Planning and scheduling model of production process in iron and steel enterprise

Guozhang Jiang[1], Chongwu Lei[1], Honghai Liu[2], Gongfa Li[1, 2*]

[1]*College of Machinery and Automation, Wuhan University of Science and Technology, Wuhan Postal 430081, Hubei, China*

[2]*Intelligent Systems and Biomedical Robotics Group, School of Creative Technologies, University of Portsmouth, PO1 2DJ, United Kingdom*

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Abstract

According to the analysis of the characteristics of production process in iron and steel enterprise, production planning and scheduling model of multi-stage hybrid procedure and match of production scheduling mode and time were studied. Then the production planning model of production process in iron and steel enterprise was set up. Simulation analysis of production planning and scheduling was carried out using the production procedure of an iron and steel enterprise as an example. The good simulation results show that the established models are correspond to the actual conditions.

Keywords: production planning and scheduling, iron and steel enterprise, production process, multi-stage, simulation

1 Introduction

Iron and steel enterprises need dynamic, timely, ordered and integrated production strategy of production planning and scheduling urgently in order to realize the improvement of product structure and the increase of the production efficiency. It's quite necessary to pay high attention to production planning and scheduling of enterprises.

Steel production process contains a complete process flow, including raw materials, sintering, ore tank, blast furnace tapping, metal adding, LD tapping, refining, continuous casting, slab yard (slab transportation), heating furnace, rolling-coiling and shipping department. The temperature variation with time plays a significant role in each of the steel production process, influencing directly the realization of production planning and scheduling.

2 Production scheduling of multi-stage hybrid procedure

The scheduling of multi-stage hybrid procedure, dependent of the major production plan, uses process level scheduling as a method to realize the optimal configuration of production resources and to make sure of the smooth production progress on condition that the delivery date is guaranteed. Thus, to formulate a reasonable and effective job shop scheduling is an important routine for all manufacturing enterprises.

However it is usually difficult to formulate a scheduling which can satisfy each objective due to the complexity, dynamic randomness and multi-targets characters of real production.

The scheduling of production system can be represented by a model which can reflect the actual production status concisely and completely. The flow shop scheduling problem of hybrid procedure uses methods of mathematics to abstract and describe the production activities and resources (materials, devices, working crew and so on) of enterprises, with the help of computers to carry out statistics, operation and analysis of the system to create fine conditions for a timely and feasible production scheduling. Currently, studies on production scheduling mainly focus on two types, discrete ones and flow ones [1] gives investigations about a typical discrete-typed flow shop scheduling model of an enterprise. Few literatures are found on hybrid process because of the actual difficulty in modelling these kinds of scheduling problems. This study aims to build the mathematical model of the production scheduling of multi-stage hybrid procedure, using the real production of steel enterprises as examples.

Assuming that there are N batches of tasks, each one of which goes through M work centres and completes M procedures. Interruption is allowed between one procedure and the following. All tasks have similar process routes. This type of production scheduling is listed as production scheduling of multi-stage hybrid procedure. The following are assumed to be true in this discussion. 1) Every procedure must be completed in the specified work centre; 2) Every procedure is allowed to start only when the previous procedure is finished; 3) No more than one batch of task is allowed to go at any moment and in any work centre; 4) Once one procedure begins, no interruption is allowed. The optimized target is to find a scheduling to minimize the total cost of earliness/tardiness.

*** Corresponding author** e-mail: ligongfa@wust.edu.cn

The problems of the production scheduling of multi-stage hybrid procedure is already an NP problem. Combined with the nonlinearity, randomness and uncertainty of real production process, the large-scale problem can sometimes meet with the so-called combination explosion problems, which makes it difficult to obtain the optimal solution. The essence of production scheduling problems lies in optimization. That is, on the condition of satisfying the constraints, to choose the best or better solution from a series of feasible scheduling plans to assign the production resources and time to the work. Of course the constraints are complicated. It has been an effective way to solve the production scheduling problems by using computer techniques with the development of computer technology. The main means are to search for the optimal solution or the near optimal solution. The current searching approaches include enumeration method, analytical method, random method and so on. Genetic algorithm is a type of random searching method. Genetic algorithm has been widely applied to fields like engineering design, job scheduling, automatic control machine learning, image processing and artificial life for its obvious advantages of flexibility, glottal search performance, universality and robustness. The traditional management way of mankind suffers from the disability of timely production arrangement according to order changes, which has been the main bottleneck in restricting the development of modern enterprises. In order to reduce cost and promote competitiveness, enterprises need to improve production management by means of information integration, process optimization and resource optimization.

Steel production is a multi-process, multi-unit and multi-stage hybrid procedure and also shows combination of discrete and continuous modes. The converter and refining equipments work discretely. The conticaster works continuously within the working life of the tundish to improve work efficiency and reduce set number and production costs. Hot rolling and cold rolling again are discrete production procedure. The entire production process is iron-making, hot metal pretreatment, steel-making, refining, continuous casting and hot rolling. It contains many production processes, each of which requires many kinds of equipments. The mode of the production procedure is multi-stage hybrid. Figure 1 shows the steel-making system model of multi-stage hybrid procedure.

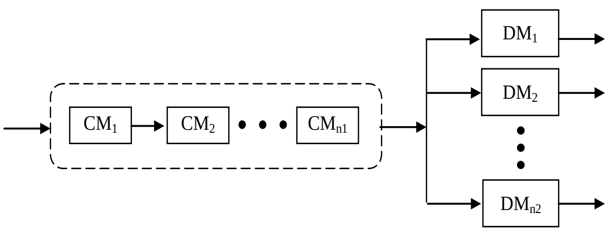

FIGURE 1 The steel-making system model of multi-stage hybrid procedure

3 Match of production scheduling mode and time

The continuous steel making and rolling production line consists of one converter, one refining equipment, one conticaster and tandem mill. The working processes are linked end-to-end. The match among time, temperature and logistics is quite tight, which makes the traditional artificial scheduling unsatisfactory. Thus, the integrative continuous production line of shortened process usually adopts automatic control system, which uses computers to process information and scheduling to optimize the production management.

However, experiences are lacked when it comes to the entire steel-making continuous production line scheduling. Thus, it's essential to study and build the scheduling management model of the process of the continuous production line.

3.1 PRODUCTION PROGRESS AND EQUIPMENT

The production process flow of steel-making production lines is as follows. First, the melted iron are transferred from the converter to the steel tank and go through refining in LF furnace. After processing, the steel grades which don't need to be dehydrated are sent direct to the conticaster for casting. The billets completed in the conticaster are cut into one certain dimensions and transferred by billet shifting machine and hot delivery table into walking beam furnace. After heated, the billets are rolled into different kinds of lumber. Under normal circumstances, the billet rolling ability of the tandem mill accords with the billet providing ability of the conticaster to ensure synchronized production. If there is a short failure or pause of rolling, the billets will be sent to the stepping buffer unit. When the rolling mill gets right, the billets waiting in the buffer unit will then be transferred to heating furnace. Then the rolling machine will go full steam ahead. In that the compact rolling ability of the rolling mill is much bigger than the billets providing ability of the conticaster, and that the billets in the buffer units have played a fine part of buffering, the rolling mill will recover to maintain synchronized production with the conticaster. The process of cold billet knockout from the tandem ill amounts to that in the converter steelshop. The transfer of the cold billet into the heating furnace amounts to the production process in the tandem rolling workshop.

The continuous production line of steel-making actually contains several units, i.e. converter, LF furnace, conticaster, heating furnace, hot billet buffering device and tandem mill. Take some steel-making enterprise as an example, the main performance parameters of each unit are as follows.

1) Converter. The nominal capacity is 120t. The production of steel water is 120t. The tap-to-tap cycle is 42min.

2) LF furnace. The nominal capacity is 120t. The production of steel water is 120t. The usual process cycle is 35~55min, dependent on the types of steel. Varying the

power input will change the average ramp up rate, which can be used to justify the actual process cycle of LF furnace and coordinate the match between the converter and tandem mill as a buffer.

3) Conticaster. The pattern is continuous straightening, two-strand. The types of steel include low carbon steel and high strength low alloy steel. The casting section contains two types, 240mm×240mm and 180mm×180mm. The restranding time is 36min/casting. The output time of the billet is 32min.

4) Heating furnace. The waling beam type furnace is adopted. The specification of the billets is 240mm×240mm×6000mm. The production capacity of hot billets is 132t/h. The production capacity of cold billets is 100t/h. The output time relates to the billet section and reheating schedule.

5) Hot billet buffering device. The buffering time is 30~36min.

6) Tandem mill. The time from rolling termination to gate change is about 10min. The time from rolling termination to frame change is about 20min.

7) Lifting time of steel ladle. The ladle is lifted from converter to LF furnace, and then to the rotary table. After casting, the time of deslagging is respectively 6min, 5min and 6min. The performance parameters and operating time are the basis in of carrying out the logistics control of the production line, which should be tested, statistically detected, analyzed and confirmed. Only when the performance parameters, operating time and fluctuation range of every process unit are possessed, can it be possible to establish the realistic scheduling management.

3.2 CHOOSING OF PRODUCTION MODE

Steel-making and continuous casting are key links in steel production procedure, especially continuous casting. Because on the one hand, continuous casting is a phase-transition in which steel water turns from liquid water to solid billet. On the other hand, there is an inevitable preparation time before casting resumption after a certain amount of continuous casting, during which time it's impossible to cast steel water and also there is no billet output. In continuous production line, both the steel-making process and steel rolling process must adapt to this characteristic, i.e. to provide qualified steel water according to the pace of continuous casting [2, 3]. Under normal circumstances, the hot continuous casting billets outputted from the conticaster will be rolled 100% in the afterwards rolling mill. If the converter and continuous casting don't match well and interrupt happens, dummy bar has to be installed again, which will not only cost time and make the normal order of production disturbed, but also affect the product quality, cause yield loss and improve the consumption of fire resistant materials. Thus, adjust and control should be carried out with continuous casting as the centre in continuous steel-making production line. The control target starts with the optimal choice of key parameters of the conticaster. The steel type, section, casting speed, the continuous casting heats and preparation time should be determined first. And then it will be possible to determine the production capacity of the conticaster. Specific requirements for the flow and timing of converter and rolling mill are given to make sure the continuity and stability of the production line. Figure 2 shows the production paths for a hybrid steel-making system.

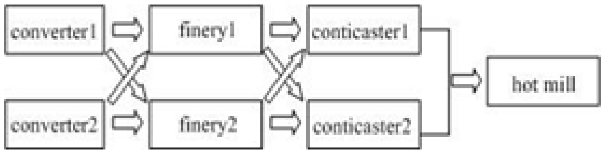

FIGURE 2 The production paths for a hybrid steel-making system

The production modes can be divided into 3 kinds due to the production match type between the conticaster and the converter [4].

3.2.1 Large cycle fit mode

This kind of production mode based on the cycle of continuous casting. If the number of continuous casts is "n". Then, the aim is to make the sum of n casting and the preparation time between two casts (i.e. the cycle of continuous casting) equal to the sum of the refining time of n furnaces of steel water. Because this mode is based on the casting period and that the period is larger than the refining period, so it's called large cycle fit mode.

If the sum of the "i"th steel water processing time in the LF furnace and the lifting time of the ladle from converter to the LF furnace is equal to or larger than the refining period of the converter, it will be impossible for the ladle to reach the LF station on time. The ladle has to wait outside the LF station for a while. The LF station needs to be allocated with several ladle carts. However, the ladle carts will interfere with each other. Also, LF can't play buffering performance between the converter and conticaster. Of course, all of these are unreasonable. Take into account that the buffering ability of LF furnace $t = t_{converter} - t_{crane}$ reduces along with the shortening of the refining period and the lengthening of LF's shortest processing period. If $t = t_{converter} - t_{crane} = 0$ happens, the LF furnace will lose its buffering performance. If the amount of planned casts is less and the preparation time is longer, the casting speed allowed will not be able to satisfy the restriction of large cycle fit mode for single tank casting time.

3.2.2 Small cycle fit mode

This production mode based on the refining period of the converter. That is to maintain the consistency between single tank casting time and the refining time. Similarly, the refining period is smaller than the casting cycle. This is why it is called small cycle fit mode. This mode is able to give the best match of furnace and machines. Also, the processing cycle of the LF furnace remains unchanged, which shows great repeatability and reproducibility. It is easier to be understood and the buffering action of the furnace will perform better. However, the converter could not do continuous production. In one casting, the converter need a timeout according to the preparation time of continuous casting. This timeout can be used for hot fixing or equipment maintenance. Also, the timeout could be used to lower the input power intentionally, or to carry out heat preservation after adding the steel crap in order to prolong the refining cycle of the steel in the first furnace to make it match with the conticaster.

3.2.3 Large and small cycle combination fit mode

This fit mode is between the large cycle fit mode and the small cycle fit mode. This mode starts with the key parameters of the conticaster. If the best casting speed chosen according to the steel type and steel section, based on which the single tank casting time is chosen, then the single tank casting time can be able to either longer or shorter than the refining time as long as the two times are close. The imbalance between the converter and continuous casting is justified by LF furnace. When the single tank time is shorter than the refining time, it's not necessary for the conticaster to lower intentionally the casting speed to maintain the accordance of single tank casting time and refining time as in small cycle fit mode. What's more, the timeout after finishing one casting is shorter than that in the small cycle fit mode, which can improve the utilization rate of factory equipments and production capacity.

Considering the multi-stage scheduling and match problems, this study will choose the first kind of mode, i.e. large cycle fit mode, according to the analysis on the 3 production modes.

In the large cycle fit mode, the following relations exist.

$$nt_{CC} + t_P = nt_{LD}\,, \tag{1}$$

where, t_{CC} is the single casting time, t_{LD} is the refining time in the converter, t_P is the preparation time for one casting, n is the amount of casts.

In this mode, the converter goes continuously with the same refining cycle. But the processing period of the LF furnace in one casting will vary along with the difference of processing furnace, calculated from

$$t_{LFi} = t_{LFO} + (n-i)t_P/n\,, \tag{2}$$

where t_{LFi} is the processing cycle of the i-th steel water in the LF furnace, t_{LFO} is the minimal processing cycle which can meet the technical requirements, i is the sequence number of the LF processing and $i \le n$.

Now there are 2 converters, 2 LF furnaces, 2 conticasters and 1 rolling mill, among which, 1 converter faces 1 LF furnace and 1 conticaster. Assuming that there are k rolling units, each of which has w slabs. Also, there are m casts in each production line and each casts will cast n furnaces.

The starting time of each station of the i-th steel water in each production line is

$$T_{LDi} = (i-1)\times t_{LD} \tag{3}$$

$$T_{LFi} = i\times t_{LD} + i\times t_{LD\to LF} + \sum_{l=0}^{i-1} t_{LFl} \tag{4}$$

$$T_{CCi} = i\times t_{LD} + i\times t_{LD\to LF} + \sum_{l=1}^{i} t_{LFl} + i\times t_{LF\to CC} + T_P + (i-1)\times t_{CC} \tag{5}$$

where $T_P = \left[\frac{i-1}{n}\right]\times t_P$ is the preparation time of the cast($\left[\frac{i-1}{n}\right]$ is a rounding function), $T_{LDi}, T_{LFi}, T_{CCi}$ are the processing starting moment of the i-th steel water in the converter, the LF furnace and the continuous casting station, respectively, $t_{LD\to LF}, t_{LF\to CC}$ are the transfer time from the converter to the LF furnace and from the LF furnace to the conticaster, respectively.

The starting time of the j-th slab in every procedure process is calculated from

$$T_{ROj} = T_{CCi} + t_{CC} + j\times t_{CC\to RO} + (j-1)\times t_{RO} + T_Q\,, \tag{6}$$

where, $T_Q = \left[\frac{j-1}{w}\right]\times t_Q$ is the preparation time needed for the rolling unit ($\left[\frac{j-1}{w}\right]$ is a rounding integration)

where, t_Q is the preparation time of the rolling unit, $t_{CC\to RQ}$ is the transfer time from the conticaster to the tandem mill.

The total time of the production process is

$$T = mn\times(t_{LD} + t_{LD\to LF} + t_{LF\to CC} + t_{CC}) + \sum_{l=1}^{mn} t_{LFl} + (m-1)\times t_P + kw\times(t_{CC\to RO} + t_{RO}) + (k-1)\times t_P\,. \tag{7}$$

4 Production scheduling simulation analysis

The production plan and scheduling in steel-making enterprises are transmitted to every flow shop according to the order contracts and inventories. Then, the flow shop determine the refining, continuous casting and fit mode to arrange the production scheduling time according to global optimization principle based on the performance parameters of the units and some other principles. These are the basic control of all kinds of operation targets in the production process. The continuous production flow process of steel begins from charging to finished products of hot rolling [5]. An realistic production scheduling of the steel enterprises is shown in Figure 3. The scheduling results of the actual working procedure time and production is shown in Figure 4. Based on this, the ideal production scheduling model is built on basis of the production plan and the performance parameters of each unit [3, 4]. Here, take an realistic steel enterprise as an example to illustrate the general process. Make production plans according to the steel products order contracts and inventories. Determine the steel type, casting section and number of casting furnaces. Choose the production fit mode and put it into the database. The computer will arrange the ideal working procedure time and production scheduling sheets, i.e. formulate an ideal production plan and scheduling model, according to the procedure time sequences of each unit, based on the starting time of the converter refining. Working instructions are decomposed, that is to set out the production states of the converter, LF, conticaster, heating furnace, hot slab buffering devices and tandem mill at each moment, based on which the control of all kinds of operating targets is carried out. For example, to make grade steel according to the production plan. The casting slab is 200mm×1600mm, 4 casts are permitted and corresponding melting numbers are given. Put these data into the database to determine the production mode. If large cycle fit mode is chosen, the preparation time for casting of the 200mm×1600mm slab stored in the computer is 58min. The single tank casting time is 36min based on the model. Then compute the casting speed of the production line based on Equations (1) – (7), with combination of single tank casting time, refining time and hot rolling. Then the operating time sequence of each flow procedure can be calculated. Figure 5 is the simulation chart of the production scheduling. That is, Figure. 5 gives an ideal scheduling mode of a continuous production process concluding steel-making and steel rolling.

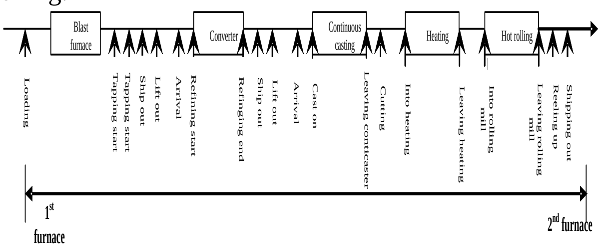

FIGURE 3 scheduling arrangement of the steel making production procedure

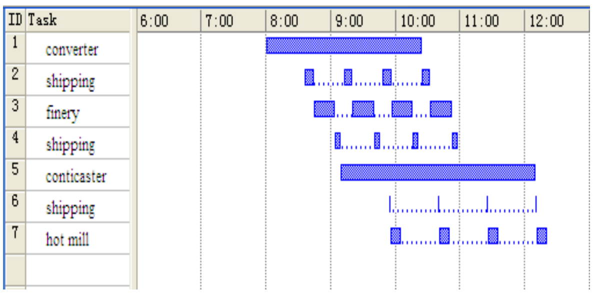

FIGURE 4 The real working procedure time and production scheduling

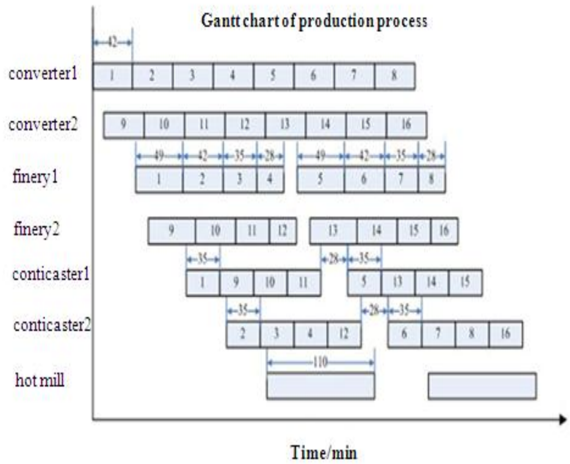

FIGURE 5 The ideal table of working procedure time and production scheduling

It can be seen from Figure 5 that:

1) The steel water production capacity of the converter is 12t. The refining cycle is 42min. There is a timeout of 18min after the continuous production of 4 converters of steel water, which could be used to carry out equipment maintenance and repair.

2) The Lf processing cycle reduces with the increase of the processing numbers. The minimal processing cycle is 28min.

3) The single tank casting time of the conticaster is 35min. The preparation time between two casts is 28min. The output time from casting beginning to send the first billet into the heating furnace or the hot buffering devices is 30min.

4) The transfer time of the ladle from the converter to LF, from LF to the conticaster are 4~6min. The dispatch table gives the dislagging working time of the crane.

5) 15 minutes after the rolling mill stops working, the inventories of billets in the hot buffering devices reduces gradually, which is the same when it comes to the inventories after the rolling mill restarts.

6) There is an accordance between the rolling capacity of the rolling mill and the billets providing capacity of the conticaster. Both are 80t/h.

In continuous production line, every working procedure time is constrained by its process condition and some external conditions. The variation of one working procedure time will cause changes in the adjacent working procedure, which will result in disturbances in the entire flow process. Thus, real-time control is needed. The database system needs two data sheets. One is a permanent data storage sheet about the real-time simulation of the working procedure time and production scheduling, with the refining number as the only symbol. The other one is an ideal data sheet for the current casting, which is an ideal scheduling model. The latter one gives the production pattern, effects range and processing mode of refining and continuous casting. If the combination of the computers and experiences is adopted, then whether to continue casting will be determined after one casting. If the answer is yes, then the requirements of service life of the equipment should be satisfied, i.e. the water gap of the tundish and the conditions of the fire resistance materials. In the meantime, there is requirements on time plan, mainly the plan of the ladle continuous casting. Also, there is another problem which needs to be paid attention to. That is, after LF processing and lifting, whether the link is available after the last furnace of steel water finishes its casting.

5 Conclusions

Gantt chart is obtained after the application of the production scheduling model of the steel-making process. Production plan and scheduling of the enterprise are realized.

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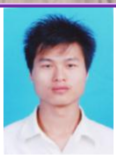
Authors

Guozhang Jiang, born on December 15, 1965, Tianmen, China

Current position, grades: Professor of Industrial Engineering, and the Assistant Dean of the college of machinery and automation, Wuhan University of Science and Technology.
University studies: the Ph.D. degree in mechanical design and theory from Wuhan University of Science and Technology, China, 2007.
Scientific interest: computer aided engineering, mechanical CAD/CAE and industrial engineering and management system.
Publications: 120.



Chongwu Lei, born in 1988, Hubei China

Current position, grades: student M.S. degree in mechanical manufacture and automation at Wuhan University of Science and Technology.
University studies: B.S. degree in mechanical design manufacturing and automation from Jiangcheng College, China University of Geosciences, Wuhan, 2012.
Scientific interest: production planning and scheduling, industrial engineering and decision support system.

Honghai Liu, born in 1973, China

Current position, grades: Professor in Intelligent Systems, Head of Intelligent Systems and Biomedical Robotics, University of Portsmouth.
University studies: PhD in Intelligent Robotics in 2003 from Kings College, University of London, UK.
Scientific interest: approximate computation, pattern recognition, multi-sensor based information fusion and analytics, human machine systems, advanced control, intelligent robotics and their practical applications.
Publications: 300.
Experience: research appointments at King's College London, University of Aberdeen, and project leader appointments in large-scale industrial control and system integration industry.

Gongfa Li, born in 1979, Hubei China

Current position, grades: Associate professor, college of Machinery and Automation, Wuhan University of Science and Technology.
University studies: Ph.D. degree in mechanical design and theory from Wuhan University of Science and Technology in China.
Scientific interest: modeling and optimal control of complex industrial process.
Publications: nearly twenty papers in related journals.