorded as (O_j, D_j).

2.3 Freight stratification theory

In order to improve the space utilization coefficient, we divide the whole car into several layers, and choose a suitable value in $(a_j = |{x'}_j - x_j|, b_j = |{y'}_j - y_j|, c_j = |{z'}_j - z_j|)$ as the layer height δ.

After we defined a certain δ, the goods will be loaded in the corresponding layer by an allowable height difference: $c_j \in (\delta - \xi, \delta + \xi)$. ξ is determined by the layer height and the goods height. In the actual loading process, the height difference between different goods can be filled by padding wood, so as to ensure the same height of the goods layer, and make the goods placed neatly and stably. At this point, there is a set of layers $\{\delta_k\}$, and $\sum(\delta_k + \xi_k) \le Z_i$.

2.4 The representation of relative position for two goods

Here, H_{st} denote the relative position between s and t. If s and t have contact parts in space, then $\|H_{st}\| = \overline{O_t D_s}^x \cdot \overline{O_t D_s}^y = 0$. We denote an unfeasible scheme of overlapping goods by $\overline{O_t D_s}^x > 0 \cap \overline{O_t D_s}^y > 0$, where $\overline{O_t D_s}^x$ and $\overline{O_t D_s}^y$ are the projections of $O_t D$ onto the X and Y axis, respectively, as shown in Figure 2. Meanwhile, under the constraint of the stratification theory, good height differences are within $|2\xi|$. Thus, we can obtain a better scheme with a bigger $\|H_{st}\|$.

2.5 Genetic annealing algorithm

Based upon past experience, several parameters Φ, p_c, p_m and T of the genetic algorithm are defined to solve the problems.

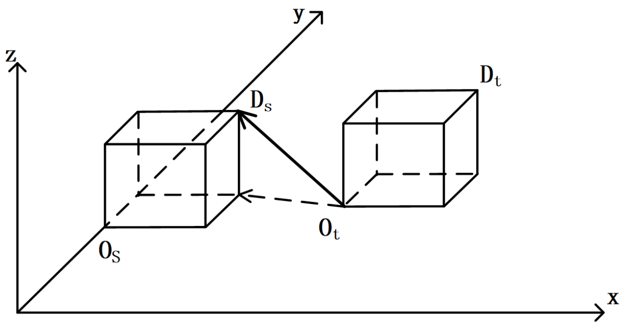

Figure 2: Freight model parameters

It is worth to note that, if the average volume of goods is small, even take a stratification approach, the number of goods loaded in car is still very large, such that with the goods number increase, the number of layout schemes also increase explosively. Since the complex calculations and slow convergence, original algorithm rarely obtains the optimal solution. Therefore, we propose an improved genetic annealing algorithm for the railway freight loading problem.

3 Railway freight loading model

3.1 Model definitions

In order to reduce the complexity of the model, some influential factors in the actual situation are defined as follows.

Definition 1. The goods can be placed in any direction, and the final placement must be parallel to the axis. Goods deformation can be ignored.

Definition 2. Goods and the outer packing are strong enough and can be stacked. If there is a suspended part below a good, we consider that a support is placed below without weight. The size of single good should be more than 0.02m3 according to the requirements of less-than-carload freight, that is, $\left|\left(x'_j - x_j\right)\left(y'_j - y_j\right)\left(z'_j - z_j\right)\right| \geq 0.02m^3$.

Definition 3. The gravity center of goods is considered be the geometric center: $G_j = \left((x'_j - x_j)/2, (y'_j - y_j)/2, (z'_j - z_j)/2\right)$. Car weight and loading capacity see Regulations for Railway Freight Traffic for the details.

Definition 4. The studied goods are non-dangerous goods, or can be assorted packing, which will be sent and arrived at same station without loading and unloading.

Definition 5. Let $\eta = (0, 1)$ be a determination coefficient. We define $k = (x_k, y_k, z_k)$ as a point, $k \in H_s$ and $k \in H_t$ indicate that s is in contact with t, then $\eta_{st} = 1$; if not, $\eta_{st} = 0$.

3.2 Constraints

The constraints of railway freight transportation are complex, especially in multi-type goods transportation. Consideration should be given to the overall constraints of the loaded car. The freight loading scheme, in addition to meet the Regulations for Railway Freight Traffic (hereafter this text will be abbreviated as Freight Regulations) and the Regulations for Loading and Strengthening of Railway Freight (hereafter this text will be abbreviated as Loading Regulations), but also need to meet the car restrictions. They are defined in the following equations (1)-(7) (α_h and α_z see Loading Regulations for equation details):

$$\max\left(\left|x'_j\right|\right) \leq X_i \tag{1}$$

$$\max\left(\left|y'_j\right|\right) \leq Y_i \tag{2}$$

$$\sum\left(\left|\delta_k + \xi_k\right|\right) \leq Z_i \tag{3}$$

$$\delta_k - \xi_k \leq \min\left(\left|z'_j\right|\right) \leq \max\left(\left|z'_j\right|\right) \leq \delta_k + \xi_k \tag{4}$$

$$\frac{\sum[(x'_j + x_j)\cdot g_j/2]}{\sum g_j} - X_i/2 \leq \alpha \tag{5}$$

$$\frac{\sum[(y'_j + y_j)\cdot g_j/2]}{\sum g_j} - Y_i/2 \leq \alpha \tag{6}$$

$$\frac{\sum\left[\left((z'_j + z_j)/2 + h_i^{\star}\right)\cdot g_j\right] + G_i \cdot h_i}{\sum g_j + G_i} \leq 2000mm \tag{7}$$

In addition to the above constraints, it should be satisfied with the actual situation and logical constraints, such as non-overlapping in space or overloading constraint. We obtain equations (8)-(10):

$$\sum g_j \leq Q_i \tag{8}$$

$$\overline{O_t D_s}^x \leq 0 \cup \overline{O_t D_s}^y \leq 0 \tag{9}$$

$$\left|\left(x'_j - x_j\right)\left(y'_j - y_j\right)\left(z'_j - z_j\right)\right| \geq 0.02m^3 \tag{10}$$

3.3 Objective functions

Generally speaking, the most important issues of railway freight transportation are the safety and efficiency. Existing literatures are mainly focus on the utilization coefficient of car volume capacity and loading capacity [11]. Based on the further analysis of the full-load situation, this paper introduces the layout optimal degree as a new objective function, and proposes a multi-object model.

3.3.1 Objective function W_1

The utilization coefficient of car loading capacity. The calculation of W_1 involves the type, quantity and weight of the loaded goods, we can obtain equation (11).

$$\max W_1 = \sum \omega_i/m = \frac{1}{m}\sum_{i=1}^{m}\left(\frac{\sum \mu_j^i g_j}{Q_i}\right) \quad (11)$$

$$i = 1, 2, \ldots, m$$

where $\mu_j^i = \{0, 1\}$, if j is put on i, then $\mu_j^i = 1$, if not, $\mu_j^i = 0$.

3.3.2 Objective function W_2

The utilization coefficient of car volume capacity. Similar to (11), we can obtain equation (12).

$$\max W_2 = \frac{\sum \sigma_i}{m} = \frac{\sum_{i=1}^{m}\left(\sum \mu_j^i \frac{(x_j \cdot y_j \cdot z_j)}{(X_i \cdot Y_i \cdot Z_i)}\right)}{m} \quad (12)$$

3.3.3 Objective function W_3

Layout optimal degree. There are obvious pros and cons of the different arrangement of goods on the car (as shown in Figure 3), Plan A is better than Plan B and Plan C. Then we introduce layout optimal degree to denote the pros and cons of arrangement with respect to all loaded goods. We obtain equation (13).

$$\max W_3 = \sum \|H_{st}\| = \frac{\sum_{s\neq t} \eta_{st} \cdot \left(\overline{O_t D_s}^x \cdot \overline{O_t D_s}^y\right)}{\sum \eta_{st}} \quad (13)$$

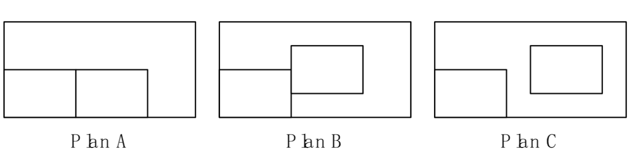

Figure 3: Comparison of different relative positions

Based on the analysis above, the optimizing model of railway freight loading problem is constructed as follows:

$$\max W_1 = \frac{\sum omega_i}{m} = \frac{\sum_{i=1}^{m}\left(\frac{\sum \mu_j^i g_j}{Q_i}\right)}{m};$$

$$\max W_2 = \frac{\sum \sigma_i}{m} = \frac{\sum_{i=1}^{m}\left(\frac{\sum \mu_j^i (x_j \cdot y_j \cdot z_j)}{(X_i \cdot Y_i \cdot Z_i)}\right)}{m}$$

$$\max W_3 = \sum \|H_{st}\| = \frac{\sum_{s\neq t} \eta_{st} \cdot \left(\overline{O_t D_s}^x \cdot \overline{O_t D_s}^y\right)}{\sum \eta_{st}}$$

such that

$$\max\left(\left|x'_j\right|\right) \le X_i;$$

$$\max\left(\left|y'_j\right|\right) \le Y_i;$$

$$\sum (|\delta_k + \xi_k|) \le Z_i;$$

$$\delta_k - \xi_k \le \min\left(\left|z'_j\right|\right) \le \max\left(\left|z'_j\right|\right) \le \delta_k + \xi_k;$$

$$\frac{\sum [(x'_j + x_j) \cdot g_j/2]}{\sum g_j} - X_i/2 \le \alpha;$$

$$\frac{\sum [(y'_j + y_j) \cdot g_j/2]}{\sum g_j} - Y_i/2 \le \alpha;$$

$$\frac{\sum \left[\left((z'_j + z_j)/2 + h_i^\star\right) \cdot g_j\right] + G_i \cdot h_i}{\sum g_j + G_i} \le 2000mm;$$

$$\sum g_j \le Q_i;$$

$$\overline{O_t D_s}^x \le 0 \cup \overline{O_t D_s}^y \le 0;$$

$$\left|(x'_j - x_j)\,(y'_j - y_j)\,(z'_j - z_j)\right| \ge 0.02m^3;$$

$$\eta_{st} = \begin{cases} 1 & k \in H_s \cap k \in H_t \\ 0 & else \end{cases};$$

$$i = 1, 2, \cdots, m;$$

$$j = 1, 2, \cdots s, \cdots t, \cdots, n.$$

4 Improved genetic annealing algorithm

In this paper, the improved genetic annealing algorithm (short for GA-SA) is used to solve the problem: Firstly, a group of individuals is produced by selection, crossover and mutation operations in Genetic Algorithm (short for GA). Then we can obtain the new individuals in offspring by the simulated annealing. In the above multi-objective optimizing problem, it is difficult to find a set of solutions, which can satisfy all sub goals. As a consequence, we only need a Pareto Solution of the optimizing model.

4.1 Model parameters

4.2 Combination of objective functions

Two target functions of W_1 and W_2 are combined by weight, which can be expressed as equation (14).

$$\max U_1 = \max(\alpha W_1 + \beta W_2) \tag{14}$$

For the weight coefficients, referring to the actual experience, we denote the weight by the volume ratio and loading ratio for goods and car [1], shown in equation (15).

$$\frac{\alpha}{\beta} = \frac{\dfrac{\sum_i \sum_j \mu_j^i g_j}{\sum_i \sum_j \mu_j^i (x_j \cdot y_j \cdot z_j)}}{\dfrac{\sum_i Q_i}{\sum_i [X_i \cdot Y_i \cdot (Z_i - h_i^*)]}} \tag{15}$$

For the objective function 3 and equation (14), there is no direct connection between the two forms, so the possibility-satisfiability method is used to transform the multi-objective programming, we obtain equation (16).

$$\lambda, \theta = \begin{cases} 1 & \text{(completely satisfied with the index)} \\ \lambda, \theta & \\ 0 & \text{(completely dissatisfied with the index)} \end{cases} \tag{16}$$

Equation (14) is a $f_{\max}$ function, we obtain equation (17).

$$\lambda(r) = \begin{cases} 0 \\ (r - r_B)/(r_A - r_B) \\ 1 \end{cases} \tag{17}$$

Equation (3) is a $f_{\min}$ function, we obtain equation (18).

$$\theta(r) = \begin{cases} 0 \\ (r_B - r)/(r_B - r_A) \\ 1 \end{cases} \tag{18}$$

4.3 Genetic algorithm parameters

Let the population and crossover probability denote by M and p_c, respectively, H' is the group of goods be loaded in same layer, then M and p_c can be defined by floating value [12–18]. The size of M will change with the number of goods in H'. In order to retain the excellent individuals, we define p_c be inversely proportional to the individual fitness, we can obtain equation (19).

$$p_c = \begin{cases} [f^+ - f(c_t)]/[f^+ - f^-], & f^+ \neq f^- \\ randbetween(0, 1), & else \end{cases} \tag{19}$$

4.4 Algorithm steps

4.4.1 Parents genetic coding

If $c_j \in (\delta - \xi, \delta + \xi)$, then we put c_j into H' from H, $(x_j - x'_j) \cdot (y_j - y'_j)$ is the area occupied by c_j. If $\sum (x_j - x'_j) \cdot (y_j - y'_j) > X_i Y_i$, H' is loading complete, if not, then expand the range of $(\delta - \xi, \delta + \xi)$ until it meets the scope of H'. At this time, the initial parent generation is defined by $C_0 = (0, 0, \cdots, 0)$ and $C'_0 = (1, 1, \cdots, 1)$, respectively, such that the offspring, product in genetic process, can cover the scope of the solutions as much as possible.

4.4.2 Population fitness

The values of the objective functions are used as the population fitness P_t (t is the generation number).

4.4.3 Crossover and mutation operations

Let the crossover probability and mutation probability be denote by p_c and p_m, such that the crossover and mutation operations of the chromosomes for parents can be denote by $C_{t+1}C_t$ and $C_{t+1}C_t$, respectively, then we get a new offspring.

4.4.4 Simulated annealing calculation for new offspring

Let C_t and C'_t be two initial generation groups, C_{t+1} and C'_{t+1} be two second generation groups, then carrying out simulated annealing and genetic operations by initial generation probability ρ and second generation probability $1 - \rho$, we get the final individuals in new offspring. Where

Table 1: Goods loading data

No.	Goods code	Length (mm)	Width (mm)	Height (mm)	Weight (t)	Quantity
1	1-4	2 800	2 000	1 200	4.10	4
2	5-16	1 000	1 000	1 000	0.20	12
3	17-20	3 000	800	2 000	1.10	4
4	21-34	4 800	900	1 000	3.80	14
5	35-42	2 900	800	900	0.40	8
6	43-50	1 900	1 200	900	2.10	8
7	51-60	1 250	600	800	0.30	10
8	61-70	940	400	500	0.33	10

Table 2: Usage for loaded car

	Single weight	First layer		Second layer		First layer		Second layer		Total
		Quantity	Weight	Quantity	Weight	Quantity	Weight	Quantity	Weight	
1	4.1	4	16.40							
2	0.2					2	0.40	3	0.60	
3	1.1			3	3.30					
4	3.8	1	3.80			6	22.80	6	22.80	
5	0.4			4	1.60					
6	2.1	5	10.50			2	4.20	1	2.10	
7	0.3			8	2.40			2	0.60	
8	0.33			4	1.32	4	1.32	2	0.66	
Total			30.70		8.62		28.72		26.76	94.8

we define ρ in equation (20).

$$\rho = \frac{1}{1 + \exp[(f_t - f_{t+1})/T]} \tag{20}$$

4.4.5 Fitness calculation of new population

The same as 4.2.2, population fitness of second generation ($t + 1$ generation) is iterative calculated until the end condition or the end generation are satisfied.

5 Numerical example

5.1 Simulation results of freight loading

In reference to examples in [1] and [2], we set up the goods data, as shown in Table 1. Let us assume that the gravity center of goods is the geometrical center. We choose the type of C62 as the study car, and its technical parameters are as follows, tare mass: 21.7t, marked loading capacity: 60t, car body volume: 12500mm×2900mm×2000mm, car floor height from rail top: 1083mm, center height of gravity for empty car: 1000mm, lateral shift for goods gravity center: 100mm, longitudinal shift for goods gravity center can be defined by loading capacity, and the height of gravity center for loaded car must be less than 2000mm.

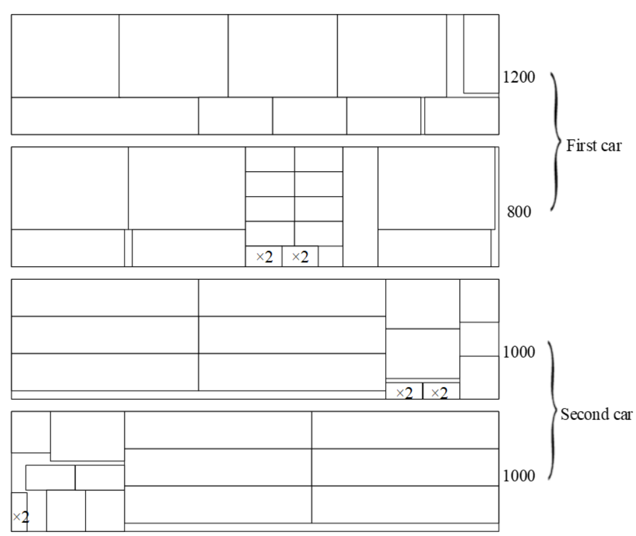

Figure 4: Representation of layers

By calculation, we can obtain the first and second layer of the first car: c_1^1 = [1000, 1200] and c_2^1 = 800; the first and second layer of the second car: c_1^2 = [900, 1000]

Table 3: Comparison of different algorithms

Basic technical parameters	Neural Network algorithm		First Fit algorithm		Algorithm in this paper	
	First car	Second car	First car	Second car	First car	Second car
Longitudinal shift tolerance (mm)	1 053.0	914.6	1 053.0	914.3	1 106.3	354.4
Longitudinal shift (mm)	81.3	278.4	81.3	278.4	7.48	132.48
Lateral shift tolerance (mm)	100.0	100.0	100.0	100.0	100.0	100.0
Lateral shift (mm)	9.6	43.6	9.6	43.6	78.1	10.33
Gravity center height for car loaded (mm)	1 654.0	1 729.0	1 654.0	1 729.0	1 575.1	1 760.9
Loading capacity (t)	42.7	49.2	44.8	49.2	39.32	55.48
Utilization coefficient of car loading capacity (%)	71.00	82.00	75.00	82.00	65.53	92.47
Total volume of the loaded goods (m3)	66.678	67.048	66.684	67.532	69.764	65.324
Utilization coefficient of car volume capacity (%)	91.97	92.48	91.98	93.15	96.23	90.10

and c_2^2 = [800, 1000]. The specific layout is shown in Figure 4 and Table 2.

As a consequence, the improved genetic annealing algorithm obtain a superior solution, which ensures better objective functions and speeds up algorithm converging.

5.2 Discussion

We compared the First Fit Algorithm (see *e.g.* [1]) and Neural Network Algorithm (see *e.g.* [2]) with the proposed algorithm in a same numerical example, as shown in Table 3.

We note that, the basic technical parameters of proposed algorithm are better than First Fit Algorithm and Neural Network Algorithm in many respects. And 3.27%, 0.64% increase in utilization coefficient of car loading capacity; 1.02%, 0.65% increase in utilization coefficient of car volume capacity for details, respectively. Moreover, the new loading schemes are more flat on each layer. By objective function equation (13), the lateral and longitudinal shift of goods gravity center were reduced by 44.69%. As a consequence, the improved genetic annealing algorithm proposed above can efficiently obtain the optimal solution of the railway freight layout problem.

6 Conclusion

In order to increase the car utilization coefficient and obtain flat layers in the loading scheme, we introduce the layout optimal degree, couple with the combination of car loading capacity and volume capacity, to construct the railway freight optimizing model. The following findings were obtained from this research.

The value of layer height δ and the acceptable horizon ξ directly affect the computational complexity and scheme results, reasonable choice of which are very important.

The weight ratio and possibility-satisfiability method for multi-objective function can express the best form of the solution. By simplifying the objective functions, compared with literature 1 and 2, the optimal solution increased by 3.27% and 0.64% in utilization coefficient of car loading capacity, respectively, and increased by 1.02% and 0.65% in utilization coefficient of car volume capacity, respectively.

The stratification theory optimizes the basic parameters of loaded car. Compared with the First Fit Algorithm, the average longitudinal shift of goods gravity center reduced from 179.85mm to 69.98mm, and the average longitudinal shift increased from 26.6mm to 44.215mm, but still in the allowed range.

On the basis of stratification theory, the upper and lower exchanges between layers can make the gravity center height lower, this method reduces the average height by 23.5mm compared with the previous algorithm.

Vector product is used to express the layout optimal degree. To some extent, the layout optimal degree describes the pros and cons of the different arrangement. But the degree is out of proportion to the position relationship, and it can only indicate the advantages and disadvantages.

Furthermore, since there are too many parameters involved in the problem, this paper makes a simplified design for the actual situation, especially the rectangular outer packing for all goods. But in fact, the shapes of the goods transported by railway have great randomness and strong irregularity, and further research is needed.

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List of notation

$1-\rho$	is the annealing probability of second generation
α and β	are the weight of W_1 and W_2;
δ	is the layer height;
η and μ_j^i	are two determination coefficients;
λ and θ	are the possibility-satisfiability of equations (3) and (14);
Φ	is the final evolutionary generation;
ρ	is the annealing probability of initial generation
ξ	is the acceptable horizon of good heights when we load goods into a layer;
D_i^+	is the end-point of the car body coordinate set;
$f(c_t)$	is the fitness value with respect to an individual c_t;
H	is a good set;
H'	is the group of goods be loaded in a same layer;
h_i^*	is the plane height of car body;
i	is the car sequence number;
M	is the population;
r	is the specific value of target function;
T	is the simulated annealing temperature in initial state;
t	is the generation number;
α_h	is the lateral shift for gravity center of goods;
α_z	is the longitudinal shift for gravity center of goods;
δ_k	is the layers set;
ω_i	is the coefficient of utilization for car loading capacity;
σ_i	is the utilization coefficient of volume capacity for i;
^{x} and ^{y}	are the projections of O_tD onto the X and Y axis;
a_j	,b_j,$c_j$are the length, width and height of H_j;
C_0 and C_0'	are the initial parent generations;
C_t and C_t'	are two initial generation groups
C_{t+1} and C_{t+1}'	are two second generation groups
D_j	is the loading end-point of H_j with respect to the loaded car;
f^+ and f^-	are the maximum and minimum value of individual fitness;
f_t and f_{t+1}	are the fitness of C_{t+1} and C_{t+1}'.
G_j	is the gravity center;
g_j	is the weight of j;
h_i	is the gravity central height of empty car;
H_j	is the good in H, ($H_j \in H$);
H_{st}	is the relative position value between s and t;
O_0	is the start-point of the car body coordinate set;
O_j	is the loading start-point of H_j with respect to the loaded car;
O_sO_t and D_sD_t	are start-point and end-point coordinates with respect to s and t;
p_c	is the crossover probability;
p_m	is the mutation probability;
P_t	is the population fitness;
Q_i	is the maximum loading capacity of car i;
r_A and r_B	are the ideal index values that are completely satisfactory and dissatisfactory;
V_i	is the car coordinate system;
X_i, Y_i, Z_i	are the total loading limits of the goods on the X, Y and Z axis with respect to the loaded car;

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