Chapter 11
Order Acceptance and Capacity Balance for Steel Plant Based on Production Capacity Network Flow

Zhi-min Lv and Jian-zhong Du

Abstract There is a collaborative problem between the production department and marketing department of steel enterprise because of the diversity of varieties and the complexity of production process. For this kind of issues in the condition of multi products and multi processes, this paper proposes a production capacity network flow (PCNF) model that can quickly extract the information of problem and simplify the process of mathematical modeling. To solve the problem of order acceptance and capacity balance in steel enterprises, we abstract the capacity of supply and demand in the steel manufacturing process into a PCNF model, and develop a mathematical model. The model is solved by a heuristic algorithm, and the objective of solution is based on degree of satisfaction in practical production, rather than seeking the optimal solution of the problem. Instances of the application show that the accuracy and efficiency of the algorithm can meet the practical demand.

Keywords Order acceptance • Capacity balance • Production capacity network flow model • MTO • MTS

Introduction

As the steel market has changed from sellers' to buyers', order-driven production mode becomes the mainstream. But in steel plant, it is difficult to reverse the product demand to capacity demand because of the long and complex process, so it is necessary to find an effective method to complete this transform. In addition, there are both MTO and MTS mode in steel enterprises. The flexibility of MTS

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brings another problem of how to choose varieties. Therefore, finding an effective method to solve that problem and achieve the balance of production capacity will be difficult and urgent. Due to the process is not unique, combining different products or adjusting the process might be a possible method to achieve that goal. Hence, this paper is from a new point to solve those problems.

In the past years, most researchers assumed that the production process was fixed and the order attribute is simple when they balanced the problem of order acceptance and production capacity. Slotnick (2011) had reviewed the past research on order acceptance problem. Kalantari et al. (2011) presented a novel decision support system for order acceptance/rejection in a hybrid MTS/MTO production environment, which considered the constraint of production capacity. Cao Junjie and Shi Hongbo (2010) developed a practical model of order planning with resource constraints based on compressor enterprise, and adopted improved genetic algorithm to search for the decision situation. With the multi nodes production environment, Xiao Yiyong et al. (2008) introduced an order acceptance model, which solved by simulated annealing algorithm that optimized both selection and sorting for orders. For multi processes issue, Lao Ben-xin and Li Xiao-hua (2010) discussed how to calculate the capacity requirement when there are optional processes.

Nowadays, many researches focus on the coordinated approach to production and sales for manufacturing enterprise. But for steel industry features multi varieties and multi processes, related research is rare on the knowledge of authors. In some researches, order planning is decomposed into mid-term and short-term production planning, and an integrated steel enterprise mid-term planning model is presented (Song Xiaoqing et al. 2011; Lv Zhimin et al. 2011). On the basis of mid-term planning, the demand of capacity is allocated for every process and then coming into a short-term planning which could guide production scheduling (Lv Zhimin and Song Xiaoqing 2011). This model is closer to actual production process of iron and steel enterprise, which can be a guide for system design.

In this paper, according to the characteristics of the steel production process, the production capacity network flow model is proposed. It is abbreviated by PCNF. PCNF shows the relation between production capacity demand and supply. It can help to develop the mathematical model and solution method. Instead of complex mathematical method, a practical logic process is proposed to calculate and evaluate capacity quickly.

Problem Description and Mathematical Modeling

Problem Description

The process of steel production can be divided into several stages, including iron-making, steelmaking, refining, continuous casting, hot rolling and cold rolling and so on. Every stage as well is also divided into a number of processes, which contains

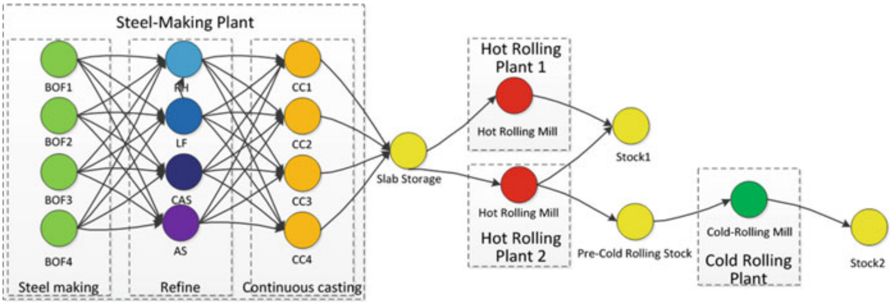


Fig. 11.1 The network structure of steel production flow

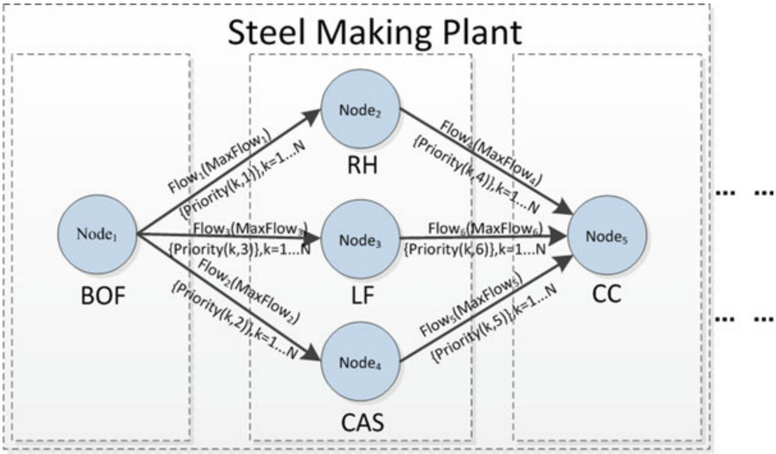


Fig. 11.2 Diagram of production capacity network flow

multiple units. Capacity utilization influences each other during the processes, which forms a complex network structure as shown in Fig. 11.1.

We extracted a part of network flow from production process, which is shown in Fig. 11.2. This is a production capacity network flow (PCNF) model that can extract the information of problem and simplify the process of mathematical modeling. As shown in Fig. 11.2, Node_i represents the equipment. Flow_j represents the occupied production capacity by which directed lines point to. Meanwhile the maximum available flow is represented by MaxFlow_j. Products have different process routes from the initial node to the final node, which are not parallel but distinguished by their priorities. The higher priority is, the more possible the route will be selected. The same path for different products may have different priority. Priority(k,j) represents the priority on route j to product k. {Priority(k,j)} represents the priorities set of all the products at this route. Penalty factor is available to represent priority in model calculation.

The node of production capacity network can not only express a single device in the production, but also a group of equipment with the same considerable attributes. The latter is more suitable for representation and calculation of production capacity.

There is a flow restriction in production capacity network flow. For this kind of network, there are various studies of maximum flow problem. Punnen and Zhang (2009) classified several well-studied bottleneck problems such as the bottleneck transportation problem (BTP), bottleneck assignment problem (BAP), bottleneck path problem (BPP) as bottleneck network flow problem (BNFP). Meanwhile he put forward a complex algorithm of $O(\min\{m(n\log n)^{2/3}, m^{3/2}\sqrt{\log n}\})$, which reduced the time complexity of the algorithm. Melkonian (2007) introduced flows in dynamic networks with aggregate arc capacities, and gave a linear programming formulation for the problem which is based on the time-expanded network of the original dynamic network.

Because the variability of equipment's working state, the number of network nodes, flow and network access conditions will change over time, the production capacity network is a more complex dynamic network model.

In this paper, the production process abstracted into network flow model to unify capability of manufacturing process including smelting, casting, hot rolling (including finishing), cold rolling (including cold rolling finishing) and other major processes.

Mathematical Model

The establishment of mathematical model is simplified according to the production capacity network flow model. The mathematical model is abstracted based on the following assumption: (1) Sales department would provide the market demand forecasting, or the forecasting of future sales proposal. (2) Sales contracts and its execution state in the past, current and future period are known. (3) The working time and effective operating rate of equipment are known. (4) The fundamental data of process and capacity demand on every device for each variety and specification is known. (5) The hot metal supply quantity in future period is known. (6) The quantity constraints of producible products with limit specification are known. (7) The selling price has been determined. (8) The quantity of the materials with open order in inventory is known. (9) The expected costs for all related products are known. (10) The current production process is clear.

- Description of symbols
  Notations used for the problem formulation:

  N: Total number of product;
  L: Total number of processes;
  M_j: Total number of equipment at process "j";
  F_{cost}: The fixed cost of production;
  x_i: Planned output of product "i";

I_{ij}: The inventory of product "i" at process "j";
ω_{ij}: Whether product "i" passes process "j" or not;
λ_i: Whether product "i" is extreme material or not;
φ: The achieved satisfaction degree to the least extent;
θ_{ij}: The yield rate of product "i" at process "j";
p_i: The price of product "i";
c_{ij}: The cost of product or semi-finished product of product "i" at process "j";
q_{ij}: The number of WIP of product "i" at process "j";
$D_b(ij)$: The minimum production lot of product "i" at process "j";
$D_{up}(ij)$: The maximum allowed quantity of product "i" with limit specification at process "j";
Or_{jk}: The capacity occupied by signed contracts of device "k" at process "j";
$D_{order}(i)$: The signed production quantity of product "i" in planning period;
$D_{pre}(i)$: The proposal quantity of product "i" in future period;
$obligate_i$: The necessary quantity of product "i";
Cap_{ijk}: The capacity per hour of device "k" of product "i" at process "j";
Q_{jk}: The available capacity during the current planning period of device "k" at process "j", in hours;
T_{jk}: The available time of device "k" at process "j";
M_{jk}: The maintenance time of device "k" at process "j";
L_{jk}: The capacity occupied by active product of device "k" at process "j".

- The objective:

$$\sum_{i=1}^{N} (x_i \cdot p_i) \tag{11.1}$$

$$\sum_{i=1}^{N} \left[x_i \cdot p_i - \sum_{j=1}^{L} c_{ij} \cdot x_i\right] - F_{\cos t} \tag{11.2}$$

$$\sum_{i=1}^{N} \sum_{k=1}^{M_j} \frac{\left(\frac{\omega_{ij}(x_i + D_{order}(i))}{\theta_{ij}} + q_{ij}\right)}{Cap_{ijk}} \leq \sum_{k=1}^{M_j} (T_{jk} - M_{jk}) \tag{11.3}$$

- Subject to:

$$\sum_{i=1}^{N} x_i >= \sum_{i=1}^{N} obligate_i \tag{11.4}$$

$$\omega_{ij} = 0, 1$$

$$\begin{cases} \dfrac{x_i}{\theta_{ij}} \geq 0; & if \quad \omega_{ij} = 1 \\ \dfrac{x_i}{\theta_{ij}} = 0; & if \quad \omega_{ij} = 0 \end{cases} \quad i = 1, 2 \ldots N; \quad j = 1, 2 \ldots L \tag{11.5}$$

$$\begin{cases} \dfrac{x_i}{\theta_{ij}} \geq D_b(ij) || \dfrac{x_i}{\theta_{ij}} = 0; & if \quad \omega_{ij} = 1 \\ \dfrac{x_i}{\theta_{ij}} = 0; & if \quad \omega_{ij} = 0 \end{cases} \quad i = 1, 2 \ldots N; \quad j = 1, 2 \ldots L \tag{11.6}$$

$$\lambda_i = 0, 1$$

$$\begin{cases} \dfrac{\lambda_i x_i}{\theta_{ij}} \leq D_{up}(ij); & if \quad \omega_{ij} = 1 \\ \dfrac{\lambda_i x_i}{\theta_{ij}} = 0; & if \quad \omega_{ij} = 0 \end{cases} \quad i = 1, 2 \ldots N; \quad j = 1, 2 \ldots L \tag{11.7}$$

$$x_i \leq D_{pre}(i) \quad i = 1, 2 \ldots N \tag{11.8}$$

$$\begin{cases} L_{jk} = \sum_{i=1}^{N} \dfrac{\omega_{ij} q_{ij} \theta_{ijk}}{Cap_{ijk}}; & \text{if } j \text{ is the post process} \\ L_{jk} = 0; & \text{if } j \text{ is the pre-process} \end{cases} \quad j = 1, 2 \ldots L; \; k = 1, 2 \ldots M \tag{11.9}$$

$$Or_{jk} = \frac{\omega_{ij} D_{order}(i)}{\theta_{ij} Cap_{ijk}} \quad j = 1, 2 \ldots L; \quad k = 1, 2 \ldots M \tag{11.10}$$

$$Q_{jk} = T_{jk} - M_{jk} - L_{jk} - Or_{jk} \quad j = 1, 2 \ldots L; \quad k = 1, 2 \ldots M \tag{11.11}$$

$$Q_j = \sum_{k=1}^{M_j} Q_{jk} \quad j = 1, 2 \ldots L; \quad k = 1, 2 \ldots M \tag{11.12}$$

$$U_j = \frac{\sum_{i=1}^{N} \sum_{k=1}^{M_j} \frac{\omega_{ij} x_i}{\theta_{ij} Cap_{ijk}}}{Q_j} \tag{11.13}$$

(11.1), (11.2), and (11.3) are objective, which respectively represent sales revenue, profit and proportion of capacity occupied. Among them, the targets of sales revenue and profit can be set based on the acceptable degree of practical application.

Equation (11.4) is mandatory minimum throughout constraint. Equation (11.5) is process route constraint. Products pass the process while $\omega_{ij} = 1$, then the process output must be greater than 0. Equation (11.6) is minimum production lot constraint.

Every process has its minimum production lot size. If the product has been planned, the planning production quantity must be greater than the minimum. Otherwise, the products would not produce any more. Equation (11.7) is product lot size constraint with limit specification. The planning output of these materials cannot be greater than maximum capacity. Equation (11.8) is general output constraints according to experience. Equation (11.9) expresses that the process capacity before WIP would not consume anymore while there are WIP inventories. Equation (11.10) is used for calculating the capacity occupied by contract plan. Equation (11.11) expresses that the available production capacity of equipment equals to standard capacity minus the occupation of equipment maintenance, WIP and signed contrasts. Equation (11.12) is used for calculating available capacity; Eq. (11.13) is occupied ratio of process capability.

Solution Procedure

The mathematic model shown in section "Problem Description and Mathematical Modeling" can be solved by intelligent optimization algorithm or other mixed optimization method. But in our research, we introduced heuristic method to solve the model. The heuristic method is based on predefined strategies. The procedure is as follows: (1) assessing supply and demand of capacity by using Eqs. (11.10), (11.11), (11.12), and (11.13); (2) identifying the bottleneck units or processes; (3) eliminating the bottleneck units or processes according to predefined strategies; (4) allocating surplus capacity. In practical applications, we can predefine various strategies to improve the applicability of algorithm.

To illustrate the solution procedure, a simple process example is shown in Fig. 11.3. Based on the technical definition, there are eight process units. When given the product demand, according to the solution procedure, bottleneck processes are 6, 1, 5 and 8 in order by utilization after assessing supply and demand of capacity. The bottleneck unit identification result is shown in Fig. 11.4. As shown in Fig. 11.4, when adjust the process which has the most utilization, the related process units are adjusted too. Choose the next process to adjust until all of the utilizations are less than 100%. Then the set of surplus processes are known as $CAP = \{1,2,3,4,5,7,8\}$. Sort all of orders by strategy which have the process as Proc and $CAP \cap Proc = Proc$ and subject to Eqs. (11.7) and (11.8), such as $Proc = \{1,2,5,7,8\}$. Allocate the surplus capacity for them until there is no matched order. The solution procedure flow is illustrated in **Procedure**:

Procedure

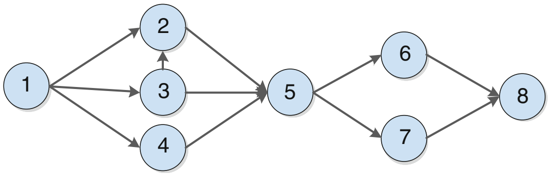
Step 1: Initialize processes for the varieties of orders;

Step 2: Calculate capacity utilization based on the initial process and the past, present and future sales contracts;

Step 3: Identify the processes whose utilization is greater than 100% as bottleneck units;

Step 4: Sort bottleneck units by utilization;

Fig. 11.3 Example of process



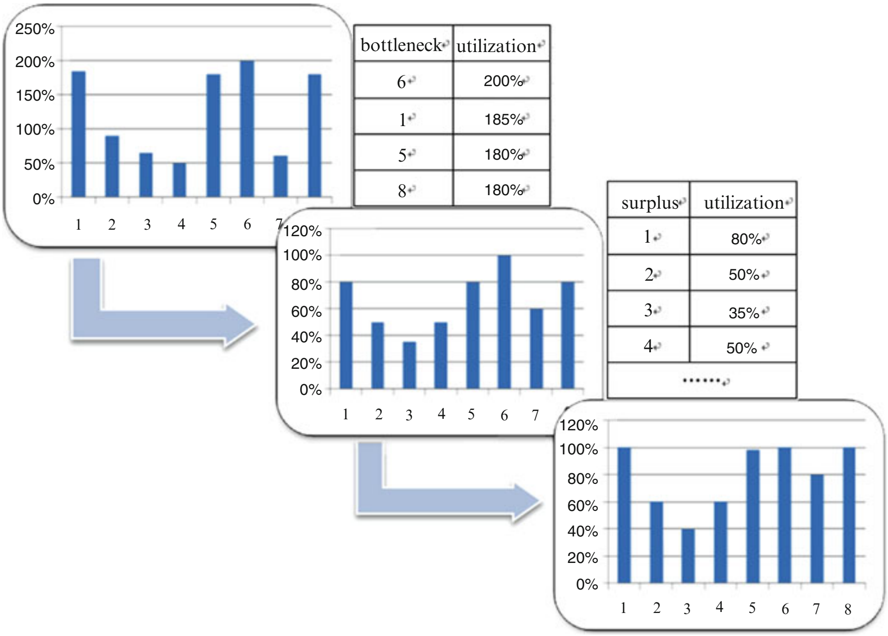


Fig. 11.4 Solution procedure

Step 5: For (units: all bottleneck units)
(1) Sort orders which include units according to strategy;
(2) Drop the first order;
(3) Calculate capacity utilization again;

IF the utilization of unit <100%

Continue;

ELSE

Back to 2);

End For;

Step 6: Define a set of processes which have surplus capacity as CAP = {ai,bj,. . .};

Step 7: Sort orders dropped according to strategy, defining whose process is Proc (i) = {a,b,c. . .};

Step 8: For (order: orders dropped)

IF CAP∩Proc(i) = Proc(i)

Calculate suitable output;
Update CAP;
IF CAP is empty

Break;

End IF;

End For;

Application

Utilizing the PCNF model and the solving process, we design the product capacity calculating and planning system for an integrated steel enterprise, which has 1 steel-making plant, 2 hot-rolling plants and 1 cold-rolling plant. The steel enterprise has 18 main devices in total and its maximum throughout per month is 762,600 t.

To prove the PCNF model and solution procedure are feasible and practical, we give an example of data of some month, which has a scale of 400 orders among which 85 orders with higher priority. The total demands are 1,337,300 t. When we put total demands as the input of the model, the result of calculating capacity utilization without adjusting is shown in Fig. 11.5. If we balance the production capacity and production demand based on the predefined strategies, one result of utilizations after adjusting is shown in Fig. 11.6. Before adjusting, BOF, CC and

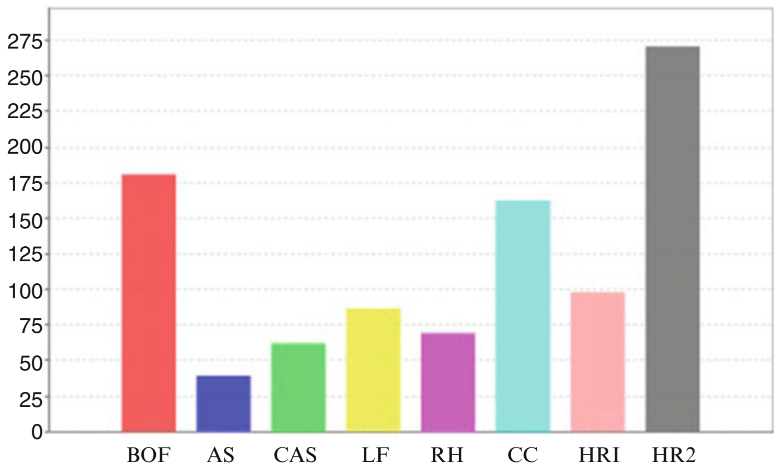


Fig. 11.5 Utilizations before adjusting

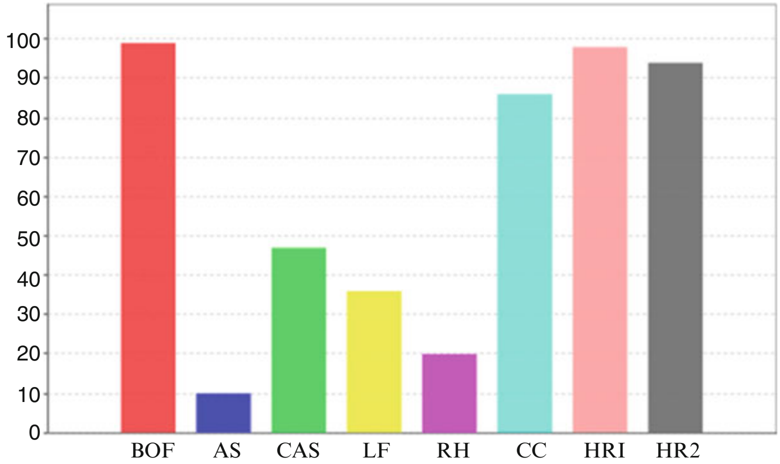


Fig. 11.6 Utilizations after adjusting

Table 11.1 Running results

Item	Value	Item	Value
Runtime	75 s	Best utilization	99%
Avg. utilization	63.20%	1st priority orders	85
Orders accepted	262	Orders adjusted	125
Total demands/t	1,337,300	Total output/t	738,100

HR2 are bottleneck process, and HR2 has the highest load rate. After adjusting, utilizations of all the processes are less than 100%. As BOF, CC, HR1 and HR2 are working on almost full load, they already can't increase the output.

This application is run on the computer, which CPU is Intel i5 2.67 GHz, RAM is 6 G Bytes. The other results are shown on Table 11.1. From this table, we know that the efficiency can completely meet the requirement of practical production. After adjusting by strategies, the work load rate of main devices, such as BOF, HR1, HR2, etc. is nearly 100%. And the output has reached 97% of the max throughout. In addition, all the orders with 1st priority will be produced in planning period.

The bigger the scale of orders is, the longer runtime will be requested. But the runtime is still within acceptable limit. Its efficiency and effectiveness can absolutely meet the needs of practical application.

Conclusion

It is an important subject that reducing production cost, improving economic benefit and providing better services for consumers by effectively using current resources. Order acceptance is the key to ameliorate customer services, maximize plant throughputs and reduce inventory levels. The contribution of this paper is that it gives a solution of the problem of order acceptance and capacity balance for steel plant. The proposed production capacity network flow model, which is called PCNF, is effective and efficient to set up the mathematical model. The actual test result shows that the model and solution method by using the predefined strategies is quick enough to calculate and evaluate the capacity, and can improve the coordination between sales department and manufacturing department.

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