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Applications of optimal mathematic-physical models in metallurgical manufacture scheduling system at Baosteel

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Abstract: The transfer of mass flow between ironmaking and steelmaking process at Baoshan Iron and Steel Co. Ltd. has been analyzed. The mathematic-physical models of transport scheduling for hot metal manufacturing have been researched combined with the practical problem in the metallurgical manufacture procedure. Taking into account these models, the scheduling software has been designed, programmed and tested on-line. The new automation system of production scheduling has been implemented successfully at Baosteel, which produces a great economic benefit.

Key words: mathematic-physical model; software applications; locomotive; transport scheduling

1 Introduction

With the improvement of ironmaking and steelmaking technology and the control of metallurgical process, hot metal scheduling and management on ironmaking and steelmaking interface should be more reasonable and precise [1]. Taking one with another in the iron and steel plant, the railage mode is only used between the BF (blast furnace) and BOF (basic oxygen furnace) in all transfer of mass flow. It can not be substituted by other transportation modes such as strap, roller and road. The varieties of complex situation, such as big mass flow quantity, many trunk lines, railroad siding, railway crossing and the change of hot metal pretreatment process, lead to the difficulty of transport scheduling [2, 3]. In order to meet practical production requirements, improve the management of production automation and heighten production efficiency, it is necessary to develop applications for transport scheduling of hot metal transportation modes. Global Positioning Systems (GPS) and data transport systems, which offer the condition to develop the transport-scheduling software for hot metal transport, have been used at Baosteel [4, 5]. With the mass flow organization in ironmaking and steelmaking interface, the optimum scheduling have been researched. With the merit of two systems, which are (1) the scheduling system for Baosteel hot metal management developed by IBM and (2) the management system about Baosteel transport developed by Haixin Company [6], software scheduling applications for hot metal transport having been put into practice successfully.

2 Research of mathematic-physical model on transport scheduling

The issues, such as the quantifying parameters of boundary questions, the optimum scheduling plan, and the design of the knowledge base and database, are essential to the utility of the scheduling software applications. The scheduling research should focus on the following problems, such as how to reasonably arrange the supply quantity of hot metal, choose railway routes, shorten the time of suffering and waiting, heighten the scheduling efficiency and reduce the scheduling charge to achieve the optimum economic benefit [7].

2.1 The time problem of hot metal scheduling

In Baosteel, there are three supply spots of hot metal (three blast furnaces), three demand spots (the No.1 Steelmaking Plant, the No.2 Steelmaking Plant, the Electrical Arc Furnace plant), and two interspace transfer spots in direction for the No.1 Steelmaking Plant (slagging-off pre-pretreatment and pretreatment), three interspace transfer spots in direction for the No.2 Steelmaking Plant or Electric Arc Furnace Plant (slagging-off pre-pretreatment, pretreatment and slagging-off post-pretreatment). Considering the limit quantity of hot metal resource and requirements, the demands of hot metal temperature, composition and transport time for steelmaking, the optimum plan for

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transport time has been resolved by the new designs. Based upon the production level at Baosteel, the hot metal scheduling problems in the transportation modes, which include the balance or imbalance of supply and requirements and the involved specific transfer in the supply chain of hot metal, have been analyzed. Mathematic-physical models for the problems have been dealt with. **Figure 1** is the physical model of hot metal transportation scheduling at Baosteel.

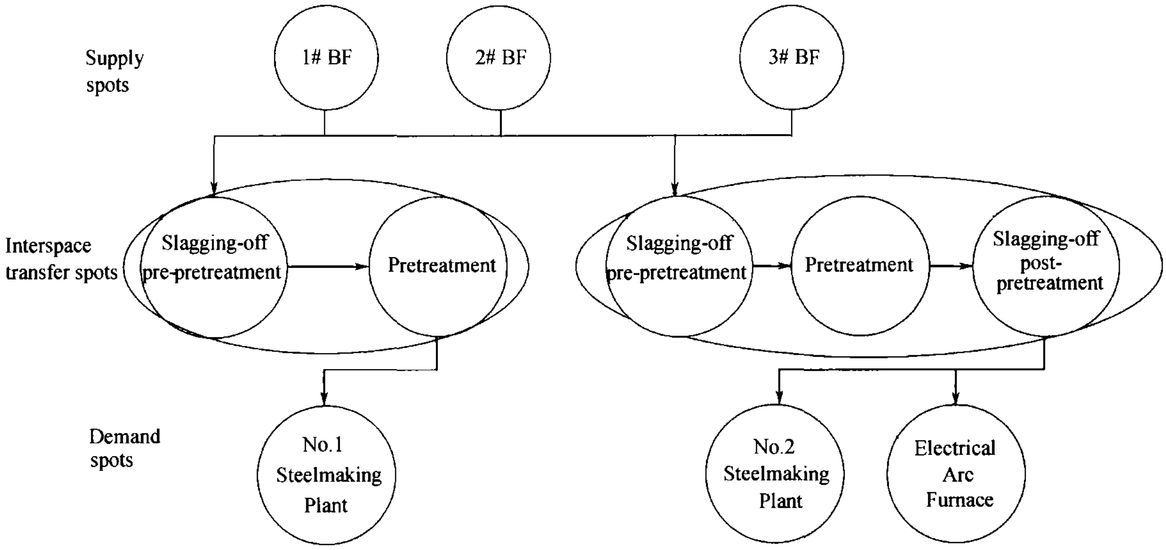

Figure 1 The physical model of hot metal transport scheduling at Baosteel.

Now, we assume that the locomotives with full-loaded torpedo ladle cars (hereinafter referred to as TPC) are moved from "m" supply spots of hot metal, passing through "p" interspace transfer spots, to "n" demand spots. Thus, there are "$m+p$" sending spots, "$p+n$" receiving spots. Moreover, not every full-loaded TPC must pass through each interspace transfer spot.

Assumptions:

a_i: The output of No.i supply spot (net supply quantity), *i.e.* the supply quantity of TPC;

b_j: The demand of No.j spot (net requirement quantity), *i.e.* the requirement quantity of TPC;

x_{ij}: The quantity of TPC of transports from the sent spot "i" to the receive spot "j";

t_{ij}: The time of transportation from the sent spot "i" to the receive spot "j";

y_i: The quantity of TPC transferring from the transfer spot "i";

t_i: The time of transferring TPC from the transfer spot "i";

Summation: the total hot metal supply quantity should be equal to the total requirement quantity, *i.e.*

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j = Q \tag{1}$$

The order of sent spots should be sorted; the supply spots should be followed by the transfer ones. The order of received spots should also be sorted; the transfer spots should be followed by the demand ones. The following is the mathematical model:

$$\min \quad z = \sum_{i=1}^{m+p}\sum_{j=1}^{n+p} x_{ij}t_{ij} + \sum_{i=1}^{p} y_i t_i \tag{2}$$

subjected to

$$\sum_{j=1}^{p+n} x_{ij} = a_i, \quad i=1, 2, \cdots, m, \quad j=1, 2, \cdots, p+n;$$

$$\sum_{j=1}^{p+n} x_{ij} = Q, \quad i=m+1, m+2, \cdots, m+p, \quad j=1, 2, \cdots, p+n;$$

$$\sum_{i=1}^{m+p} x_{ij} = Q, \quad i=1, 2, \cdots, m+p, \quad j=1, 2, \cdots, p;$$

$$\sum_{i=1}^{m+p} x_{ij} = b_j, \quad i=1, 2, \cdots, m+p, \quad j=1, 2, \cdots, n,$$

$$x_{ij} \geqslant 0, \quad i=1, 2, \cdots, m+p, \quad j=1, 2, \cdots, p+n.$$

The solution of the model is the shortest time of hot metal transport scheduling while in production modes. When this mode is applied in the application system, the hot metal productivity will be greatly improved.

2.2 The task of locomotive and the route configuration problem of transport

The task of locomotive transportation in the plant area is moving ahead with full-loaded TPC and returning with empty ones, avoiding locomotive moving without TPC.

Baosteel has three trunk lines for the No.1 Steelmaking Plant, two trunk lines for the No.2 Steelmaking Plant, one connecting railway and many railroad sidings between No.1 and No.2 Steelmaking Plant. That all these are joined with each other makes a railway network system for hot metal transport. There are 16 locomotives running on the railway system. The principle is that every locomotive draws not more than three TPC, whether they are full-loaded or not. The keys to locomotives scheduling are how to arrange locomotives' task and the selection of what routes they will operate.

The following is the corresponding mathematical model [8] and the algorithm of the application.

To assign tasks to all locomotives, every transport area should have some set of locomotives. Assuming that letter D represents the transportation area, D area possesses q locomotives. The maximum transportation capacity of per locomotive is b TPC. Today, there are m transportation tasks of TPC, namely $1,2,\cdots,m$. The transportation capacity of task i, $g_i<q$ $(i=1,2,\cdots,m)$, which is required to take place in a range of time $[t_{ei}, t_{li}]$. Here t_{ei} is the permitted earliest beginning time, t_{li} the latest beginning time; the cost of a locomotive moving from No.i to No.j spot is C_{ij}. To deliver the transport routes with the least cost it requires to solve this formula.

If t_{bi} stands for the beginning time of task i, t_{fi} the finishing time, the time of task i carried out is $t_i = t_{bi} - t_{fi}$. Assuming t_{ij} is the time of a locomotive moving from No.i to No.j spot. Here defines the variables as following:

$$y_{ki} = \begin{cases} 1 & \text{locomotive } k \text{ finished No. } i \text{ spot's task} \\ 0 & \text{otherwise} \end{cases}$$

$$x_{ijk} = \begin{cases} 1 & \text{locomotive } k \text{ moved to } j \text{ from } i \text{ spot} \\ 0 & \text{otherwise} \end{cases}$$

The following is the mathematical model of the least cost of locomotive moving route.

$$\min \quad z = \sum_i \sum_j \sum_k C_{ij} x_{ijk} \tag{3}$$

subject to

$$\sum_i g_i y_{ki} \le q \quad \forall k;$$

$$\sum_k y_{ki} = 1, \quad y_{ki}=0 \text{ or } 1, \quad i=D,1,\cdots,m, \quad \forall k;$$

$$\sum_i x_{ijk} = y_{kj}, \quad j=D,1,\cdots,m, \quad \forall k;$$

$$\sum_j x_{ijk} = y_{ki}, \quad i=D,1,\cdots,m, \quad \forall k,$$

$$x_{ijk}=0 \text{ or } 1, \quad i,j=D,1,\cdots,m, \quad \forall k;$$

$$x_{ijk}=1 \Rightarrow t_{fi} + t_{ij} \le t_{bj}, \quad i,j=1,\cdots,m, \quad \forall k;$$

$$t_{ei} \le t_{bi} \le t_{li}, \quad i=1,\cdots,m.$$

Here $\forall$ means "anyone element of the set".

The most economic transport route can be calculated to an ideal status according to the prior given model. Combined with the present transportation rules and the occupancy time in railway, the railway route is arranged reasonably and the transportation capacity is improved.

3 Computer software scheduling application

3.1 Scheduling rules

According to the present situation at Baosteel, many scheduling rules have been analyzed and summarized. The software application including the rules is helpful to adjust the scheduling on time.

(1) Working criterion.

In order to heighten the scheduling efficiency, strict rules and standardization operations are necessary [9]. They involve the fellow issues that the locomotives are not allowed to move through workshops and operation spots of working procedure, that locomotives, which choose their way from the five trunk lines, move ahead in the same railway in a single direction, that locomotives have been waited in the busiest area (the engineer applies for moving forward. The signaler specifies the priority of locomotives. Lastly, the engineer receives the priority followed by accelerating past the busiest area). In optimal scheduling environment of hot metal transport, scheduling personnel should fully consider the restrictions on time, the temperature variation, the mass flow quantity in the given direction, the conveyance carrying capacity, the mass flow supply priority and the non-negative of parameter values.

(2) Matching issue.

For the plan of transport scheduling, the following factors should be considered: (1) the match of total configurations, such as the capacity-matching between steelmaking and ironmaking, the match between the production task and the pattern of pretreatment, transportation task and transportation capacity of locomotives (deciding the quantity of locomotives), the capacity and recycle time of TPC and mass flow quantity (deciding the quantity of TPC), the mass flow quantity and railways load burthen (the network for railroads); (2) The match of producing process, such as the match between the residual quantity of TPC in Steelmaking Plant and the hot metal supply capacity (deciding the direction for hot metal transport), full-loaded TPC and the grade of steel (the relations between supply and requirements of hot metal), the steel grade and the sort of hot metal (deciding the model of pretreatment), pretreatment capacity and hot metal supply capacity, the component and temperature of hot metal post pretreatment and the grade of steel (the adjustment of the relations between supply and requirements of hot metal) , and mutual matches among the operation time of every event in procedure; (3) the matches of other issues, for example, the match between the workers and workload and so on. Only considering the reasonable matching relations, can the fluency of mass flow be guaranteed [10]. In the automatic scheduling system, these matching issues are embodied by the configuration of parameter values and the arithmetic in the software scheduling applications.

3.2 Application frame

The transport scheduler has the upper interface subsystem, namely the hot metal supply management system, and the lower interface subsystems, namely the data transferring system and the dynamic survey system of GPS. **Figure 2** is the configuration of automation transport scheduling system. It shows the relations of all modules in the system. The making and processing module for transport scheduling instructions is comprised of many sub-modules, such as transport scheduling instructions made automatically, instructions made by manual operation, instructions sending, instructions implementing and management, the optimizing database of transport scheduling instructions.

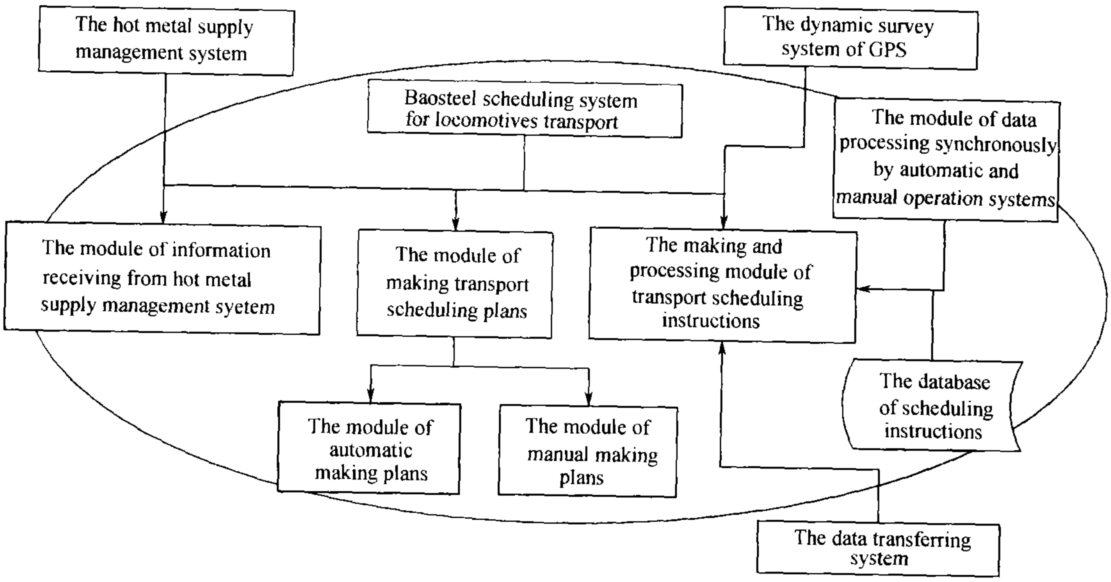

Figure 2 The configuration of automation transport scheduling system.

3.3 Instructions database of transport scheduling

The instructions of automation scheduling for locomotive transportation come from an instruction database of scheduling, which is the foundation. Its establishment is one of the most important factors for the transport scheduling model. The transport scheduling is usually implemented according to some certain patterns, which means that some conditions bring out the corresponding scheduling instructions. Transport scheduling instructions are relatively unchangeable. So the transportation scheduling experts find the relations between the conditions and the instructions in terms of basic transportation status. Then software development engineers save these relations with codes that computer can identify into a relational database, which is called instruction database of transport scheduling. Finally the experts should check on the database's precision and maturity.

Figure 3 is the diagrammatic sketch of the system procedure and the data treatment.

The method of "weakening instruction conditions" for the optimum of instructions database of transport scheduling was used, we sort the type of locomotive tasks to confirm the specific tasks, then, confirm a group of corresponding instruction conditions according to each task. All groups of conditions are queued by the amount of each group of conditions and then make the condition serial number. The group with most conditions ranks the first; the condition serial number is No.1. The group that has the second most conditions, its condition serial number is No.2, and things go on like this. The conditions are weakened gradually until the group that only has a unique condition has corresponding instructions too. The method of "weakening instruction conditions" consists of three main modules: the module of confirming the type of locomotive task, the model of optimal method of locomotive instruction and the mode of compiling method of locomotive instruction. There are more than eight thousands instructions in the database when the optimal work has been finished.

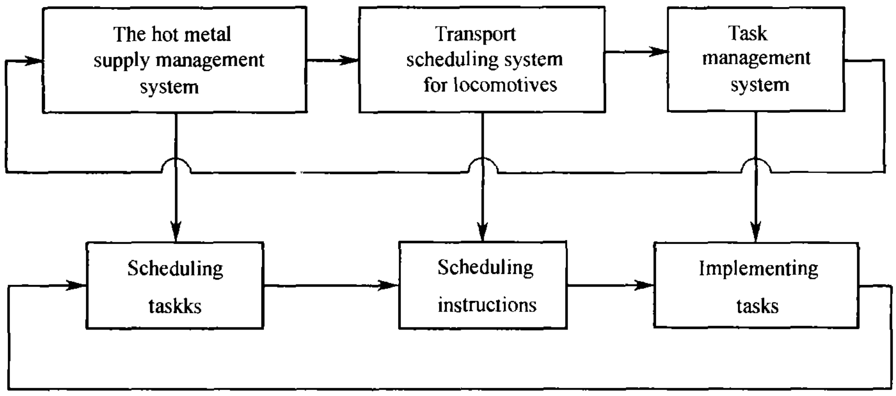

Figure 3 The diagrammatic sketch of the system procedure and the data treatment.

4 Conclusions

(1) The most difficult task is to implement the automatic scheduling of locomotive conveyance in the scheduling system of iron and steel manufacture procedure. This software application module was programmed with advanced equipment and management pattern, reasonable design and software arithmetic. Finally this most difficult problem has been solved successfully.

(2) The software application has run on-line steadily. It is characterized with friendly interfaces and simple operations, and has greatly improved the instruction precise rate, heightened the scheduling efficiency, saved the production cost and heightened the production efficiency.

(3) The scheduling system also laid the stable basis for integrated management with developing Computer Integrated Manufacturing System. The application design aims to the present status of Baosteel production, but the way of application design, the model framework, the scheduling rules and the method of resolve also adapt the scheduling of other steel plants. It is easy to make it popular.

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