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Optimization on Placing-in and Taking-out Operation for Railway Special Line Based on Improved Simulated Annealing Algorithm

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Abstract: Placing-in and taking-out operation of railway special line is one of the key links and also is a complicated system engineering that is influenced by multitudinous factors. The intrinsic mechanism of placing-in and taking-out operation for railway radial special line was analyzed according to the characters of railway radial special line. On this basis, the whole process of placing-in and taking-out operation for railway radial special line was divided into the two operations process which include placing-in scheduling and taking-out scheduling, then the optimization model of placing-in and taking-out operation for railway radial special line have been built considering that the time-window of each operation sites, the reliability train on-time and minimize the delay number of jobs is respectively regarded as the decision variable and objective function and optimization sequence of placing-in and taking-out operation was abstained under condition of non-through cars arriving at station. Meanwhile, corresponding optimization algorithm has also been put forward based on Improved Simulated Annealing (ISA) algorithm. Finally, a case study has been carried out in order to testify validity, objectivity and applicability of this model and its algorithm and the computing results of Genetic Algorithm (GA), Simulated Annealing (SA) and ISA is compared and analyzed respectively, it is shown that the results obtained by ISA are better than those obtained by SA and GA applied alone, the best solutions found so far of the ISA have less fitness value than that of the other two. This model and its algorithm can solve placing-in and taking-out operation of railway radial special line very well.

Key words: Optimization algorithm, railway special line, placing-in and taking-out operation, simulated annealing algorithm

INTRODUCTION

Placing-in and taking-out operation of railway special line is a complicated system engineering that is influenced by multitudinous factors such as train schedule diagram, the arrival and departure time, the number of shunting locomotives and so on (Shi *et al*., 2005). Meanwhile, placing-in and taking-out operation of railway special line has been proved to be an NP-hard problem. At present, the railway transportation departments and relevant scholars have paid highly attention to this problem and the relevant scholars have done much research in this area.

The optimization objective was put forward to the minimum detention time or the minimum time of shunting locomotive travelling (Wang, 2006). Influencing factors of train schedule diagram have been not taken into consideration in scheduling of placing-in and taking-out of wagons (Huang, 2007; Yan *et al*., 2008). Model of which objective function is minimum detention have been set up (Mu *et al*., 2009, 2010; Li and Zhu, 2011). Tuba search algorithm has been introduced to solve placing-in and taking-out and main factors were designed (Lei *et al*., 2011; Mu *et al*., 2012).

However, placing-in and taking-out operation of railway special line is a combinatorial optimization problem and is difficult to solve by using linear programming. Meanwhile, optimization objective of these existing studies are to minimize time of shunting locomotive travelling, the train arrived at any station is abstracted as a special class TSP problem, the establishment of these existing models do not consider some important operation time factors of placing-in and taking-out system, such as the time of goods operation, the time of loading and unloading operation, the result of compressing detention time of wagon is greatly restricted. Moreover, these existing studies have paid highly attention to placing-in and taking-out operation of railway branch-shaped special line, few studies is to solve placing-in and taking-out operation of railway radial special line, furthermore, these existing studies have paid highly attention to placing-in and taking-out operation under condition of through wagon flows. Nevertheless, railway radial special line is an important special line and

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placing-in and taking-out operation of railway radial special line is affected by no-through wagon flows.

For this purpose, optimization model of placing-in and taking-out operation for railway radial special line for Non-through wagon flow have been built considering conditions of the time-window of each operation sites and considering that operation of SA algorithm highly depends on parameters, parameters of SA algorithm based on nested partitions is applied to solve the optimization parameters of SA algorithm. Then corresponding optimization algorithm has also been put forward based on the improved Simulated Annealing algorithm (ISA).

NOTATIONS AND PARAMETERS

J:	Set of all operation locations J = {1,2,...,n}
p_i:	The time required of shunting locomotive travelling from the i-th operation location to station
m_i:	Placing-in operation cars in the i-th operation location
q_i:	The operation time of any car in the i-th operation location
t^e_i:	Beginning spare time of operation location
r_d:	The earliest arrival taking-out cars at station
t_s:	The earliest beginning time for operations of shunting locomotive
C_i:	Ending time of placing-in operations in operation location
T_i:	The delivery time of machined job
R:	The set of operation locations for arranged operation cars
R_1:	The set of operation locations for missing operations cars who has been arranged
$\bar{R}$:	The set of operations locations for non-arranged operation cars
$\pi(R)$:	The scheduling of placing-in operations corresponding to R
r_i:	The beginning time
d_i:	The handling over time
fi(j = 1,2,...,l):	The departure time of the j-th freight train on train scheduling diagram
m:	The number of railway special line
n:	The number of operations car of each special line

SETTING CONDITIONS

In order to improve the feasibility, practice of placing-in and taking-out operation was combined according to characters of railway radial special line. Then the four setting was proposed as:

- Suppose that current train schedule diagram can reflect the actual car flow and rational car flow jointing, arrival time of freight trains and transfer trains has been given
- One shunting locomotive undertakes the operations of placing-in and taking-out
- $[d_i, d4'_i]$ represents the time-window of operation locations which means the time interval between the latest placing-in time and the latest taking-out time
- Suppose that the distribution of railway special line is radial special line

ESTABLISHMENT OF OPTIMIZATION MODEL

Optimization schedule model of placing-in cars for non-through cars flow: Suppose that shunting locomotive was regarded as machine and regard placing-in operations for i-th railway radial special line as job J_i and regarded placing-in operations time for railway radial special line as machining time p_i, the beginning placing-in time r_i is to ensure freight trains departure on time. Regard the latest allowing placing-in time as deadline d_i. Operations of operation cars are completed before car unit arrival time as far as possible.

Thus, it can be seen that the objective function is to reach the minimum delay operation cars which are the delay jobs $\sum U_i$ in this model.

Hence, scheduling of placing-in and taking-out is transformed into scheduling problem:

$$1/r_i, d_i/\sum U_i \tag{1}$$

According to the whole process of placing-in and taking-out operation for railway radial special line, C_i is the ending time of placed-in operations in operation location C_i can be denote as:

$$C_i = 2\sum_{s=1}^{r-1} P_{i_r} + P_{i_r} + T_{i_r}, \ (r = 1, 2, \cdots, n) \tag{2}$$

where, $T_i = m_i q_i$ is the delivery time of machined job. Beginning time r_i which is decided by the maximum value among placing-in time, the earliest beginning delivery time of arrival operation cars belonging to local station and spare time and r_i can be denote as:

$$r_i = \max\{t_i^e - p_i, r_d, t_s\} \tag{3}$$

Handling over time d_i means the latest permissible arrival time of operation cars to ensure the freight trains which are made up of these cars leave on time. This time is reckoned according to departure time of corresponding freight trains. f_j is the departure time of the jth freight train.

The minimum time interval between arrival time of car unit i at operation location and departure time of freight train j is existed in practical. During this minimum interval, such as wagon operations, placing-in and taking-out operations, train decentralization, train formation, changing car unit and preparations for departure, must be completed. So Δt_{ij} is denoted as the minimum time interval (the actual numerical value is reckoned by standard operation time).

Based on the above analysis, the permissible latest arrival time of car unit is denote as:

$$d_i = f_i - \Delta t_{ij} \tag{4}$$

Thus it can be seen, if the arrival time of car unit i is later than d_i, then this car unit cannot be one part of the freight train j. And this means freight train j must find out other wagon flow. Or else, j will miss the departure time for lack of wagon flow.

Optimization schedule model of taking-out cars for non-through cars flow: Suppose that shunting locomotive was regarded as machine and regard taking-out operations for i-th railway radial special line as job J_i and regarded taking-out operations time for railway radial special line as machining time p_i, the beginning taking-out time r_i is to ensure freight trains departure on time. Regard the latest allowing placing-in time as deadline d_i. Operations of operation cars are completed before car unit arrival time as far as possible.

The objective is to meet minimum operation cars which cannot be taking-out on time and this means the delay jobs $\sum U_i$ is the minimum in the model.

Hence, scheduling of taking-out operations is transformed into scheduling problem as:

$$1/r_i, d'_i / \sum U_i \tag{5}$$

where, m_i is the operation of taking-out cars in the i-th operation location. q_i is the operation time of any car in the i-th operation location. C'_i is ending time of taking-out operations. r'_i is the beginning time of taking-out operations. Beginning time of taking-out operations is depended on the maximum value between beginning time and ending time.

Thus it can be seen that the ending time of taking-out cars in operation location C'_i can be denote as:

$$C'_i = r'_i + 2p_i \tag{6}$$

r'_i can be denote as:

$$r'_i = \max\{C_i - p_i, t_s\} \tag{7}$$

where, d' is the handling over time. Handling over time means the latest permissible time of car unit taken out at station to ensure the freight trains which are made up of these car unit leave on time. This time is reckoned according to departure time of corresponding freight trains. $f_j = (j = 1,2,...,l)$ is the departure time of the jth freight train on train scheduling diagram.

The minimum time interval between arrival time of car unit i at operation location and departure time of freight train j is existed in practical. During this minimum interval, operations, such as wagon operations, placed-in and taking-out operations, train decentralization, train formation, changing car unit and preparations for departure, must be completed. So Δt_{ij} is denoted as the minimum time interval (the actual numerical value is reckoned by standard operation time). The permissible latest arrival time of car unit is $d_i = f_j - \Delta t_{ij}$.

If the arrival time of car unit i is later than d'_i, then this car unit cannot be one part of the freight train j. And this means freight train j must find out other wagon flow. Or else, j will miss the departure time for lack of wagon flow.

SOLUTION BASED ON IMPROVED SIMULATED ANNEALING ALGORITHM

Design of SA parameters based on nested partitions in sequence: Operation of SA algorithm highly depends on parameters. The convergence constraints consist of enough initial temperature, reasonable decreasing function and reasonable sampling method. Because above factors are hard stratified at the same time, the definition of parameters value is a combination optimization problem (Yang *et al*., 2009).

Suppose the amount of the flowing parameters value, initial temperature, sampling frequency and decreasing temperature rate is P_T, P_L and P_ε, respectively. Then the number of combined parameters is $P_T \times P_L \times P_\varepsilon$. Referencing for parameter design in response surface methodology where random of parameters and combination of parameters don't take into consideration, SA parameters based on nested partitions in sequence is applied in the study to solve the problem.

- **Step 1:** Define solution space Θ and the number of sub-partition is $M(\sigma(k))$, $|\Theta| = S$:

$$M(\sigma(1))\times M(\sigma(2))\times\ldots\times M(\sigma(n))=S$$

Divide the best hope zone $\sigma(k)$ into sub-partitions $\sigma_1(k)$, $\sigma_2(k)$,..., $\sigma_M(k)$ Combine $\Theta\backslash\sigma(k)$ with σ_{M+1}. When $|\sigma(k)| = 1$, when $|M=1$, when $|\sigma(k)| = s$, $|\sigma_{M+1}(k)|$

- **Step 2:** Choose N_0 samples $\theta^{j1}, \theta^{j2},...\theta^{jNj}$ from $\sigma_1(k)$,..., $\sigma_M(k)$, $\sigma_{M+1}(k)$ randomly to make up the sample set $\{\theta_1,...,\theta_i,..., \theta_k\}$
- **Step 3:** Distribute the total calculated quantity T to k solutions in sampling set. And value of performance in ascending sequence after amount of T/k simulation. The first solution is θ_{opt} that the one with the minimum value of performance
- **Step 4:** Choose the minimum performance value in samples as the hope index of partition,

$$\hat{I}(\sigma_j)=\min_{i\in\{1,2,\ldots,N_j\}} L(\theta^{ij})$$

$$\hat{j}\in \arg\min_{i\in\{1,2,\ldots,k\}} L(\theta_i)$$

If θ_{opt} is in the best hope sub-partition. Then this sub-partition is regarded as the best hope partition in the next iteration phase. Or else, it turns back to calculate again and chooses Θ as the best hope partition in the next iteration phase:

$$\sigma(k+1)=\begin{cases}\sigma_{\hat{i}_k}(k) & \hat{i}_k < M+1\\ \Theta & \text{otherwise}\end{cases}$$

- **Step 5:** If constraints are met, then output the optimal solution and performance value. Or else, it turns to step 2

Improved simulated annealing algorithm: The solution is $P = \{P_1, P_2, P_3,..., P_n\}$. P_i denotes the corresponding train number which is assigned with train number i at first. Initial solution is $P = \{P_i|P_i = i, i = 1,2....n\}$ which means train sets are assigned with their original train number. Decreasing temperature function is $T_{k+1} = T_K\times\lambda$. For any given solution, new solution can be generated by exchanging two different train numbers. If the new solution satisfies constraints, it can be feasible. Repeat above steps and new neighborhood consisting of several solutions can be reached (Yan *et al*., 2010):

- **Step 1:** Data processing. Origin trains are labeled in sequence from zero. One label consists of arrival and departure train number and related time. Convert arrival time and departure time into minutes which means convert 0~24 h into 0~1440 min. And save them in two files
- **Step 2:** Set control parameter T_0, λ finial temperature T_f, the number of iterations in current temperature u and successful iteration frequency is l.
- **Step 3:** Read arrival and departure time from files. Set up initial solution S_0, $T_i = T0$, $u = 1$
- **Step 4:** Exchange P_i, P_j to generate new solutions S_i define $u = u+1$
- **Step 5:** If $f_j\geq f_i$, then it turns to step6, or else, $f_j = f_i$ Record the current optimal solution, $l = l+1$ .It turns to step 6
- **Step 6:** $\Delta f_{ij} = f_j - f_i$, if $\exp(-\Delta f_{ij}/T_i) > \varepsilon$, ε is, the random number in (0,1), $f_i = f_j$, $l = l+1$, or else, it turns to step 7
- **Step 7:** If $u\geq U$ or $l\geq L$, $T_{K+1} = T_k\lambda$, $u = 0$, $l = 0$, it turns to step 8, or else, it turns to step 4
- **Step 8:** If $T_{i+1}\leq T_f$, then end the calculation. Or else, it turns to step 4

EMPIRICAL ANALYSES

To verify the precision of the model in the previous sections, Lanzhou freight station is chosen to verify the effectiveness of model and algorithm, there are 4 radial special lines in any railway station (which is labeled line 1, line 2, line 3 and line 4). Chart of railway radial special line in this station are shown as Fig. 1.

There is only one shunting locomotive taking on placing-in operation and taking-out operation. For any time, the number of placing-in and taking-out cars and loading time of every car have been given, The latest placing-in time and the latest taking-out time in every operation location has also been given. The related parameters of Lanzhou freight station are shown as Table 1.

The objective is to reach the minimum unfinished placing-in and taking-out operation car by

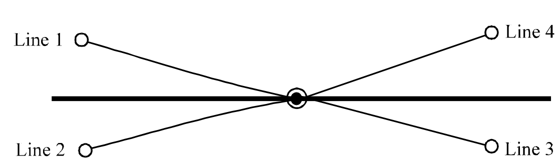

Fig. 1: Chart of railway radial special line

Table 1: Related parameters of Lanzhou freight station

Operation location	Single way of placing-in and taking-out time p_i (min)	Amount of operation cars m_i	Loading time of operation car q_i (min)	Time-window $[d_i, d'_i]$ (min)
1	10	6	10	[50,125]
2	15	6	15	[70,160]
3	20	12	10	[25,180]
4	5	10	13	[85,210]

finding the most reasonable scheduling of placing-in and taking-out operations.

The results can be obtained according to algorithms and models:

- Definition of scheduling of placing-in operations

Initial scheduling is given following the sequence:

$$d_{i1} \le d_{i2} \le \cdots \le d_{in}$$

The finial scheduling result of placing-in for Lanzhou freight station is 3-1-4-2. The delay number of jobs is 1.

- Definition of scheduling of taking-out operations

Initial scheduling 1-3-2-4 is given following the sequence:

$$r'_{i1} \le r'_{i2} \le \cdots \le r'_{in}$$

The finial scheduling result of taking-out for Lanzhou freight station is1-3-4-2 .

The optimization result shows that the schedule of taking-out and placing-in is consistent with the literature (Mu *et al.*, 2012) which is using saving algorithm.

Compared with the traditional method of the schedule of taking-out and placing-in, there are four characteristics of this model and algorithm in this study:

- The definition of parameters value for SA algorithm is a combination optimization problem, SA parameters based on nested partitions in sequence is applied in the study to solve the problem
- Modeling is not limited to a fixed delivery operation mode of taking-out and placing-in
- The shift operations are consider take into the processing range of model for taking-out and placing-in of radial special lines
- Processing range of this model above mentioned is not limited to mode of fixed cars flow

Therefore, this model and its optimization algorithm above mentioned is more close to the actual and has wide range of application.

Due to the schedule of taking-out and placing-in is the NP-hard problem itself, when the operating point is increasing and the number of schemes are increasing steeply, the search for exact solutions will be very difficult. While improved simulated annealing above mentioned is employed to solve this problem. This method can achieve the schedule of taking-out and placing-in with high quality according to the specific situation and make a reasonable decision. It also has the certain reference value to other types of special line.

COMPUTATIONAL RESULTS AND DISCUSSION

In order to further illustrate the forward-looking and scientific of this model and its optimization algorithm above mentioned. Genetic algorithm simulated annealing and ISA is employed to solve this problem respectively and the computing results of genetic algorithm (GA), simulated annealing (SA) and ISA is compared and analyzed.

The performances of the GA, SA and ISA are tested with the same parameters and stop criteria, which the best solution found so far stays fixed at some consecutive generations.

For the three optimization algorithm, the population size is set to be 50, pc to be 0.8, pm to be 0.02 and ç to be 0.9. Each instance is randomly run 19 times for each algorithm.

The evolutionary curve of GA, SA and ISA were shown respectively in Fig. 2-4.

Thus it can be seen from Fig.2-4 that the results obtained by ISA are better than those obtained by SA

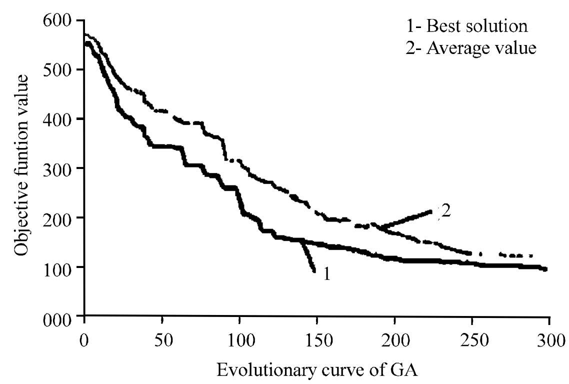

Fig. 2: Evolutionary curve of GA

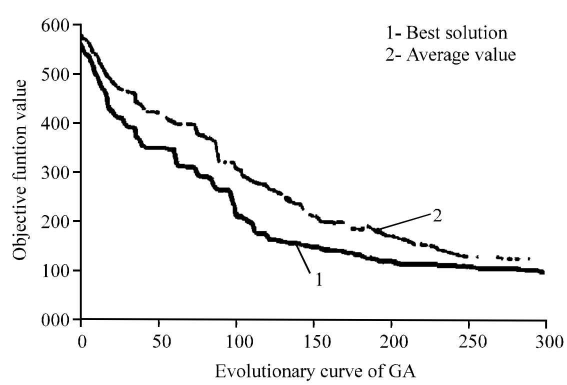

Fig. 3: Evolutionary curve of SA

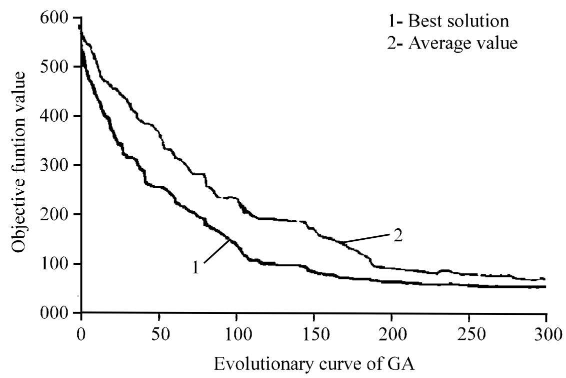

Fig. 4: Evolutionary curve of ISA

and GA applied alone. The best solutions found so far of the ISA have less fitness value than that of the other two.

It is difficult for simple GA to maintain a high diversity over time. As a result of the roulette wheel process some best solutions duplicate themselves increasingly the new generation and low-fitness solutions gradual drop out.

CONCLUSION

The improvement of algorithm and model proposed in the study, comparing with the tradition method, is reflecting the practical situation more precisely by using scheduling theory and to find operation locations where generate delay job (the scheduling is not the initial) for optimizing organization operations. However, there is only one shunting locomotive taking on placing-in and taking-out operations in the settings and the circumstance is certain. So studying on operations with more shunting locomotives or study operations in uncertain condition can be the emphasis in the next phase. Meanwhile, for the prevalent drawback of local minimum in potential field based navigation algorithm, certain heuristic techniques are required to be appended in some unfavorable cases. The mending methods will be presented in the future work.

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