Intelligentized Dispatching Control of Railway Transport of Molten Iron in Metallurgical Enterprise

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Abstract. Focusing on railway transport of molten iron in steel enterprise, this paper tries to meet the demand and supply of molten iron between blast furnace and steel mill through TPC (torpedo car) transport. Taking mill railway as a network, based on path selection of molten iron transport and automatic collision avoidance algorithms, the paper puts forward the method of optimizing molten iron dispatch by taking advantage of TPCs to operate flexible time in accordance with the distance between the demand and supply of molten iron and network point, as well as field factors as track switches and signals etc. Ultimately, an intelligentized molten iron dispatching simulation system is formed in the paper to assist staff to optimally allocate locomotive and TPCs.

Introduction

The workflow of molten iron transport in steel enterprise includes the whole process from blast-furnace casting, to molten iron transporting to steel mill, to TPCs dumping, and finally to empty TPCs carrying back to blast furnace for awaiting molten iron. The procedure is extremely complex, for the dispatch of molten iron transport must timely adapt with the twinkling change of production and operation. However, in most of the steel enterprises, the dispatching method adopted for molten iron dispatch is still artificial scheduling on the whole. Therefore, brainwork intensity of dispatchers is high, and decision-making model and level vary with each individual.

At present, in terms of molten iron dispatching, the dispatching method popularizing at home and abroad is mostly to establish co-ordination transportation of supply and marketing[1]. In the light of the model, objective function with the shortest total path is summed up. In some documents, their dispatching methods only solve the single problem of path[2] or TPCs[3]. Others merely take transporting capacity of system into account[4]. All these methods do not consider numerous uncertainties on cost of production, energy consumption and field, such as low regularity of blast furnace's topping point, capacity dissipating up locomotives in the transportation process, large magnitude of tank cars dueing to a waste of bearing capacity and locomotives collision regardless of railroad section ability. In the mean time, the impacts of throat points and signals should not be neglected.

By analyzing the multitude factors that affect the dispatch of molten iron transporting, molten iron transporting system and blast furnace (the transporting process of converter molten iron sector), this paper ties to proceed optimization and simulation to the dispatch of molten iron transporting on the premise of its regulation giving sufficient consideration to flexible time and equipment occupation in the whole process of transportation.

Mathematical description of problems

Now consider locomotive crew 1.2.3…..q haul TPCs go through L_j, L_{j+1}, $\cdots L_k$, $L_k^{'}, L_{k-1}^{'}$, $\cdots L_j^{'}$ (L_j is the route for heavy TPCs from blast furnace to steel mill; $L_j^{'}$ is the route for empty TPCs from steel mill to blast furnace); feasible speed set of locomotive is $V\{0, v_1, v_2, v_3\}$, v_j is the running speed on L_j, $v_j^{'}$ is on $L_j^{'}$, and the speed of locomotive on each route can not exceed v_3:

T_i is the running time for heavy TPCs from number i blast furnace to molten iron pretreating, min;

$T_q(v, k)$ denotes the transporting time in optimal program;

T_i^d denotes the added time of torpedo car carted from number i blast furnace in the stage of molten iron pretreating;

T_i^{rz} denotes the running time for torpedo car of number i blast furnace, min;

x_{ih} denotes premium magnitude from supply centre of number i blast furnace to demand centre of number h, $h \leqslant r$, there are r demand centers at most;

a_i denotes production volume (net supply) in number i blast furnace in T period, that is, supply of torpedo ladle, $i \leqslant b$, there are b supply centers at most;

b_h denotes consumption (net supply) in number h demand centre in T period, that is, demand of torpedo ladle;

ξ denotes flexible time of torpedo car working in number i blast furnace, min;

$T_{\max}$ denotes maximum latency;

n_i^{BF} denotes the tapping frequency of number i blast furnace;

Q_i^{BF} denotes the iron content at every turn of number i blast furnace;

n_i^g denotes cycle number of torpedo ladle in number i blast furnace;

C^{TP} denotes the volume of torpedo ladle;

$Y_i = (T_i + T_i^d)/T_i^{rz}$ is continuous parameters of TPCs[5];

T_{locom} is annular running time of a set of locomotives on route L_j, L_{j+1}, $\cdots L_k$, $L_k^{'}, L_{k-1}^{'}$, $\cdots L_j^{'}$.

Model is as follows:

Objective function:

Min ξ;

Min T_{locom};

Max $Y_i = (T_i + T_i^d)/\ T_i^{rz}$;

s.t:

The time of heavy TPCs transport and geminate transiting must be less than the total working time of torpedo ladle:

$$(T_i + T_i^d) < T_i^{rz} \quad (i = 1,2\cdots b); \tag{1}$$

Production capacity restriction:

$$\sum_{i=1}^{b} x_{ih} = b_h; \tag{2}$$

$$\sum_{h=1}^{r} x_{ih} = a_i; \tag{3}$$

Production balance constraints:

$$\sum_{h=1}^{r} a_i = \sum_{i=1}^{b} b_h \ ; \tag{4}$$

Balance constraints between TPCs supply and molten iron production:

$$n_i^{BF} Q_i^{BF} = \frac{60T}{T_{\mathrm{i}}^{\mathrm{rz}}} n_i^g C^{TP} \ ; \tag{5}$$

$$\frac{60T}{T_i^{rz}} n_i^g \ = \ a_i \ ; \tag{6}$$

Running time for heavy TPCs from number i blast furnace to molten iron pretreating can not more the

$$T_i^{rz} < T_{\max} \ ; \tag{7}$$

Velocity constraint of locomotive:

$$0 < V_{\mathrm{g}} < V_3 \ , \quad \mathrm{g=j \cdots k}; \tag{8}$$

$$0 < V_{\mathrm{g}}^{'} < V_3 \ , \quad \mathrm{g=j \cdots k}; \tag{9}$$

It is a problem of multi-objective programming. We should analyze and optimize practical problems under significance of objective function. Then, rational objective function value can be acquired on the basis of meeting constraint conditions.

Algorithm design

It is a problem of multi-objective programming, involving much complex variants. A large number of random factors exist and the algorithm of direct calculating is difficult to be devised. Therefore, we should optimize the primal problem step by step in accordance with characteristics of

Practical problems and production rules, and design algorithm appropriating for the problem with the idea of integrated regulation. The main steps of the algorithm are:

Step 1: route selecting of mills;

Step 2: collision detection of locomotives;

Step 3: optimized dispatching, including optimization of TPCs and locomotives.

3.1 Route selecting of mills

In general, with regard to railway route selection, graph theory and method are adopted to simplify railway network so as to solve the problem with side and apex. As for road network of the mills, mathematical description is preceded through network. We divided the region into different function zones for the producing disposing, transport and consumption of molten iron because the operating path of TPCs is affected by spatial position of route starting point and terminal point. Thus, road network model of transportation system can be set up and the shortest path in the system of railway transport of molten iron can be found out by Dijkstra algorithm during the initial plan of path.

3.2 Collision of locomotives

When TPCs are being steered on the railway under the traction of locomotives, we usually keep checking the road conditions ahead by using reservation protocol. That is, in running process, TPCs possess their planned section of railway in advance and other trains can not travel on the section simultaneously. Therefore, subscription of section probably generates conflict if several trains are in motion according to their planned section (the shortest route).At this point, there must be some reasonable causes to determine which train should subscribe the section.

(1) Dynamic cross detection

Suppose s_1 and s_2 are two trains, and their arranged route can be expressed by using moving array as: Q_1=(L_i, L_{i+1}, L_{i+2})and Q_2=(L_j, L_{j+1}, L_{j+2}) (L_i denotes the route that s_1 occupies at present, and L_{j} is for s_2). Now, taking s_1 as object, if L_{i+2} in Q_1 is identical to any one of the elements in Q_2, we can get to know that s_1 lost the subscription of L_{i+2} because s_2 has occupied or subscribed the section. Hence, reasonable causes like section 2.2.2 of this paper need to be found to determine the subscribing right of L_{i+2} should be given to s_1 or s_2.

(2) Dynamic priority rating confirmation

Dynamic priority rating means importance degree or priority endowed in the working process of molten iron tanker. It can be accumulated according to the transportation environment and condition. The formula is as follows:

$$P_i = R_i \sum_{j=1}^{n} W_j C_j + M_i \quad \text{(j=1…n)} \tag{10}$$

R_i denotes if there is mission for number i train or not. 1 stands for “yes” and 0 stands for “no”. …denotes the priority level of number i train; C_j denotes factors which should be taken into account for dynamic priority rating of trains; W_j denotes the weight of those factors; M_i denotes the static priority of the train; n denotes the number of those factors.

C_j denotes the main relevant elements, which are listed at follows:

(1) Urgency degree of torpedo’s demand for the torpedo ladle;
(2) Urgency degree of converter’s demand for the load molten iron in the torpedo ladle;
(3) Temperature declining degree of molten iron with the passage of time;
(4) Frequency magnitude of giving way.

If it is equal in the magnitude of priority rating, we should submit to FCFS principle.

(3) Collision prevention patterns

After the priority has been confirmed, the tanker ordering first transits the subscribed section first, while those failed in subscription should take the following two ways to avoid collision: ① wait for transiting; ② evade the route which has failed to be subscribed And calculate the second shortest path.

Suppose the feasible maximum speed of locomotives is v', P_h denotes the train subscribed successfully and P_l denotes failed train. In case of ①, s_h and s_l should Speed up reasonably making use of speed regulatory mechanism of trains; in case of ②, T_l should do the same thing. In both cases, the speed of the trains must be equal or lesser than v'. Thus, wasted time for P_l could be cut down.

3.3 Optimized dispatching

(1) Running flexibility of TPCs

In the field, the running job of TPCs includes disposition, transmission and waiting. The procedure of waiting takes up most of the time and the proportion of disposition and transmission is smaller. Therefore, its running job must be arranged reasonably so as to shorten run cycle for high circulation efficiency. Now, we can optimize the running process of TPCs by utilizing the concept of flexible time[3].

Here, flexible time in the running of TPCs refers to their waiting time for linking up all the working procedures in the transporting process between blast furnace and converter. The main procedures for waiting include distribution treatment of heavy TPCs, pulling of empty TPCs and distribution to blast furnace of empty TPCs. For its complex process, it is obvious that there must be flexible time in the running of TPCs.

Suppose torpedo ladle needs to transport molten iron from blast furnace to steel mill, the running time parameter of torpedo ladle in number i ($0 < i \leqslant b$)blast furnace can be expressed mathematically as following:

$$t = T_i^s + T_i + T_i^d + T_i^f + T_i^{dc} + T_i^{xh} + \xi \tag{11}$$

In the above expression, T_i^s denotes iron receiving time of torpedo ladle in number i blast furnace, min;

T_i^d denotes working time for TPCs coming from number i blast furnace at pretreating place, min;

T_i^f denotes running time of empty TPCs from molten iron pretreating to number i blast furnace, min;

T_i^{dc} denotes waiting time for TPCs carting from and arriving at number i blast furnace because of switch taking up by other trains;

t_i^{dc} denotes delaying time for switch using of TPCs carted from number i blast furnace, min;

$t_i^{dc'}$ denotes delaying time for switch using in the course of arriving at number i blast furnace, min;

T_i^{xh} denotes waiting time for signals direction when carted from and arriving at number i blast furnace;

t_i^{xh} denotes waiting time of TPCs carted from number i blast furnace for following signals direction, min;

$t_i^{xh'}$ denotes waiting time of TPCs for following signals direction in the course of arriving at number i blast furnace, min;

From the above expression, it is clear that the running time of TPCs transportation is determined by running condition of locomotives. So the time can be substituted by the working time of locomotives and only flexible time is a part of TPCs turnover. Consequently, if we suppose T_{locom} denotes the running time of TPCs hauling by locomotives, it can be transformed as following:

$$T_i^{rz} = T_{locom} + t \tag{14}$$

In the meanwhile, according to demand-supply equilibrium of molten iron, we can get the relational expression between iron output of number i blast furnace in T hours and traffic volume of TPCs:

$$n_i^{BF} Q_i^{BF} = \frac{60T}{T_{\mathrm{i}}^{rz}} n_i^g C^{TP} \tag{15}$$

From the above expression, we can deduce calculation method of TPCs cycling number:

$$n_i^g = n_i^{BF} Q_{\mathrm{i}}^{BF} \; T_{\mathrm{i}}^{rz} / 60\mathrm{T} \, C^{TP} \tag{16}$$

Judging by the above, we can see that operational optimization of TPCs can be achieved by means of reducing its flexible time and waiting time.

(2) Merging and optimization of locomotives running

In the process of molten iron transporting, because of short distances between preceding slagging-off location and pretreatment location and after slagging-off location, and same speed of locomotives running in these stations, the three stations can be put into one, namely, pretreatment station. Similarly, we can merge decanting station and cinder scarfing station into after-treatment station. Hence, molten iron transporting from blast furnace to steel mill can be merged to circulating motion of TPCs hauled by locomotives[5]. As shown in figure 1:

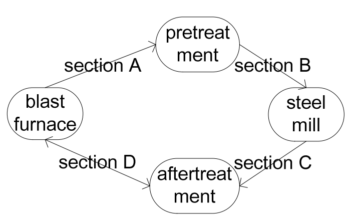

Figure 1 Merger diagram of TPCs transporting

Suppose n denotes the number of locomotives in a set;

$\bar{v}$ denotes the average running speed of heavy TPCs hauled by locomotives from blast furnace to steel mill;

$\bar{v}'$ denotes the average running speed of empty TPCs hauled by locomotives from steel mill to blast furnace;

m denotes the average parking times of locomotives in transit;

T_{go} denotes transporting time of heavy TPCs hauled by locomotives;

$\bar{a}$ denotes average acceleration from blast furnace to steel mill;

$\bar{a}'$ denotes average acceleration from steel mill to blast furnace;

T_{back} denotes return time of empty TPCs hauled by locomotives;

T_{other} denotes other lost time including handling time for loading, unloading and collision avoidance, average delaying time of switch and average waiting time of signals direction;

$\bar{T}_{dc}$ denotes average delaying time of switch;

$\bar{T}_{xh}$ denotes average waiting time of signals direction;

$T_{coupling}$ denotes coupling time, T_{unload} denotes unloading time, $T_{avoidconfl}$ denotes handling time of collision avoidance;

ß denotes magnification factor of interference incidents;

The available formula is:

$$T_{locom} = T_{go} + T_{back} + T_{other} \tag{17}$$

$$T_{go} = (L_j / V_j + L_{j+1} / V_{j+1} + \ldots + L_k / V_k) + m\bar{v} / \bar{a} \tag{18}$$

$$T_{back} = (L'_k / V'_k + L'_{k-1} / V'_{k-1} + \ldots L'_j / V'_j) + m\bar{v}' / \bar{a}' \tag{19}$$

$$T_{other} = ß(T_{coupling} + T_{unload} + T_{avoidconfl} + \bar{T}_{dc} + \bar{T}_{xh}) \tag{20}$$

On the basis of station merging, we can transform the expression above. For instance, section A=（L_1，L_2，L_3，L_4）, similarly, section B=（L_5，L_6，⋯，L_k）, ... section D=（L'_k，L'_{k-1}，⋯，L'_j）.Suppose lengths of the sections are L_A，L_B，L_C，L_D， and arriving and departing speeds are v_A, v_B, v'_C, v'_D respectively. Thus (17) can be transformed into:

$$T_{locom} = T_{locom}(j, k, v) = \frac{L_A}{v_A} + \frac{L_B}{v_B} + \frac{L_C}{v'_C} + \frac{L_D}{v'_D} + m\left(\frac{\bar{v}}{\bar{a}} + \frac{\bar{v}'}{\bar{a}'}\right) + T_{other} \tag{21}$$

Nowadays, for large volume of torpedo ladle, most of steel enterprises employ the transporting way of "one to one", that is to say, one locomotive hauls one TPC only.

So, we just let the T_{locom} at minimum degree, we can use the locomotives and TPCs effectively.

3.4 Example simulation

In order to verify station-yard capacity, locomotive numbers and working car numbers, we conducted simulation drawing of molten iron transport in Fangchengang base for the whole process of 12 hours, exploiting flow chart of automatic dispatch. The simulation results are shown in figure 2, figure 3.

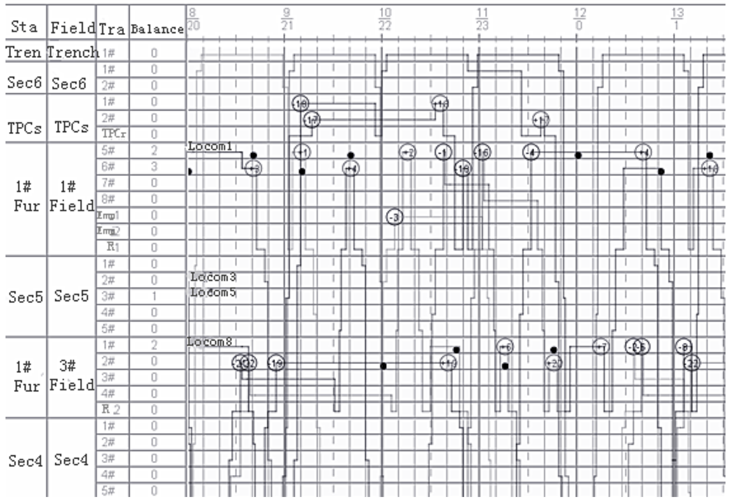

Figure 2 Molten iron dispatching situation of blast furnace 1

By collecting the information on static-dynamic equipment of railway station and tapping program of molten iron, computer can automatically produce molten iron dispatching system of railway in enterprises. Through analytical comparison of molten iron dispatching program between computer and manual programming in a same section, we easily find that the program produced by computer system not only can meet the production requirements primitively, but the majority of which is superior to manual ones. All in all, computer programming has realized automatically programming of molten iron dispatching. It reduces working intensity of dispatchers and provides theory and application foundation for automation of molten iron transport in the future.

In conclusion, for the optimization of molten iron dispatching, on one hand, we should try to decrease cycle numbers of torpedo ladle by cutting down its flexible time, meanwhile, turnover rate and continuation degree need to be improved; on the other hand, hauling locomotive quantity and non-working time must be cut down, and process operation level should be advanced by taking empty TPCs promptly. In addition, there must be a rapid and reasonable decision scheme for route selection to reduce delaying time, thus, it can utter-mostly avoid molten iron cooling and large energy consumption.

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