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Study on Railway Marshalling Scheduling Model and Algorithm of Enterprise Station

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ABSTRACT

Railway marshalling transportation is a crucial part of enterprise production supply chain, with the development of national economy; enterprises face more and more pressure on station railway marshalling operation. Realizing enterprise railway dispatching plan automatically by computer, which can improve the level of the station scheduling and transport efficiency, at the same time can reduce the scheduling cost. Based on the basic rules of marshalling and dispatching of railway freight trains at enterprise stations, this paper investigates the site of special railway line at enterprise stations and establishes the space of dispatching state and regulation base according to the actual situation. The information feedback model is designed according to the train information, carriage information and real-time information of the track of the station. Based on the analysis of the railway regulation and the demand of the station, establish the scheduling rule method library. Based on the state space and feedback model of the station, using the scheduling rule method library, this paper designs an enterprise railway automatic marshalling algorithm with a certain universality, and realizes automatic train marshalling and scheduling operation. Considering the economic benefit of the station and the efficiency of the marshalling model, this paper introduces the time cost function and applies the improved greedy algorithm to optimize the automatic marshalling model, realizing the optimal marshalling of railway station in a short time.

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1. Introduction

Railway marshalling transportation is responsible for the incoming of raw materials, the transportation of semi-finished product and the delivery of finished products, and a lot of other works. Therefore, railway marshalling and dispatching is an important infrastructure to ensure the normal operation of enterprises. Because the station railway is generally small in scale and the cost of using the existing railway intelligent dispatching system is high, most railway enterprises in China still rely on the dispatcher to manually compile the marshalling scheduling plan, which causes a huge gap with the advanced national intelligent railway network. But with the development of national economy, enterprise station railway faces more and more pressure. As the railway freight volume of station increases, the need for marshalling and scheduling becomes more and more frequent. As the same time, job types of scheduling techniques are increasing and require greater flexibility. For enterprises, the operation of station railway marshalling not only needs to meet the planned production and transportation demand, but also needs to consider reducing the cost of the dispatching process, such as labor cost and energy consumption cost, which is great significance for reducing the transportation cost of enterprises and promoting environmental protection and energy conservation. Under the constraints of enterprise station railway scale and production cost, the existing intelligent railway dispatching system can hardly be applied directly to enterprise railway. Train scheduling and marshalling problem is a typical n-p problem. The conventional design idea is solved by mathematical modeling and genetic algorithm. In the field of mathematical modeling, Li[1] proposed a train control system based on global information feedback model for train scheduling. Krasemann[2] and He[3] respectively apply the greedy algorithm to reduce interference and avoid train interference, so as to realize rapid rescheduling of trains. By introducing genetic algorithm, Rui[4] solved the fuzzy scheduling problem in railway management system.

This paper designs a kind of general marshalling scheduling algorithm for enterprise station railway and realizes the automatic compilation of enterprise railway scheduling plan by computer. This algorithm cannot only shorten the time of planning, improve the quality of the planning, reduce the burden of staff, but also to improve the level of the station scheduling in practical transport production and the efficiency of enterprise railway transportation has very important significance.

1.1 Background Knowledge

Station railway: also known as station yard, it refers to all railway tracks, including arrival and departure yard, parking yard, throat area, overhaul area, pulling out line, loading and unloading walking line and so on.[5]

Disassembly: decompose the trains according to the different demand of carriage distribution.

Distribution: according to the related requirements of the station planning sheet, in combination with the train arrival at the station, select the corresponding train group to carry out the disassembly operation, and arrange enough carriages for the marshalling departure in time.

Marshalling: according to the planned requirements reorganize the trains.

Stage plan: according to the station equipment capacity, production status and the state of the railway approved vehicles, pre-prepared the station equipment application program within a certain period.

1.2 The Research Target

Disassembly, distribution and marshalling are the core processes of station train marshalling and scheduling. The common goal of the three processes is to organize a new train as soon as possible and prepare for departure at the minimum cost on the premise of meeting the planning requirements [6]. Because the train scheduling process involves a large number of variables and multiple rules, the rules should be transformed into constraints when modeling, so the train marshalling scheduling problem is essentially a large-scale combinatorial optimization problem. This paper mainly studies the following problems:

Design the automatic train marshalling scheduling model. According to the real-time status of the station, the computer can automatically compile the scheduling scheme, and the feasible marshalling meeting the planning requirements is obtained.

The marshalling scheduling model is universal and flexible, which can be applied to different railway stations of different enterprises and can be used to deal with emergency priorities.

Considering the economic benefit and cost of the enterprise station, the automatic marshalling model is optimized so that the obtained scheduling scheme has the shortest marshalling time and the minimum starting cost.

In the design of marshalling scheduling model, the scale of data processing needs to be taken into account to avoid data explosion, reduce the amount of data processing and improve the solution speed under the premise of ensuring the optimal solution.

2. Mathematical Models

2.1 Train State Model

When the stage plan starts, there are n carriages in the sta-

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tion, and the status of the train in the station is shown in list A, A=[S(1), S(2)… S(n)]. S(i) represents the full state of a single carriage, S(i)=[S_w, S_c, S_p, S_t, S_l, S_n, S_o, S_a].

S_w, S_c, S_p and S_a represent the carriage wagon number, carriage category, carriage commodity and carriage attribution respectively. Each carriage has a fixed wagon number and place of attribution, and can only carry a specific commodity. In the same way each commodity must be carried by a specific category of carriage. S_t and S_l indicate the train's position and state, S_t indicates the parking track of the carriage, and S_l indicates the positioning of the carriage on the corresponding track. S_n refers to the effective state of the train, and S_n=1, 0 is set to indicate whether there is any follow-up plan for the carriage. S_o represents the train's working state, S_o=1, 2, 3 respectively represent the three working states of railway carriages in the station during the stage planning period. When S_o=1, the carriage is in the existing state, which means that the carriage has completed all the foreordination tasks and is placed on the respective track, which can be directly invoked. When S_o=2, the carriage is in the waiting loading and unloading state, which means that the carriage has arrived at the station, and the train information has been entered through the loading and unloading inspection, waiting for the unloading operation after the disassembly. When S_o=3, the carriage is in running state, which means that the carriage is about to arrive at the station according to the railway operation diagram and has been registered on the dispatch schedule.

2.2 Orbital State Model

When the stage plan starts, there are m orbits in the station, and the status of the orbit in the station is shown in list B, B = [P(1), P(2)... P(m)]. P(i) represents the full state of a single orbit, P(i) = [P_t, P_w, P_f].

P_t represents the orbit name, P_w represents the carriage capacity of the track, number each track from 1 to P_w, and the carriage can stop at the corresponding sign. F is the orbit function set of the station. P_f={1,2,3,4,5} represents the five types of functions of the station's track: arrival and traction marshalling line, preparatory emergency task line, parking traction line, loading line and unloading line.

2.3 The Introduction of Time Cost

2.3.1 Time Cost of Scheduling Operations[7]

Suppose the marshalling waiting time of the carriage is T_w and the stage planning cycle is T_D. The marshalling waiting time of the carriage under different working conditions is as follows:

Existing trains:

$$\mathrm{T}_W = t_{jt} + t_{bz} + \triangle t \quad (1)$$

Arrival waiting for loading/unloading trains:

$$\mathrm{T}_W = t_{jt} + t_{zx} + t_{bz} + \triangle t \quad (2)$$

Running trains:

$$\mathrm{T}_W = T_{dd} + t_{jt} + t_{zx} + t_{bz} + \triangle t \quad (3)$$

t_{jt} refers to the time when the carriage hangs and disconnects from the original track, t_{bz} refers to the time when the carriage is marshaled in a dispatch operation, △ t refers to the waiting time caused by equipment or human factors. t_{zx} refers to the loading and unloading operation time. T_{dd} is the estimated arrival time of the scheduled train.

2.3.2 Orbital Time Cost

The list L represents the connectivity relationship between the different orbits, L= [T(1), T(2)…T(n)], T(i)= [T_l, T_r, T_w], T_l and T_r are two connected orbits, and T_w is the time cost of moving trains between T_l and T_r. To sum up, the time cost of completing all the scheduling shall not exceed the phase scheduling cycle, the scheduling must be completed within the specified time with constraints:

$$T_D \geq \sum T_W \quad (4)$$

The goal of optimal marshalling scheduling is to satisfy the phase plan while achieving the minimum time cost.

$$\left(\sum \mathrm{T}_w\right)_{\min} \quad (5)$$

3. The Scheduling Rule Method Library

Due to the considerations of production products, geographical location and other factors, the enterprise station railways often have great uniqueness under the principle of abiding by the national railway scheduling rules, while the factors of marshalling and scheduling among different stations are also very different. The system universality can be greatly improved by establishing a database of scheduling rules, encapsulating each general scheduling rule independently and making calls based on different station situations [8]. By using scheduling rules, the generation of invalid scheduling schemes can be avoided and the amount of data processing can be reduced.

3.1 General Constraint

3.1.1 Security Constraint

There is only one locomotive activity in the station at any

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time. Only one scheduling job can be performed at the same time, which avoids the interference between scheduling operations and ensures the safety of station scheduling.

3.1.2 Anti-pollution Constraint

In order to ensure the safety of commodities and avoid pollution, a carriage only transports one commodity.

3.2 The Selection Rule of the Carriage

The purpose of the rule is to select the appropriate carriage from all carriages of the station by screening the commodity name Rc and quantity of the carriage Rn. Initialize the station status space, get all the train list A, A=[S (1), S (2)… S (n)], according to this algorithm the whole suitable carriage list A_0 can be obtained. The algorithm pseudocode is as follows.

Table 1. Algorithm pseudocode of selecting the fitting-carriage

```
Algorithm 1:Select the fitting-carriage
Input: A=[S(1), S(2)… S(n)], S(i)=[Sw, Sc, Sp, St, Sl, Sn, So, Sa], Rc, Rn
Output: the fitting-carriage list A0
A1←[], A2←[], A0←[]
for S(i) in A do
    if S(i). Sc=Pc then
        A1.append(S(i))
    end
end
if length(A1)≥Rn then
    for S(j) in A1 do
        if S(j). Sn=0 then
            A2.append(S(j))
        end
    end
    if length(A2)≥Rn then
        A0←A2
    else
        A0←A1
    end
    Output A0
else
    Output 'The stage plan cannot be completed'
end
```

3.3 The Read Rule of Emergency Priority Plan

Set the priority symbol R_p, R_p =0, 1, for each plan on the stage plan list, if there is an emergency priority plan, R_p=1, it is preferred to carry out the plan scheduling. The preparatory emergency task line is used as the target marshalling track, which is not subject to the lower limit of the marshalling starting load.

3.4 The Parking Rule of the Disintegrating Train

In the process of disassembly, it is often necessary to make temporary movement of the unqualified carriages. According to the functional definition of the track, only the arrival traction marshalling line and parking traction line can be temporarily scheduled and parked. The purpose of the rule is to obtain all temporary orbits that satisfy the functional type and are currently empty and put them in the list B*. Initialize the station status space, get the entire train list A, A=[S(1), S(2)… S(n)], get the entire orbit list B, B=[P(1), P(2)... P(m)]. The algorithm pseudocode is as follows.

Table 2. Algorithm pseudocode of selecting fit temporary orbit

```
Algorithm 2:Select fit temporary orbit
Input: A=[S(1), S(2)… S(n)], B = [P(1), P(2)... P(m)]
Output: the fit temporary orbit list B*
B1←[], B2←[],B3←[]
for S(i) in A do
    B1.append(S(i). St)
end
B2←CB(B1)
for S(j) in B do
    if Pf= 1|| Pf=3 then
        B3.append(S(j))
    end
end
B*← B2∩B3
Output B*
```

3.5 Load Constraint of Locomotive[6]

$$L_f^{\min} \le L(j) \le L_f^{\max}, \forall j \in D \tag{6}$$

$$W_f^{\min} \le W(j) \le W_f^{\max}, \forall j \in D \tag{7}$$

While considering the marshalling time, the economics of scheduling operations should be constrained. In the formula, D denotes the train sets that need to be moved, L is the number of locomotive traction carriages. Formula (6) is the limitation of the number of carriages towed by locomotives. The main objective of the constraint is to prevent the enterprise from excessively pursuing the shortest scheduling time while ignoring the economic benefits. This constraint is mainly used to limit the number of carriages of trains that have been marshalled and are waiting to leave. The number of carriage per departure at the enterprise station shall reach a certain lower limit, but not exceed the carrying capacity of the locomotive at the same time.

Formula (7) is the limitation of the total weight of the locomotive towed carriage, W is the tractable load of locomotive. This constraint limits the economic benefit and time cost of locomotive departure from the perspective of load. The total weight of the waiting train shall not exceed the traction capacity of the locomotive, but it must meet the lower limit of departure.

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4. Greedy Algorithn Design

Greedy algorithm means that when solving problems, it always makes the best choice in the current situation. The core of the station railway marshalling and dispatching is to find the marshalling scheme with minimum time cost and optimal economic benefits based on the completion of the plan. At the same time, when the number of stations and the number of trains reaches a certain scale, the number of possible scheduling and marshalling schemes will explode, and the introduction of greedy strategy can effectively avoid this situation. In this paper, greedy algorithm is introduced in the selection of carriage, composition of carriage group and the selection of track involved in scheduling. Taking advantage of the greedy algorithm, the optimal solution can be obtained by generating fewer schemes in less time.

4.1 The Application of Greedy Algorithm

4.1.1 The Choice of the Best Carriages

According to the analysis of the waiting time T_w formula of different working states of the carriages, it can be known that the waiting time of the three working states is gradually increased in the existing state, waiting for loading and unloading state and running state, and the shortest waiting time is the carriage in the existing state. According to the screening by scheduling rules, all adaptive carriage list A_0 has been obtained. Greedy algorithm is used to get the optimal carriage list A* the algorithm pseudocode for finding the optimal carriage is as follows.

Table 3. Algorithm pseudocode of selecting the best carriages

```
Algorithm 3:Select the best carriages
Input: A0=[S(1), S(2)… S(m)], S(i)=[Sw, Sc, Sp, St, Sl, Sn, So, Sa], Rn
Output: the best-carriage list A*
A*←[]
for S(i) in A0 do
    if S(i). So=1 then
        A*.append(S(i))
    end
end
if length(A*)<Rn then
    for S(j) in A0 do
        if S(j). So=2 then
            A*.append(S(j))
        end
    end
    if length(A*) <Rn then
        A*←A0
    end
    Output A*
else
    Output A*
end
```

4.1.2 The Choice of the Best Dispatch Orbit

According to the parking rule of the disintegrating train, select the optimal dispatch channel with the minimum moving cost. However, if there are multiple train disassembly operations in a plan, different orbits may interfere with each other, so this greedy strategy is used for the plan of single disassembly only. The algorithm flow is as follows.

Step 1: Initialize the station status space, get the list L of connected relationships of all tracks in the station, and get the carriage's orbit T_0 which need to move, then according to the parking rule of the disintegrating train get the temporary track list B*.

Step 2: Traverse all orbit in list L. If $T_l = T_0$, or $T_r = T_0$, put all the orbits that are connected to T_0 in list L_1.

Step 3: $L^* = L_1 \cap B^*$. According to the track design rules of the station, there is no unconnected part in the track of the station, so $L^* \neq$ null.

Step 4: Iterate through the list L* to find the femoral T_{best} with the minimum T_w moving time cost.

4.1.3 The Choice of the Best Carriage Groups

According to the daily safety regulations of railway stations, carriages parked on each track are connected in a row. In the selection of multiple marshalling carriages, if some adaptive carriages were joined together in a row, the time cost of disassembly, Distribution, and marshalling on these carriages would be greatly reduced. Therefore, when the optimal carriages in list A*connected to form into a group, if the group containing the number of carriages greater than or equal to the planned number R_n of carriages, we will get the optimal cost of marshalling time; because at this point the train needs to carry out the least number of disassembly operations. At the same time, if the first carriage of the group is at the beginning of the track 1 position, the time cost of scheduling will be further reduced. Since there is more than one carriage group that meets the conditions of greedy strategy, all suitable carriage groups are placed in the list G*. The algorithm for finding the best carriage group is as follows.

Step 1: Initialize the station status space, get the best-carriage list A*, and read the stage plan to get the required the required number of carriages R_n.

Step 2: Locating all carriages in A* and get the connected carriage group list G, G= [g_1, g_2…g_n], g_i=[S(1), S(2)… S(q)].

Step 3: Traverse all carriage groups in list G. If group g_i contains carriages more than or equal to R_n, the corresponding group g_i would be stored in the group list G_1, until the traversal is complete to get the full group list G_1.

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Step 4: If G_1≠null, all groups in list G_1 are traversed. If group g_i contains carriages whose S_l=1, the corresponding group g_i is stored in the best-group list G*, until the traversal is complete to get the full best-group list G*.

Step 5. If group g_i doesn't contain carriages whose $S_{l=}1$, according to choice of the best dispatch orbit, make temporary movement of the unqualified carriages, G*= G_1, and record the time cost T_w.

4.2 Marshalling Algorithm Design

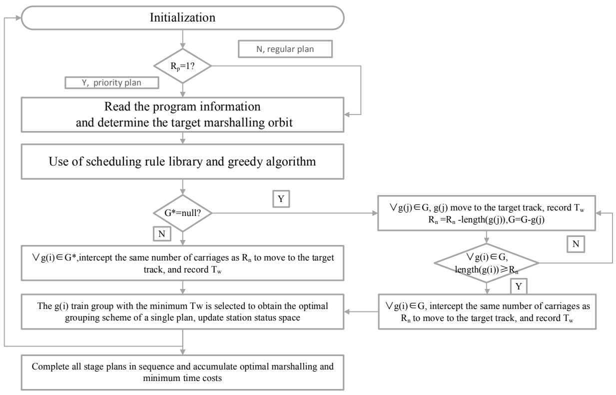

Figure 1. Flowchart of marshalling algorithm

Step 1: Initialization. Initialize the station state space, the orbital list and the phase scheduling plan sheet.

Step 2: Emergency priority planning judgment. Use the traversal scheduling plan sheet. If there is an emergency priority plan in the phase plan table, R_p=1, the emergency plan is prioritized firstly. If not, the regular plan should be marshalled in sequence.

Step 3: Read the program information and determine the target marshalling orbit. In the orbital list B, if there is a regular plan, arbitrarily select the orbit P(i) of P_f=1 as the target marshalling orbital T*. As for emergency priority plans, choose the orbit whose P_f=2 as the target marshalling orbital T*.And read the stage plan to get the required commodity name R_c and the required number of carriages R_n.

Step 4: Use of scheduling rule library and greedy algorithm. According to the choice of the best carriages, get the fitting-carriage list A_0. According to the choice of the best carriages, get the full best-carriage list A*. According to the choice of the best carriage groups, get the best carriage group list G* and the connected carriage group list G.

Step 5: When the list G* is not empty, as for each group g(i) in G*, respectively intercept the same number of carriages as R_n to move to the target track, and record the time cost T_w. The carriage group g(i) with the minimum Tw is selected to obtain the optimal grouping scheme of a single plan, then update station status space.

Step 6: If the list G* is empty, sort the carriage group in list G from large to small, then, each group g(j) in G respectively move to the target track and record the time cost T_w, R_n =R_n -length(g(j)), G=G-g(j). Update the station status space and determine whether the remaining carriage groups can directly meet the planned number. If there is g(i) in G, length(g(i))≥R_n, intercept the same number of carriages as R_n to move to the target track, and record the time cost T_w. These groups have the lowest cumulative time cost are selected to obtain the optimal grouping scheme of a single plan, then update station status space.

Step 7: Sequential read plan, repeat steps 1-6, until all the plan is completed, and record all marshalling time to calculate the least time-consuming marshalling scheme.

4.3 Algorithm Analysis

The algorithm is universal and flexible. In terms of the program design, the track state, the station train state, the track connectivity relationship and the stage schedule can be directly modified, which greatly improves the universality of the model. The emergency plan has been set with a sign, which can be quickly recognized and scheduled.

The concern of this algorithm lies in step 5, 6. For the general enterprise station, the parking of the train carriages should be as neat as possible. For example, after unloading, the carriages will be parked separately according to the name of the product or the place where the carriages belong. And the station should be maintained with enough carriages for daily production and transportation and emergency response. The more standard of the station, the more efficient of the greedy algorithm; If the carriages carrying the same cargo are parked together in an orderly way after loading and unloading, the number of carriages in the list G* can always meet the planned number, and the efficiency of this algorithm will be greatly improved.

5. Experiment and Performance Analysis

This paper takes the railway station of Baling petrochemical supply and Marketing Department of Yueyang city, Hunan province, China as the experimental environment, and conducted the experiment on the stage plan and the state of the field. There are 27 tracks and 41 sets of side connections in the station, and have 67 carriages, 7 stage plans, and 1 available locomotive in the experimental environment. The experimental results of automatic marshalling algorithm based on greedy strategy and scheduling rule base are as follows.

Plan 5 is a priority plan, so it is executed first by the algorithm. It can be seen from the experimental results, there is no big difference between the two methods when

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Table 4. Comparison of experimental results

	Scheduling rule library			Scheduling rule library+ Greedy algorithm			Data processing volume decrease percentage	Percentage decrease in data processing time
	Scheme quantity	Optimal time cost (min)	Solve time (s)	Scheme quantity	Optimal time cost (min)	Solve time (s)		
Plan5	2	40	3.77	2	40	2.31	0%	38.72%
Plan1	1	35	2.66	1	35	2.67	0%	0%
Plan2	9	80	6.91	1	80	2.09	88.89%	69.95%
Plan3	2	45	2.67	2	45	2.64	0%	1.12%
Plan4	22	40	11.87	2	40	6.65	90.91%	43.97%
Plan6	137	80	43.50	48	80	34.58	64.96%	20.45%
Plan7	110	40	50.01	44	40	27.60	60%	44.81%
Total	340	360	122.64	128	360min	64.28	62.35%	47.59%

the carriages are parked neatly and in sufficient quantity on the spot, such as the marshalling of plan 1 and plan 3. When non-marshalling carriages movement is required, greedy algorithm can quickly select temporary track to realize marshalling, such as plan 2 and plan 4. The scheduling algorithm introduced by greedy strategy is better than using only the scheduling rule library. When the number of available carriages is large, but the parking locations are scattered, which cannot meet the planning needs at one time, the running time of automatic marshalling algorithm and the number of schemes generated will increase with the increase of the number of scheduling. At this time in order to avoid the problem of local optimization caused by greedy algorithm, greedy strategy is only used in the choice of temporary dispatch channel, but not in the choice of optimal carriages. At this point, the algorithm still effectively improves the performance, as shown in the experimental results of plan 6 and 7. When the entire schedule is marshaled, there will be interference between different plans, and the algorithm's operation time and data processing amount will increase, but the algorithm still achieves the expected performance. The experimental results show that the designed automatic marshalling strategy can realize the automatic compilation of scheduling plan in a very short time, and get approximate optimal marshalling scheme and the minimum time cost.

6. Conclusion

In this article, through the analysis of enterprise station marshalling scheduling process, determine the scheduling process real-time information, the automatic compilation algorithm of station railway marshalling and dispatching is established. This model is well balanced fast marshalling and optimal time cost contradictions. In this paper, the time cost is used as the index to measure the marshalling scheme. In addition to solving the optimal scheduling scheme, the greedy algorithm reduces the complexity of the algorithm and improves the solving speed. And the economic benefits of the enterprise are guaranteed by multiple constraints of the scheduling rule base. The feasibility and reliability of the model have been verified by practical simulation. The algorithm proposed in this paper is progressive significance to realize automatic scheduling and intelligent marshalling of enterprise stations.

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