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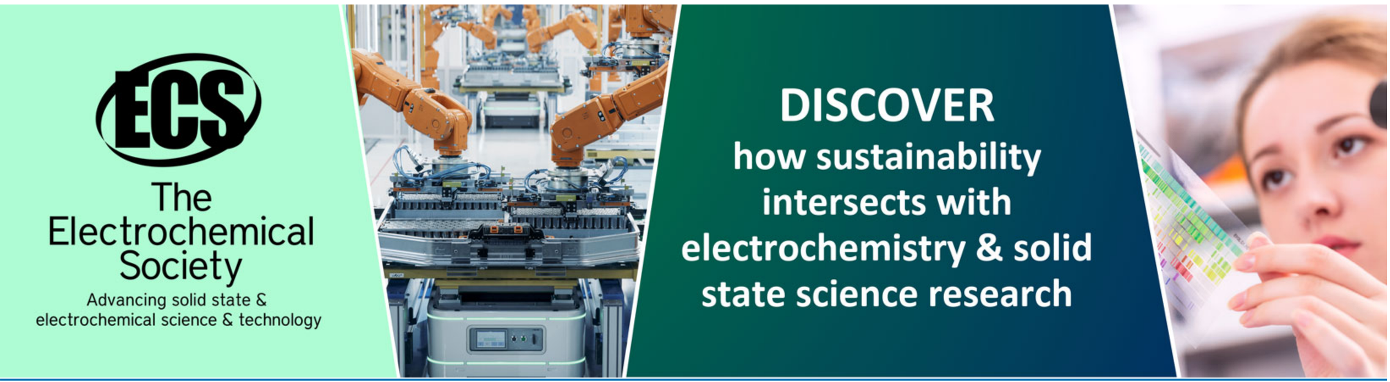

Adjustment method for train disintegration and classification sequence in marshalling station

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Abstract. Adjustment of train disintegrating and classifying schemes in the marshalling station is the key of wagon-flow allocating optimization. The train disintegration and classification sequence is subjected to the priority of time departure. Under above-mentioned arrangement, the priority of time departure scheme is difficult to ensure the full-load of each departure train. On the basis of analyzing for interval time of departure train, waiting departure time and the relation among each time parameter, several concepts will be given. Using the method of single machine scheduling problem is to minimize the influence for classification and disintegration sequence adjustment. The necessary conditions of adjustment can be obtained and the influence after adjustment is shown by graphic deduction. Finally, the conception of time pass theory is provided. The rationality of this method has been proved by a case study. This method lays a foundation for adjustment of train classification and disintegration sequences.

1.Introduction

The initial disintegration and classification scheme is the foundation of operation scheme, also is precondition for car flow assignment in marshalling station. Foreign scholars' researches on disintegration and classification are as follows: D R Martinelli[1]put forwarded an optimization on railway traffic control operation plan; M A Turnquist[2]set up a machine scheduling model which acquired new scheme by analysis the time parameters; Z Z Avaramovic[3]through analysis the connection of car flow follow get scheme. Domestic scholars' researched are as follows: Li Haodong[4] focused on survey of stage plan for railway marshalling station. Wang Shidong[5] made a mathematical model and algorithm for automatically programming. Xue fen[9-11]'s researches were on stage plan, such kind method established mathematical model and solved this kind of problem by hybrid algorithm.

The concepts of compact continuing classification and the greatest adjustment between adjoin trains were put forwarded by Xue fen, however the influence for whole scheme after an adjustment not be taken into account [12]. Peng Qiyuan combined classification with disintegration process, and focused on after-effect, however not given systematic adjustment approach and condition [13].

According to concepts of compact continuing classification and the greatest adjustment between adjoin trains[12], the marshalling station can be divided into two sub-systems. The operation in each subsystem can be regarded as machine scheduling. Under the condition of one shunting locomotive for disintegration and one for classification, the trains which are not full-load can use partial adjustment method to meet the requirements of railway station. The key part of this thesis is the analysis on the how to guarantee full-load as far as possible and punctuality of departure time of each train.

2. Analysis of Operation Systems

Marshalling station is a technical station which includes different types of work. The operation procedure has the same characteristics with machine scheduling. On the basis of analyzing machine scheduling problem, the marshalling station can be divided into two subsystems, one is arrival disintegration subsystem and the other is classification departure subsystem, each subsystem includes three assembly lines. The assembly lines for how to work under horizontal and vertical model can be shown as Fig.1 .

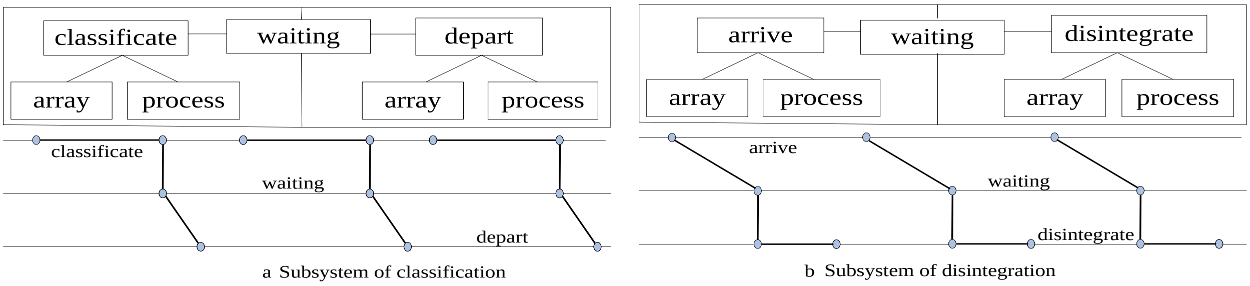

Figure 1. Flow operation of subsystem.

3. Classification Sequence Adjustment

3.1. Parameters Concept

m_0 , n_0 , B_n , J_m —The number of arrival trains in periods; the number of departure trains in periods; Sequence of classification; Sequence of disintegration.($m = 1,2,3,\ldots,$ m_0 , $n = 1,2,3,\ldots,$ n_0)

T_B , T_F , T_J , T_D —The operation time of classification; The operation time of departure; The operation time of disintegration; The operation time of arrival.

t_{CF}^{n} , t_{D}^{m} —Departure time ; Arrival time.

t_{ESJ}^{m} , t_{LSJ}^{m} , t_{EFJ}^{m} , t_{LFJ}^{m} , $t_{EFJ}^{m'}$, $t_{ESJ}^{m'}$, $t_{LSJ}^{m'}$ —The starting time of earliest disintegration; The starting time of latest disintegration; The ending time of earliest disintegration; The ending time of latest disintegration; The ending time of earliest disintegration after adjustment; The starting time of earliest disintegration after adjustment; The starting time of latest disintegration after adjustment.

t_{ESB}^{n} , t_{LSB}^{n} , $t_{ESB}^{n'}$, $t_{LSB}^{n'}$ —The starting time of earliest classification; The starting time of latest classification; The starting time of earliest classification after adjustment; The starting time of latest classification after adjustment.

$T_{DB}^{n(n+1)}$, T_{DCF}^{n} , $T_{JCF}^{n(n+1)}$, $T_{DCF}^{n'}$, $T_{JCF}^{n(n+1)'}$ —The waiting classification time of departure trains; The waiting departure time; Interval time between adjacent departure trains; The waiting departure time; Interval time between adjacent departure trains after adjustment.

$T_{DJ}^{m(m+1)}$, T_{DD}^{m} , $T_{JD}^{m(m+1)}$, $T_{DD}^{m'}$, $T_{JD}^{m(m+1)'}$ —The waiting disintegration time of arrival trains; The time of waiting disintegration; Interval time between adjacent arrival trains; The time of waiting disintegration after adjustment; Interval time between adjacent arrival trains after adjustment.

Δt , ΔT —The change after classification adjustment; The change after disintegration adjustment.

3.2. Analysis of Initial Sequence

First, analyzing the time parameters at the condition of one shunting locomotive is under classification operation. If car flow follow is adequate, that is $T_{JCF}^{n(n+1)} > T_B$ （ $n \in \{n|1, n-1\}$ ） . The waiting classification time $T_{DB}^{n(n+1)}$ will come into being as shown in Fig.2 (a). It will provide enough time for car flow accumulation. If $T_{JCF}^{n(n+1)} \le T_B$, car flow follow time is short, the trains will be depart compactly and the inspect operation of departure trains will be saturated. The waiting departure time T_{DCF}^{n} will appear as shown in Fig.2 (b).

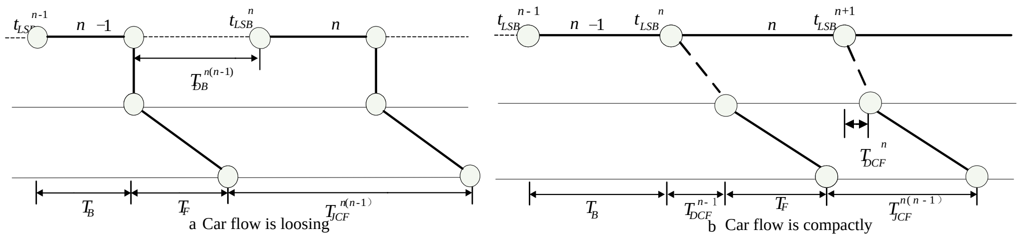

Figure 2. Analysis of initial classification sequence.

In order to guarantee full-load and punctuality, t_{LSB}^{n} as an important parameter can get easily according to reference documentation [12] for follow-up adjustment:

$$t_{LSB}^{n_0} = t_{CF}^{n_0} - T_F - T_B \quad (1)$$

The latest classification starting time of other trains are closely linked with tightness degree.

If $T_{JCF}^{n(n+1)} > T_B$, car flow follow is loose, the latest classification starting time will be got by inverse derivation:

$$t_{LSB}^{n} = t_{CF}^{n} - T_F - T_B \quad (2)$$

If $T_{JCF}^{n(n+1)} \le T_B$, the departure trains are compact classification, the latest classification starting time can be expressed as:

$$t_{LSB}^{n} = t_{LSB}^{n+1} - T_B \quad (3)$$

$$t_{LSB}^{n} = t_{F}^{n_0} - T_F - (n_0 - n + 1)T_B \quad (4)$$

3.3 The Process of Classification Sequence Adjustment

3.3.1. Classification Sequence Adjustment between Adjacent Trains. As shown in Fig. 2(b), if the interval of latest classification starting time between adjoint trains can meet $t_{LSB}^{n+1} - t_{LSB}^{n} = T_B$, it will be named compact continuing classification [12]. If each train can meet the compact continuing classification in periods, that can be defined as section compact continuing classification, that is $t_{JCF}^{nn_0} \le (n_0 - n)T_B$. If the discrepancy between $T_{JCF}^{n(n+1)}$ and T_B is large, it will not be compact continuing classification. Summed up above-mentioned, if it meet the condition of $t_{LSB}^{n+1} \le t_{CF}^{n} - T_F$, it will not be delayed. The adjustment scheme is as shown in Fig. 3.

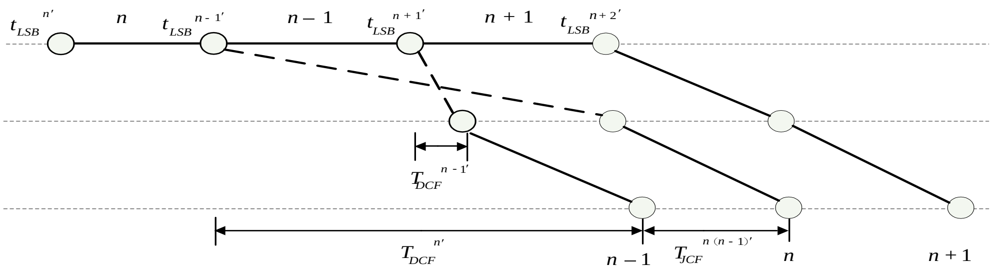

Figure 3. Adjustment scheme of classification sequence.

The parameter computation method after adjustment can be referenced to documentation [12]:

$$t_{LSB}^{n-1'} = t_{LSB}^{n-1} + T_B + T_{DCF}^{n-1} - T_{DCF}^{n-1'} - T_B \quad (5)$$

$$t_{LSB}^{n'} = t_{LSB}^{n} + T_B + T_{DCF}^{n} - T_{DCF}^{n'} - T_B = t_{LSB}^{n} + T_{DCF}^{n-1} - T_{DCF}^{n-1'} - 2T_B \quad (6)$$

3.3.2. The Influence Analysis after Adjustment. In order to guarantee punctuality of departure time, it has to meet $T_{DCF}^{n-1'} \geq 0 \bigcup T_{DCF}^{n'} \geq 0$. It only needs to prove $T_{DCF}^{n-1'} \geq 0$.

If $T_{DCF}^{n} \geq T_B$, and adjust $t_{LSB}^{n'}$ to t_{LSB}^{n-1}, that is $t_{LSB}^{n'} = t_{LSB}^{n-1}$,it will ensure $T_{DCF}^{n-1'} \geq 0$ and the delay of departure time will not be occurred . After an adjustment, changes between the latest classification starting time can be defined as Δt .When $t_{LSB}^{n'} = t_{LSB}^{n-1}$, that will be $\Delta t = 0$.

The proved method is as shown as follows:

Based on the available conditions: $T_{DCF}^{n-1'} = t_{LSB}^{n} - t_{LSB}^{n'} + T_{DCF}^{n-1} - 2T_B, t_{LSB}^{n'} = t_{LSB}^{n-1}$ and $T_{DCF}^{n-1} \geq T_B$.

And $T_{DCF}^{n-1'} = t_{LSB}^{n} - t_{LSB}^{n-1} + T_{DCF}^{n-1} - 2T_B = T_{DCF}^{n-1} - T_B$ will be derived out. Therefore, $T_{DCF}^{n-1'} \geq 0$.

If $T_{DCF}^{n} \leq T_B$, it will lead overall advancement of latest classification starting time. To sum up, the computation method of Δt can be derived as shown:

$$\Delta t = t_{LSB}^{n-1} - t_{LSB}^{n'} = T_B - T_{DCF}^{n-1} \quad (7)$$

After classification sequence adjustment, the largest adjustment for $t_{LSB}^{n'}$ is $t_{LSB}^{n-1} - (T_B - T_{DCF}^{n-1})$, under this condition the train will not be delayed.

3.3.3. The condition of classification sequence adjustment. Only supported by following conditions the adjustment is effective:

Condition (1): In adjustment, ρ is defined to reflect virtues or defect degree of car flow. If $t_{LSB}^{n'} \geq t_{ESB}^{n}$, that is $\rho = 1$.If not, $\rho = 0$.

If $T_{DCF}^{n-1} \geq T_B \bigcup t_{LSB}^{n-1} \geq t_{ESB}^{n}$, the adjustment will be optimal between adjoin trains. It just needs to prove $t_{LSB}^{n'} \geq t_{ESB}^{n}$.

Due to $t_{LSB}^{n'} = t_{LSB}^{n-1}$, it just needs to prove $t_{LSB}^{n-1} \geq t_{ESB}^{n}$.By the analysis of 3.3.2, $T_{DCF}^{n-1'} \geq 0$ will be got.

Condition (2): it needs to judge unfollow-up effect after an adjustment. Under the constraint condition of $t_{LSB}^{n'} \geq t_{LSB}^{n-1}$ [13], it will achieve the aim of full-load.

The stepping trains classification sequence can be adjusted step by step[12].The method can use

$t_{LSB}^{n} - t_{LSB}^{n'} = XT_B$ to express.

4. Disintegration Sequence Adjustment

4.1. Analysis of Initial Sequence

Adjusting the disintegration sequence of arrival trains also can guarantee full-load. In order to guarantee the requirement of car flow in classification subsystem, the t_{EFJ}^{m} is an important parameter must be considered. When trains arrived on time, it can provide stable car flow, that is $T_{JD}^{m(m+1)} > T_J$ （$m \in \{m|1, m-1\}$）, as shown in Fig.4 (a). The arrival trains need a period of waiting time for disintegration, it can use $T_{DJ}^{m(m+1)}$ to indicate. The interval time will disappear when trains arrival frequently. At the same time, the disintegrate operation is compact in subsystem. As shown in Fig.4 (b), $T_{DJ}^{m(m+1)}$ will disappear, but the arrival waiting disintegration time T_{DD}^{m} will come with the saturate car flow and busy inspection operations.

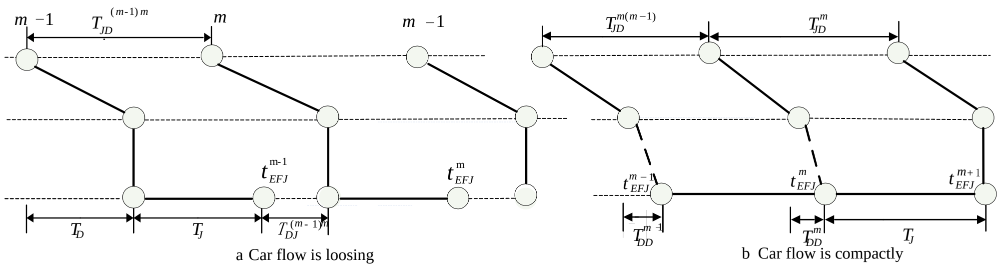

Figure 4. Analysis of initial disintegration sequence.

In order to guarantee the demand of car flow, t_{EFJ}^{m} is an important parameter, it can easily get according to tightness degree:

If $T_{JD}^{m(m+1)} > T_J$, car flow follow is loose, it will be got by extend calculation for time:

$$t_{EFJ}^{m} = t_{D}^{m} + T_D + T_J \tag{8}$$

If $T_{JD}^{m(m+1)} \le T_J$, car flow is intensive, it will take follow track model:

$$t_{EFJ}^{m} = t_{D}^{m_0} + T_D - (m_0 - m - 1)T_J \tag{9}$$

4.2. The Process of Classification Sequence Adjustment

4.2.1. Classification Sequence Adjustment between Adjacent Trains. Only meet the initial condition, $t_{EFJ}^{m} - t_{EFJ}^{m-1} = T_J$, it can adjust the disintegration sequence. The adjustment condition of disintegration sequence will be got by inverse derivation according to arrival time and technical operation time: $t_{EFJ}^{m+1} \ge t_{D}^{m} + T_D + 2T_J$. The disintegration sequence adjustment scheme is as shown in Fig.5:

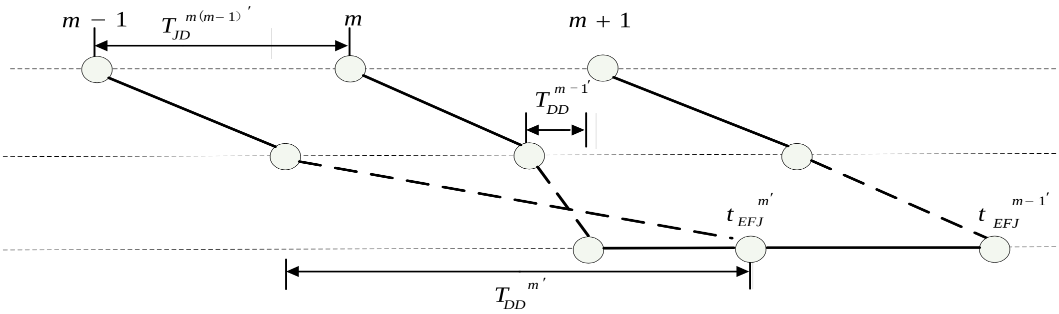

Figure 5. Adjustment scheme of disintegration sequence.

The ending time of earliest disintegration after adjustment can be expressed as follow:

$$t_{EFJ}^{m-1'} = t_{EFJ}^{m-1} - T_J - T_{DD}^{m-1} + T_{DD}^{m-1'} + T_J = t_{EFJ}^{m-1} - T_{DD}^{m} + T_{DD}^{m'} + 2T_J \quad (10)$$

$$t_{EFJ}^{m'} = t_{EFJ}^{m} - T_J - T_{DD}^{m} + T_{DD}^{m'} + T_J = t_{EFJ}^{m} - T_{DD}^{m-1} + T_{DD}^{m-1'} - 2T_J \quad (11)$$

4.2.2. The Influence Analysis after Adjustment. After initial adjustment, in order to provide effective car flow for classification subsystem, it has to meet $T_{DD}^{m'} \geq 0 \bigcup T_{DD}^{m-1'} \geq 0$ .It only needs to prove $T_{DD}^{m'} \geq 0$.

After an adjustment, changes between the ending time of earliest disintegration can be defined as Δt

If $T_{DD}^{m} > T_J$, the disintegration trains are stable, the greatest adjustment is: $t_{EFJ}^{m-1'} = t_{EFJ}^{m}$ .After the greatest adjustment, $\Delta T = 0$. It also meet the adjustment condition $T_{DD}^{m'} \geq 0$ .The prove process as shown as flow:

The proved method is as shown as follows:

Based on the available conditions: $t_{DD}^{m'} = t_{EFJ}^{m'} - t_{EFJ}^{m} + t_{DD}^{m}, t_{EFJ}^{m-1'} = t_{EFJ}^{m}$ and $T_{DD}^{m} \geq T_J$.

And $T_{DD}^{m'} = T_{DD}^{m} - T_J$ will be derived out. Therefore, $T_{DD}^{m'} \geq 0$.

If $T_{DD}^{m} \leq T_J$, trains arrive compactly, it will influence other trains disintegration time:

$$\Delta T = t_{EFJ}^{m-1'} - t_{EFJ}^{m} = T_J - T_{DD}^{m} \quad (12)$$

After adjustment, $T_{DD}^{m'} = 0$ when $t_{EFJ}^{m-1'} = t_{EFJ}^{m} + \Delta T$.

4.2.3. The Condition of Disintegration Sequence Adjustment. Only supported by following conditions, an adjustment is effective.

Condition (1):In an adjustment, ρ' is defined to reflect defect degree of car flow in disintegration adjustment. If $t_{EFJ}^{m-1'} \leq t_{LFJ}^{m-1}$,that is $\rho' = 1$ .Otherwise, $\rho' = 0$.

If $T_{DD}^{m} \geq T_J \bigcup t_{EFJ}^{m} \leq t_{LFJ}^{m-1}$, the adjustment will be optimal between adjoin trains. It just needs to prove $t_{EFJ}^{m-1'} \leq t_{LFJ}^{m-1}$.

By the analysis of 4.2.2, $T_{DD}^{m-1'} \geq 0$ will be got.

Condition (2): By constraint condition of $t_{LSB}^{n'} \geq t_{LSB}^{n-1}$ [13] ,it will guarantee enough car flow for classification.

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5. A Case Analysis

This case is used to analysis the first shift operating plan in down direction classification and disintegration sequence adjustment. The technical operation time parameters: $T_B = 15$ min , $T_F = 30$ min , $T_J = 15$ min , $T_D = 30$ min .

5.1. The Classification Sequence Adjustment

5.1.1. The Classification Sequence Adjustment between Adjacent Trains. This case is used to analysis the first shift operating plan in down direction classification and disintegration sequence. The technical operation time parameters: $T_B = 15$ min , $T_F = 30$ min , $T_J = 15$ min , $T_D = 30$ min .

Table 1. Initial classification sequence

CF	B_n	t^n_{ESB}	t^n_{LSB}	T^n_{DCF} (min)	t^n_{CF}
40 221	5	8:13	10:35	32	11:52
40 217	6	10:30	10:55	18	11:58
30 125	7	10:50	11:10	20	12:15
30 123	8	11:09	11:25	20	12:30
45 307	9	11:24	11:40	86	13:51

Adjustment method is as follow:

Step1: For train No. 40 217, judging whether it meet initial adjustment conditions. Only meet the condition of compact continuing classification, its sequence can be adjusted.

$$\because t^6_F - T_F = 11:28$$
$$\therefore t^7_{LSB} \le t^6_F - T_F$$

Step2: For train No. 40 217, judging whether it meet condition (1). $T^7_{DCF} \ge T_B$ and $t^6_{LSB} \ge t^7_{ESB}$ is clear. So, the train No. 40 217 can meet the condition $\rho = 1$.

Step3: Unfollow-up effect judgment. It must meet condition (2) before adjustment.

Because of $T^{6'}_{DCF} = T^6_{DCF} - T_B = 3$ min and $t^{7'}_{LSB} = t^7_{LSB} + T^6_{DCF} - T^{6'}_{DCF} - 2T_B = 10:55$,meet $t^{7'}_{LSB} \ge t^6_{LSB}$ .After adjustment, $\Delta t = 0$.

To sum up, if train No. 40 217 needs more time for waiting car flow, its sequence should be exchange to No.30 125.The result after adjustment is as shown in Table 2:

Table 2. Adjustment between track trains.

CF	B_n	t^n_{ESB}	t^n_{LSB}	T^n_{DCF} (min)	t^n_{CF}
40 221	5	8:13	10:35	32	11:52
30 125	6	10:30	10:55	35	12:15
40 217	7	10:50	11:10	3	11:58
30 123	8	11:09	11:25	20	12:30

5.1.2. The Adjustment for Stepping Trains. Based on adjustment result in table 2, it can continue adjust classification sequence 6 to 8. Due to $T^8_{DCF} < T_B$, therefore, $\Delta t = t^7_{LSB} - t^{8'}_{LSB} = T_B - T^7_{DCF} = 12$ min .The starting time of latest classification will be advanced 12 min.

Table 3. Adjustment among several departure trains.

CF	B_n	t_{ESB}^{n}	t_{LSB}^{n}	T_{DCF}^{n} (min)	t_{CF}^{n}
30 125	6	10:30	10:43	47	12:15
30 123	7	10:50	10:58	47	12:30
40 217	8	11:09	11:13	0	11:58

To sum up, it will cause great influences for the whole scheme; therefore, the adjustment should be canceled. And then, only make compact continuing adjustment for No. 40 217.

5.2. Disintegration sequence adjustment

5.2.1. Disintegration Sequence Adjustment between Adjacent Trains. If the No. 51 503 needs to disintegrate firstly, and then it can provides car flow for classification subsystem. The partials of initial disintegration sequence are as shown in Table 4.

Table4. Initial disintegration sequence.

DD	J_m	t_{D}^{m}	$T_{DJ}^{m(m+1)}$ (min)	t_{ESJ}^{m}	t_{LFJ}^{m}
41 315	6	9:47	22	10:39	11:10
32 137	7	9:56	28	10:54	11:25
51 503	8	10:15	24	11:09	11:40
41 321	9	10:39	15	11:24	13:20

The adjustment method is similar with classification sequence adjustment. The result after adjustment is as shown in Table 5.

Table 5. Adjustment between track trains.

DD	J_m	t_{D}^{m}	$T_{DJ}^{m(m+1)}$ (min)	t_{ESJ}^{m}	t_{LFJ}^{m}
41 315	6	9:47	22	10:39	11:10
51 503	7	10:15	9	10:54	11:25
32 137	8	9:56	43	11:09	11:40
41 321	9	10:39	15	11:24	13:20

5.2.2. The Adjustment for Stepping Trains. If No. 51 501 needs more time for disintegration, adjustment stepping trains for it must be taken into account. Because of $T_{DD}^{7} \le T_J$, $\Delta T = t_{EFJ}^{6'} - t_{EFJ}^{7} = T_J - T_{DD}^{7} = 6$ min . The disintegration time will be delayed 6 min in whole scheme.

TABLE 6. Adjustment among several arrival trains.

DD	J_m	t_{D}^{m}	$T_{DJ}^{m(m+1)}$ (min)	t_{ESJ}^{m}	t_{LFJ}^{m}
51 503	6	10:15	0	10:45	11:10
41 315	7	9:47	43	11:00	11:25
32 137	8	9:56	79	11:15	11:40

To sum up, it have to cancel the stepping trains disintegration sequence, and only make compact continuing sequence adjustment for No. 51 503.

5.3. The conclusion of case

For the two problems showed in the case, those are as follows, the first one is No. 40 217 needs more time for waiting car flow and the second is No. 51 503 needs emergency disintegrate to provide car flow for classification. Through partial adjustment method can solve those problems effectively. The most important step is judging the adjustment conditions whether it can be meet. The classification and disintegration sequence of stepping trains can be adjusted step by step until achieve the best adjustment scheme. In this case, departure time will be delayed when make stepping trains disintegration sequence adjustment. In practical situation, if adjustment objects are important trains, stepping trains adjustment must be considered. Finally, by eliminating negative effects gradually it can achieve the goal of overall optimum.

6. Conclusion

In thesis, the marshalling station is divided into two subsystems according to deferent operation. Each subsystem can be equivalent regarded as machine scheduling operation. Then analysis shows the connection between each parameter of time. Based on the principle of "first inspect first disintegrate, first depart first classificate", it can make partial adjustment. Through this kind of method, the marshalling station will acquire more time for car flow follow, which can achieve the aim of each departure trains is full-load. With help of authentic data in the case, the practical application is proved. The problem for sequence adjustment of disintegration and classification in two subsystems can be solved step by step. It makes foundation for the station stage operating plan.

Acknowledgement

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