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Optimization Model and Particle Swarm Optimization Algorithm of Operation Plan for Scheduled Freight Train

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Abstract: Conventional researches on optimization model and algorithm of operation plan for scheduled freight train usually neglected shippers' demands and suffered from solving the vast calculation task of large-scale railway network. Therefore, this study aimed at establishing new optimization model based on fully considering shippers' demands, as well as putting up with more efficient solution algorithm. The model took maximum satisfied degree of shippers' and minimum operation cost of railway enterprise as objectives, while took service frequency, transit time range, as constraints. The designed algorithm was on the basis of particle swarm optimization which was suitable for multi-objective problem and large-scale network. The study results showed that the model synthetically reflected the profits of both railway enterprise and shippers and the solution time could meet the demand of railway, meanwhile, the algorithm had strong robustness.

Key words: Railway freight transportation, scheduled freight train, operation plan, particle swarm optimization

INTRODUCTION

With the continuous increase of energy cost and increasingly serious of the environment, there are more and more problems of the express freight transportation system which is taking airway and highway as the major transport mode. So many countries pay more attention to the development of rail express freight transportation, of which scheduled freight train is the most important organization mode (Wang *et al*., 2009a). Compared with the rapid increase of express freight transport demand and the variety of shippers' requirement, the academic studies on rail transport organization of express freight are relatively barren (Yang, 2000; Ceselli *et al*., 2008). Although, before 1987, the problems of running routes and empty car distribution of express freight train had been analyzed detailedly (Haghani, 1987), the studies in recent years primarily focus on the design and optimization of plan for luggage and parcel trains and container trains. These studies include two kinds, one is aiming at the optimization of freight train plan using service network design method (Wang and Liu, 2007; Wang *et al*., 2009b; Li *et al*., 2009; Lin, 2001), another is establishing optimization model of freight train plan taking the minimum cost or maximum benefits of rail transport enterprise as objective based on the prediction of freight flow volume (Yan *et al*., 2008; Newman and Yano, 2001; Li, 2008). Moreover, there also some researches on the optimization of train formation diagram of express freight (Li and Lu, 2004), as well as optimization of scheduled transit train operating plan (Guo *et al*., 2011). Regretfully, present studies on the transport organization of railway express freight are all establishing optimization models from the production angle, seldom consider the demand of shippers, furthermore, the constraint about carrying capacities is also hardly taken into account. The solving methods of the operation plan for express freight train are often simplex algorithm or directly computing the solutions by Lingo software, which can not work if the network scale is large.

In order to overcome the above problems, firstly, this study mainly analyzes the characteristic of operation plan for scheduled freight train and the shippers' demands. Secondly, the theory of multi-objective plan is adopted to establish more practical optimization model of operation plan for scheduled freight train. And then, the solving algorithm for the model based on particle swarm optimization is designed. Finally, a case is used to verify the model and the algorithm.

ANALYSIS OF OPERATION PLAN FOR RAILWAY SCHEDULED FREIGHT TRAIN

Making operation plan of scheduled freight train is to determine departure station, arrival station, running path, running frequency and so on. When working out and

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optimizing operation plan of scheduled freight train, the chief objective is to meet the demands of shippers. We primarily consider the demands of shippers in three aspects, which are freight flow volume demand, transport time demand and service frequency demand. Among these demands, freight flow volume demand of shippers is taken the objective in the model, while the other two demands are taken constraints. The cost of transportation enterprise is also very important when operating scheduled freight train, so the minimum cost of railway transportation enterprise is another objective. The cost mainly includes four parts, which are arrival-departure cost of trains, running cost of trains, travel cost of cars, as well as throw-hang operation cost of cars.

While determining and optimizing operation plan of scheduled freight train, there are some constraints, such as a certain freight volume is essential to ensure the number of formation cars can meet the demand of operating scheduled freight train, meanwhile, the number of formation cars can not be more than the section traction weight (Zhang *et al*., 2011). Furthermore, the running of scheduled freight train is confined by the carrying capacity of section and departure-arrival capacity of station.

In order to reduce the complexity of the problem and consider the characteristics of the operation plan of scheduled freight train, the following assumptions are made to set up the model easily.

The stations considered in this paper are just the handling stations and organizing stations which have upstanding scatter and distribution function and can meet the demand for departure and arrival of the whole train.

Only consider the volume of freight flow, not probe into the freight kind and their transportation conditions. Meanwhile, the freight transportation demand and freight flow volume are all converted into car flow volume in each day and the section traction weight is also represented by the traction cars of each section.

The loading capacity of each car is same, that means the freight flow volume loaded on every car is the same. Moreover, suppose the grade of all the scheduled freight trains is the same and the running time on the same section of each train is identical.

A batch of cargo can not be separated. That is the running path of the same batch of freight flow is consistent.

OPTIMIZATION MODEL OF OPERATION PLAN FOR SCHEDULED FREIGHT TRAIN

Description of relative parameters

Parameters: we define the following parameters:

$G(S, E)$	=	Railway physical network with station set S and edge set E
$S = \{s_i\}$	=	Station set of railway network, where, $i = 1, 2, ...n$
$E = \{e_a\}$	=	Edge set of railway network, where, $a = 1, 2,..., m$
$l(e_a)$	=	Mileage of edge e_a, $a = 1, 2, ..., m$
$n(s_i)$	=	Arrival-departure capacity of station s_i, $\forall s_i \in S$
$n(e_a)$	=	Carrying capacity of edge e_a, $\forall e_a \in E$
p_{ijk}	=	The k-th path between s_i and s_j, $\forall s_i$, $s_j \in S$ and $si \neq s_j$, $k = 1, 2, ..., p_{ij}$, p_{ij} means the number of path between s_i and s_j
l_{ijk}	=	Length of path p_{ijk}
$Y_{ijk}(e_a)$	=	$Y_{ijk}(e_a) = 1$ if edge e_a being in path p_{ijk} and 0 otherwise
d_{ij}	=	Freight transport demand between s_i and s_j, $\forall s_i$, $s_j \in S$
q^0_{ijk}	=	Requiring service frequency of train t_{ijk}
q_{ijk}	=	Service frequency of train t_{ijk}
m_{ijk}	=	Number of formation cars for scheduled freight train between s_i and s_j, $\forall s_i$, $s_j \in S$, $m_{ijk} \in N^+$
$m^{min}_{ijk}, m^{max}_{ijk}$	=	Minimum number and maximum number of scheduled freight train formation cars between s_i and s_j, $\forall s_i$, $s_j \in S$
$t(e_a)$	=	Running time of scheduled train on e_a
$t(s_u)$	=	Operating time of scheduled train in s_u
c_1	=	Arrival-departure cost per train
c_2	=	Train travel cost per kilometer
c_3	=	Car travel cost per kilometer
c_4	=	Throw-hang operation cost per station

Decision variables: We define the following decision variables.

$X_{ijk} = 1$, if train t_{ijk} is operated taking s_i as original departure station, s_j as final arrival station and p_{ijk} as its running path, while 0 otherwise.

$X_{ijk}(u) = 1$, if train t_{ijk} has throw-hang operation, and 0 otherwise, $s_u \in p_{ijk}$.

$Y^{gh}_{ijk} = 1$ if d_{gh} being transported by train t_{ijk} and 0 otherwise. $s_g \in p_{ijk}$, $s_h \in p_{ijk}$.

Objective function

Minimum cost of railway transport enterprise: The cost of railway transport enterprise mainly includes four parts, which are arrival-departure cost of trains, running cost of trains, travel cost of cars, as well as throw-hang operation cost of cars. Each part is analyzed one by one.

- Departure-arrival cost of trains:

$$C_1 = c_1 \sum_i \sum_j \sum_k X_{ijk} q_{ijk} \tag{1}$$

- Running cost of trains:

$$C_2 = c_2 \sum_i \sum_j \sum_k X_{ijk} q_{ijk} l_{ijk} \quad (2)$$

- Travel cost of cars:

$$C_3 = c_3 \sum_i \sum_j \sum_k X_{ijk} q_{ijk} l_{ijk} m_{ijk} \quad (3)$$

- Throw-hang operation cost of cars:

$$C_4 = c_4 \sum_i \sum_j \sum_k \sum_{s_u \in p_{ijk}} X_{ijk}(u) q_{ijk} \quad (4)$$

Then, we get the objective function of minimum cost of railway transport enterprise as Eq. 5:

$$\text{Min } Z_1 = C_1 + C_2 + C_3 + C_4 \quad (5)$$

$$= c_1 \sum_i \sum_j \sum_k X_{ijk} q_{ijk} + c_2 \sum_i \sum_j \sum_k X_{ijk} q_{ijk} l_{ijk} + c_3 \sum_i \sum_j \sum_k X_{ijk} q_{ijk} l_{ijk} m_{ijk} + c_4 \sum_i \sum_j \sum_k \sum_{s_u \in p_{ijk}} X_{ijk}(u) q_{ijk}$$

Maximum satisfied degree of shippers' demands: The objective of satisfying shippers' demands to maximum extent can be achieved by transporting freight volume as much as possible, the expression of which is shown Eq. 6:

$$\text{Max } Z_2 = \sum_i \sum_j \sum_k \sum_{s_g \in p_{ijk}, s_h \in p_{ijk}} Y_{ijk}^{gh} \cdot d_{gh} \quad (6)$$

Constraints: In this study, the constraints being considered mainly include train running frequency constraints, number of formation cars constraints, capacity constraints, transit period constraints and unique constraints, which are analyzed one by one.

Train running frequency constraints: The running frequency of train t_{ijk} should not be less than its requirement service frequency:

$$q_{ijk} \geq q_{ijk}^0 \quad (7)$$

Number of train formation cars constraints: The number of train formation cars should be between the minimum number of formation cars and the maximum value:

$$m_{ijk}^{min} \leq m_{ijk} \leq m_{ijk}^{max} \quad (8)$$

Station capacity constraints: Number of trains arriving or depaturing at station s_i should be less than its capacity:

$$\sum_j \sum_k X_{ijk} q_{ijk} + \sum_j \sum_k X_{jik} q_{jik} \leq n(s_i) \quad (9)$$

Constraints of section capacity: Maximum number of trains on edge e_a should be less than its carrying capacity:

$$\sum_i \sum_j \sum_k X_{ijk} q_{ijk} Y_{ijk}(e_a) \leq n(e_a) \quad (10)$$

Transit period constraints: Running time of train t_{ijk} should be within the transit period being distributed to it:

$$\sum_k \sum_{e_a \in p_{ijk}} t(e_a) X_{ijk} Y_{ijk}(e_a) + \sum_k \sum_{s_u \in p_{ijk}} X_{ijk} X_{ijk}(u) t(s_u) \leq T_{ij} \quad (11)$$

where, T_{ij} represents the transit period being distributed to train t_{ijk}.

Unique choice of cars flow: A car flow is only distributed one train. For $\forall s_g \in p_{ijk}$, $s_h \in p_{ijk}$.

$$\sum_i \sum_j \sum_k Y_{ijk}^{gh} \leq 1 \quad (12)$$

This kind of restriction meaning that exact one train can be chosen if:

$$\sum_i \sum_j \sum_k Y_{ijk}^{gh} = 1$$

otherwise the flow being not transported.

Nonnegative constraints: All variable values are not less than zero.

SOLUTION ALGORITHM DESIGN BASED ON PARTICLE SWARM OPTIMIZATION

Model analysis: By analyzing above model, we can find that the optimization model of scheduled freight train plan is a multi-objective non-linear mixed integer plan. Meanwhile, for the two objective functions, one is a maximization problem and another is a minimization problem. Furthermore, the dimension of the objective functions is not unified. So, it is very difficult to solve the model directly. Therefore, we deal with the objective functions before solving the model. Firstly, we convert Eq. 6 into Eq. 13, so that the maximization problem be transformed a minimization problem:

$$\text{Min } Z_2' = 1 - \frac{Z_2}{\sum_i \sum_j d_{ij}} \tag{13}$$

Where:

$$\frac{Z_2}{\sum_i \sum_j d_{ij}}$$

expresses the satisfied degree of shippers' transport volume demand, while the target value Z'_2 represents the unsatisfied degree of shippers' transport volume demand and $Z'_2 \in [0, 1]$.

Then, we structure Eq. 14 by combining with Eq. 5 and 13, so that the bi-objective model is converted into single objective model, which considers both the operation cost of railway transport enterprise and the satisfied degree of shippers' freight transport volume demand.

$$\text{Min } Z = Z_1 \times Z_2' \tag{14}$$

$$\begin{aligned} &= (c_1 \sum_i \sum_j \sum_k X_{ijk} q_{ijk} + c_2 \sum_i \sum_j \sum_k X_{ijk} q_{ijk} l_{ijk} + \\ &c_3 \sum_i \sum_j \sum_k X_{ijk} q_{ijk} l_{ijk} m_{ijk} + c_4 \sum_i \sum_j \sum_k \sum_{s_u \in p_{ijk}} X_{ijk}(u) q_{ijk}) \\ &\times (1 - \frac{\sum_i \sum_j \sum_k \sum_{s_g \in p_{ijk}, s_h \in p_{ijk}} Y_{ijk}^{gh} \cdot d_{gh}}{\sum_i \sum_j d_{ij}}) \end{aligned}$$

Finally, we get a non-linear mixed integer plan model taking Eq. 14 as objective function and Eq. 7-12 as constraints. This kind of model belongs to NP-Hard problem, which is difficult to solve by traditional methods. In recently years, heuristic algorithms such as Genetic Algorithm (GA), Simulated Annealing algorithm (SA), Ant Colony Algorithm (ACA), Particle Swarm Optimization algorithm (PSO), *et al.* are applied to solve this kind of problem. According to the comparative analysis of some researchers, there is advantages and disadvantages of each algorithm, but PSO has the superiority in solving time and algorithm complexity (Kennedy *et al.*, 2001; Mendes *et al.*, 2004). So we design a solution algorithm for the scheduled freight train plan problem based on PSO by drawing lessons from the ideology of literature (Meng *et al.,* 2010; Tu *et al.*, 2011).

Algorithm design

Pretreatment of the paths: The physical network of the railway is quite sparse, so that there are generally only a small number of sensible paths to use. By the pretreatment of the paths, we reduce the number of paths greatly and decrease the calculation work required to solve the model. The size of the set P is limited by allowing through the physical network only paths that are within twice of the length of the shortest path. The concrete operating procedures are as follows:

Step 1: Calculating the length of the shortest path for each station pair of the railway physical network by Dijstra algorithm

Step 2: Choosing the paths the length of which is within twice of the length of the shortest path for station pair as candidate path set

Design of particle swarm algorithm

Coding of the particle and the generation of initial population: We construct a code mode with A+B+C+D+E dimension to represent the feasible structure set of scheduled freight train plan. The position vector of each particle be set as:

$X = \{X_A, X_B, X_C, X_D, X_E\}$, where, X_A, X_B, X_C, X_D

and X_E, respectively represents the value of X_{ijk}, X_{ijk} (u), Y^{gh}_{ijk}, m_{ijk} and q_{ijk}. Integer coding mode is applied for X.

Generate initial population randomly. The population size is set as N_{swarm} and its value is between 20 and 50. For the generation of individual particle, firstly, we generate a random variable rand that belongs to (0, 1), if its value is larger than a fixed value μ (we set it as 0.5), then $X_{ijk} = 1$, otherwise $X_{ijk} = 0$. For $X_{ijk}(u)$ and Y^{gh}_{ijk}, if $X_{ijk} = 1$, then we generate their initial values applying the same method, while if $X_{ijk} = 0$, then their values are all 0. For m_{ijk} and q_{ijk}, their initial values are generated randomly within their value ranges.

Fitness function: Define Eq. 14 as the fitness function of the algorithm, and calculate the fitness value of each particle. If the value is better than current extremum of the individual, then set P_t as current position, and update the individual extremum. Of course, if the best individual extremum value of all the particles is better than current global extremum, then set P_g as current position and update the global extremum.

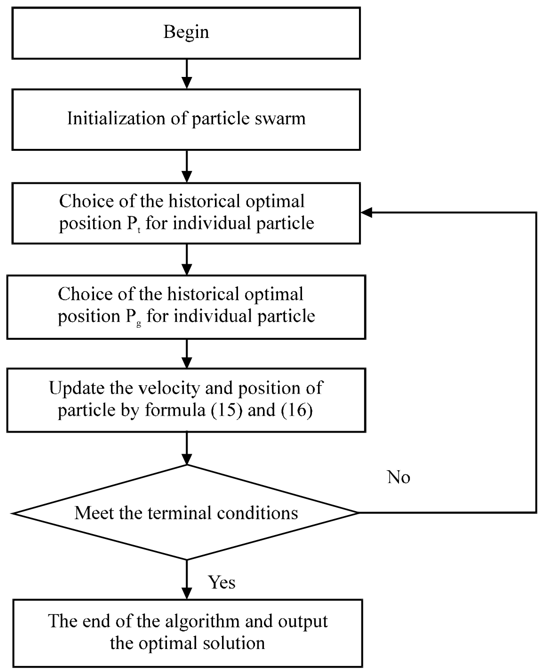

Fig. 1: Flow chart of the algorithm

Update of velocity and position: Update the velocity and position of particle respectively applying Eq. 15 and 16:

$$V_{t+1} = \omega V(t) + \lambda_1 r_1 (P_t - X_t) + \lambda_2 r_2 (P_g - X_t) \tag{15}$$

$$X_{t+1} = X_t + V_{t+1} \tag{16}$$

where, ω is inertial factor and $\omega \in [0, 1]$. λ_1 and λ_2 are both constants, which express the influence degree that the particle population has on individual particle and $\lambda_1 + \lambda_2 = 4$. r_1 and r_2 are random numbers between 0 and 1. P_t represents the optimal position of individual particle, while P_g expresses the optimal position of the particle population.

Terminal conditions: The algorithm has been convergence or achieved specified number of iterations.

The algorithm flow is as Fig. 1, from which we can see that the solving process contains five steps.

Step 1: Initialization of particle swarm

Step 2: Calculate the fitness value according to Eq. 14 and the position of each particle and then record the optimal position of all the particles

Step 3: Update the velocity and position of each particle by Eq. 15 and 16

Step 4: Judge whether the terminal conditions are met. If yes, then turn into step 5, otherwise, turn into step 2

Step 5: Determine the operation plan of scheduled freight trains according to the optimal position of the optimal particle

CASE ANALYSIS

The model and algorithm is verified by intercepting a part network from actual railway network as an example. The specific network structure is shown as Fig. 2. The circles express the railway stations which deal with the services of scheduled freight trains, while the edges express railway section between two stations and the sign beside each edge is the section number and section distance. In Table 1, car flow volumes suitable for scheduled freight train of all station pairs are given. From the table, we can see that there are only car flows of one direction, because of supposing the freight flows of both directions are balanced and we just compute the train plan of one direction, so that the calculation will be simplified. In Table 2, they are parameter values of running time, requirement number of train formation cars and carrying capacity in each section. With regard to the carrying capacity of each section, the capacities taken up by passenger trains and other high grade trains have

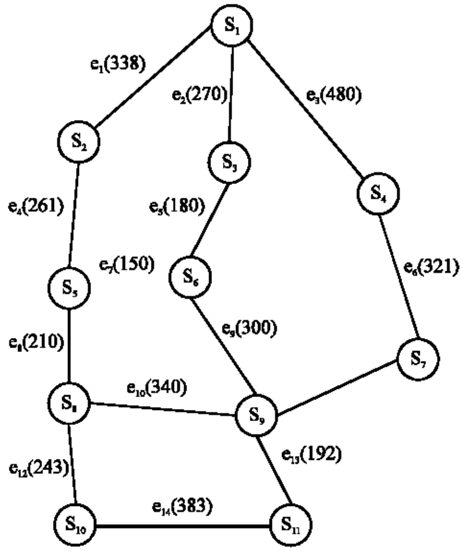

Fig. 2: Structure of railway physical network

Table 1: Car flow volume suitable for scheduled freight train of each station pair

Start station	End station: s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	s_{11}
s_1	0	15	0	18	24	16	15	25	32	15	17
s_2		0	0	0	13	0	0	5	19	6	4
s_3			0	1	10	0	0	9	20	13	15
s_4				0	0	2	7	8	24	10	13
s_5					0	8	21	6	16	11	5
s_6						0	14	10	7	25	16
s_7							0	3	7	12	0
s_8								0	14	10	22
s_9									0	7	6
s_{10}										0	0
s_{11}											0

Table 2: Running time, requirement number of train formation cars and carrying capacity in each section

Serial number	Section	Running time	Number of formation cars	Carrying capacity
1	e_1	4	30/40	10
2	e_2	3	30/40	10
3	e_3	7	30/40	10
4	e_4	4	30/40	10
5	e_5	3	30/40	10
6	e_6	4	30/40	10
7	e_7	2	30/40	10
8	e_8	3	30/40	10
9	e_9	4	30/40	10
10	e_{10}	5	30/40	10
11	e_{11}	4	30/40	10
12	e_{12}	3	30/40	10
13	e_{13}	2	30/40	10
14	e_{14}	6	30/40	10

In the column of number of train formation cars, the values before and after the slash are, respectively minimum number of scheduled freight train formation cars and maximum number of scheduled freight train formation cars

Table 3: Operation time of throw-hang and departure-and-arrival capacity in each station

Serial number	Station	Operation time	Capacity
1	s_1	2	15
2	s_2	3	8
3	s_3	3	8
4	s_4	3	8
5	s_5	2	10
6	s_6	2	10
7	s_7	3	8
8	s_8	2	10
9	s_9	2	15
10	s_{10}	3	8
11	s_{11}	3	8

been deducted. In Table 3, the values of operation time of throw-hang and departure-and-arrival capacity in each station are shown. Being similar to the carrying capacities in Table 2, the arrival and departure capacity of each station is also that of having deducted the capacities taken up by other high grade trains. According to the operation realization of railway, the requirement service frequency of each train is set as 0.5 and the transit period being distributed to each train is given as twice of its running time in the shortest path so as to ensure the elasticity to a certain extent. Furthermore, the parameter values about operation cost are as follows, c_1 = 2350, c_2 = 100, c_3 =1 and c_4 =380.

Above algorithm is applied to solve the case. We set the size of swarm as 50 and the iteration is within 200 generations. Programme to realize the algorithm by Matlab7.1 and test the case in laptop with AMD Turion 64×2 CPU and 4G internal memory. After iterating 126 generations, the optimal objective function value being 6977.4 required. According to the running result, 15 scheduled freight trains are operated, of which 6 trains are through train, while the other 9 trains have throw-hang operation. Among the freight transportation demands being suitable for scheduled train, only two groups of car flows with total three cars do not be transported and the satisfied degree of shippers' transport volume demand is up to 99.5%.

For clarity, Table 4 is adopted to express the operation plan of scheduled freight train, including original departure station, final arrival station, throw-hang station, formation cars of each train, as well as the transfer scheme of car flows. It shows that some cars are transferred in one station, which may increase the transit time, but the transit time range of all the cars being transported can be meeted, moreover, all cars run on the shortest path. Contrarily, if all car flows were transported by through scheduled train, the number of scheduled

Table 4: Operation plan of scheduled freight train

Serial number	Departure station	Arrival station	Throw-hang station	Running path	Formation cars flow	Transfer scheme of car flows
1	s_1	s_5	—	s_1-s_2-s_5	24 cars of s_1-s_5 and 15 cars of s_1-s_{10}	15 cars of s_1-s_{10} transferred in s_5
2	s_1	s_6	—	s_1-s_3-s_6	16 cars of s_1-s_6 and 17 cars of s_1-s_{11}	17 cars of s_1-s_{11} transferred in s_6
3	s_1	s_7	s_4	s_1-s_4-s_7	18 cars of s_1-s_4 and 15 cars s_1-s_7	Throw 18 cars of s_1-s_4 and hang 7 cars of s_4-s_7, 8 cars of s_4-s_8 and 10 cars of s_4-s_{10} in s_4
4	s_1	s_8	s_2	s_1-s_2-s_5-s_8	15 cars of s_1-s_2 and 25 cars of s_1-s_8	Throw 12 cars of s_1-s_2 and hang 5 cars of s_2-s_8, 6 cars of s_2-s_{10} and 4 cars of s_2-s_{11} in s_2
5	s_1	s_9	—	s_1-s_3-s_6-s_8	32 cars of s_1-s_9	—
6	s_2	s_9	s_5	s_2-s_5-s_6-s_9	13 cars of s_2-s_5, 19 cars of s_2-s_9 and 4 cars of s_2-s_{11}	Throw 13 cars of s_2-s_5 and hang 16 cars of s_5-s_9 in s_5
7	s_3	s_5	—	s_3-s_6-s_5	10 cars of s_3-s_5, 9 cars of s_3-s_8 and 13 cars of s_3-s_{10}	9 cars of s_3-s_8 and 13 cars of $_{s3}$-s_{10} transferred in s_5
8	s_3	s_{11}	s_9	s_3-s_6-s_9-s_{11}	20 cars of s_3-s_9 and 15 cars of s_3-s_{11}	Throw 20 cars of s_3-s_9 and hang 6 cars of s_9-s_{11}, 13 cars of s_4-s_{11} and 5 cars of s_5-s_{11} in s_9
9	s_4	s_9	—	s_4-s_7-s_9	24 cars of s_4-s_9 and 13 cars of s_4-s_{11}	13 cars of s_4-s_{11} transferred in s_9
10	s_5	s_7	s_6	s_5-s_6-s_9-s_7	8 cars of s_5-s_6, 21 cars of s_5-s_7 and 5 cars of s_5-s_{11}	Throw 8 cars of s_5-s_6 and 5 cars of s_5-s_{11} and hang 14 cars of s_6-s_7 in s_9
11	s_5	s_{10}	—	s_5-s_8-s_{10}	13 cars of s_3-s_{10}, 15 cars of s_1-s_{10} and 11 cars of s_5-s_{10}	—
12	s_6	s_{10}	s_8	s_6-s_5-s_8-s_{10}	25 cars of s_6-s_{10} and 10 cars of s_6-s_8	Throw 10 cars of s_6-s_8 and hang 10 cars of s_8-s_{10} in s_8
13	s_6	s_{11}	s_9	s_6-s_9-s_{11}	16 cars of s_6-s_{11}, 17 cars of s_1-s11 and 6 cars of s_6-s_9	Throw 6 cars of s_6-s_9 in s_9
14	s_7	s_{10}	s_9, s_8	s_7-s_9-s_8-s_{10}	3 cars of s_7-s_8, 7 cars of s_7-s_9, 12 cars of s_7-s_{10}, 8 cars of s_4-s_8 and 10 cars of s_4-s_{10}	Throw 7 cars of s_7-s_9 and hang 7 cars of s_9-s_{10} in s_9, while throw 3 cars of s_7-s_8, 8 cars of s_4-s_8 and hang 6 cars of s_2-s_{10} in s_8
15	s_8	s_{11}	s_9	s_8-s_9-s_{11}	22 cars of s_8-s_{11} and 14 cars of s_8-s_9	Throw 14 cars of s_8-s_9 and hang 6 cars of s_9-s_{11} and 4 cars of s_2-s_{11} in s_9

trains would be up to 35 which led to great increase of the operation cost, meanwhile, the capacity of a certain sections and stations would not be met. Furthermore, for the number of through cars between some stations, the operation of through scheduled freight train will cause the waste of the capacity.

CONCLUSIONS

To optimize operation plan of scheduled freight train fully considering shippers' demands has important significance on developing railway express freight transportation, as well as enhancing the service quality and market competitiveness of railway freight transportation. This study researched the optimization problem of operation plan for scheduled freight train to ensure shippers' demands. At first, the characteristics of the operation plan for scheduled freight train and the demands of optimization were analyzed. Subsequently, the bi-objective model was established taking minimum operation cost of railway enterprise and maximum satisfied degree of shippers' transport demand volume as objectives and taking service frequency, number of formation cars, transit time range, etc. as constraints. With regard to the two objective functions, one is minimum problem and another is maximum problem, move over, the dimension is different, so that it is difficult to design solving algorithm. Therefore, we transformed the bi-objective problem into a single objective problem firstly and then, we designed the solution algorithm based on particle swarm optimization, which was realized by Matlab7.1. Finally, a case is applied to show the feasibility of the model and the algorithm. The result shows that the model can synthetically reflect the profits of both railway enterprise and shippers and the solution time can meet the demand of railway operation, meanwhile, the algorithm has strong robustness.

However, to simplify the problem, we did not consider the influence of different kinds of cargos and we also assumed there was only one kind of scheduled freight train. In fact, there are many kinds of cargos suitable for transporting by scheduled freight train and there are several classes of scheduled trains. We will study on the optimization problem of operation plan for multi kinds of cargos and multi grades of scheduled trains deeply in future.

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