대한산업공학회/한국경영과학회 2002 춘계공동학술대회
한국과학기술원(KAIST) 2002년 5월 3일-4일

Lot Planning & Scheduling in the Integrated Steelmaking Process

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Abstract

Steel industry is the most capital intensive and the largest energy consuming industry, which operate huge and complex facilities to supply various steel products as the primary materials to almost every manufacturing industry. Major steel products are hot-rolled and cold-rolled coils, plates, and wires that are produced through molten iron making, molten steel making, casting, and rolling. Each process runs in batch between setups and the specifications of batch are different with each other. High energy consuming and heavy material handling require careful synchronization of processes, as well.

Considering the synchronization of processes, the lot planning and scheduling problem in the integrated steelmaking process covers the roll grouping with given casts, the sequencing of rolls over time, and the machine assignment and time scheduling of charges and casts. The problem is investigated by dividing it into two cases whether single or parallel machines at the molten steel making and the continuous casting processes.

Problem descriptions and solution approaches of each instance are introduced. To test their performance and conformity, implementation of the algorithms and numerical experiments are carried out with real world and constructed data sets.

1. Introduction

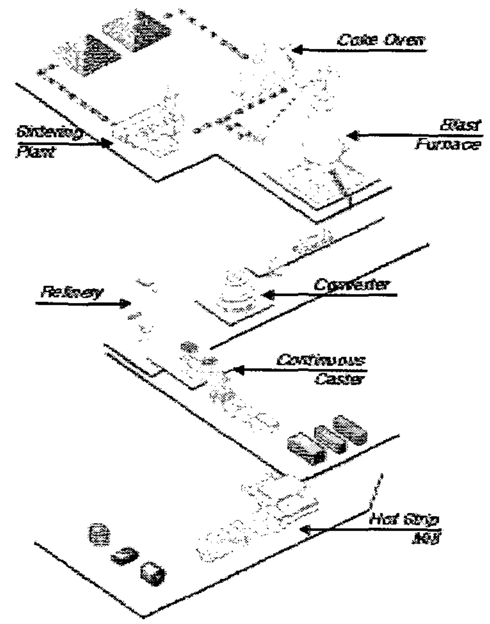
Although the advances in material science have introduced new materials substituting steel, steel keeps it primary position as the most economical and physically excellent material in almost every manufacturing industry such as construction, automotive, packaging, electronics, etc. Steel industry is one of the most capital intensive and excessive energy consuming industries. It has different characteristics distinguished from other manufacturing industries. First, as a process industry, large capital investments is required to build and run its processes, which produces steel products as a primary material of other manufacturing industries. Second, steelmaking process makes almost infinite many sorts of product from single raw material, the iron ore through highly integrated production process. Third, heavy material handling requires the synchronization of the processes and since setup costs are very expensive, large volume of production is required and long production lead time is inevitable.

Steel products are classified by their metallurgical composition, production process, and shapes. There are stainless and non-stainless steel products distinguished by metallurgical composition. The former is the alloy of ferrite, nickel, and chrome. Hot-rolled and cold-rolled products can be classified by production processes. Hot-rolled products are produced through molten steelmaking, casting, and hot charged rolling and cold-rolled products are made from hot-rolled products by cold charged rolling, annealing, and other post processes. By shape of the products, there are flat-rolled coil that is most widely used, plates and wires. Construction, automotive, ship building, and packaging industries are the major consumers of steel products, but almost every manufacturing industries use steel products as their primary materials directly and indirectly by second hand suppliers.

2. Contemporary Steel Production Process

There are two types of molten iron making process. One is using blast furnace to make iron ore and cokes into molten iron and the other is using electric arc furnace with steel scrap. The iron making using blast furnace cannot stop its production, which enforces the steel making and casting process running continuously. Molten iron is transferred to the steel making and refining process to adjust its metallurgical composition. The continuous casting produces slabs, blooms and billets, the only in-process inventories, and feeds the rolling process to produce hot coils, plates and wires. Hot rolled coils become the raw material of the cold rolling process to produce the cold-rolled coils. Figure 1 depicts one of the contemporary steelmaking processes.

The blast furnace is the major iron making processor with iron ore, coke, lime stone, sinter, etc. as the raw materials. Liquid iron, tapped from BF, will be transported to the steel making shop where basic oxygen furnaces and/or electric arc furnaces are located. BOF and EAF burn out the excessive carbon, sulfur, silicon, and other impurities from liquid iron and refine it to steel with desired contents.



[Figure 1] Contemporary steelmaking process

Liquid steel, after being degassed, can be processed in the continuous caster and cast into slabs. Or, it may be poured and teemed into ingots, then heated in the soaking pits, rolled at a rolling mill, converted into slabs. After being conditioned and reheated (these reheat processes may be skipped in some cases with new technology), slabs will be further rolled by the hot strip mill and converted into steel coils. These coils are then pickled, cold rolled, annealed, or tempered, or heat treated, and finished, depending on the required mechanical properties. They are now ready for shipment to the customers.

3. Issues on the Scheduling in Steel Industries

Among the various part of the production management issues, scheduling in the integrated steelmaking process takes its important role since little improvement of scheduling can yield great amount of profits or cost savings and vice versa. In general, the goal of scheduling is the generation of the optimal or near optimal schedule, which satisfies the constraints of processes in short computation times. With growing attention to the supply chain management, fast computing times for planning and scheduling are needed to achieve the consistent response to the ATP (Available to promise) or the CTP (Capable to promise) as well as rescheduling. Practically scheduling experts and system developers request fast and comprehensive algorithms or procedures that are easy to maintenance.

3.1. Difficulties of the Scheduling

Scheduling in the integrated steelmaking process is known to be one of the most difficult problems, but need of better schedules is growing with the development of new production technologies and ingenious management skills, the improvement of computing power, and the fast increment of IT (information technology). However, the integrated steelmaking process has the following characteristics making the scheduling problem hard to solve.

- ◎ Make-to-order
- ◎ Multi-stage compound flow shop
- ◎ Integration of continuous and discrete processes
- ◎ Out-tree product structure
- ◎ Long production lead time

3.2. Scheduling Issues in Steel Industries

The scheduling of the integrated steelmaking process has the following goals to achieve and problems to solve:

Goals

- ○ Ensuring capacity for the flexibility of scheduling
- ○ Load balancing for multiple production processes
- ○ Securing productivity of each process
- ○ Lot synchronization for minimizing energy loss
- ○ Lot grouping and sequencing to meet due dates
- ○ Lot grouping and sequencing to meet the needs of downstream processes

Problems

- Determining effective orders (demands)
- Semi-finished product design
- Designating orders or lots into the parallel production process
- Grouping orders into lots for each process
- Sequencing lots throughout the production process
- Rescheduling with rolling horizon planning

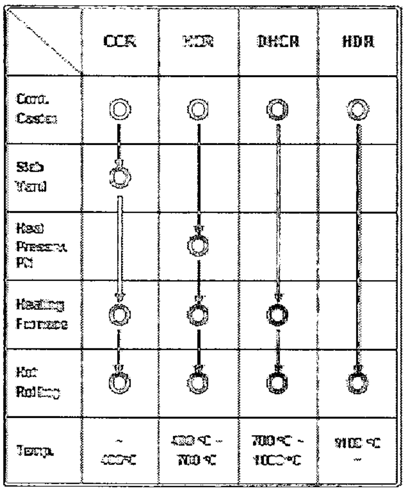
Throughout this study, the problem of sequencing of lots in the synchronized production process is investigated and it is modeled as a compound flow shop problem.

4. Lot Sequencing Problem

The lot sequencing problem in the integrated steelmaking process covers the roll grouping with given casts, the sequencing of rolls over time, and the machine allocation and time scheduling of charges and casts. There are three types of synchronization in molten steel making (SM), continuous casting (CC) and hot charged rolling (HR) processes.

4.1. Types of Synchronization

There are three types of synchronization between CC and HR processes; HDR, HCR (DHCR), and CCR. HDR stands for the hot directed rolling, in which the sequence of casting and rolling is exactly the same and there is no lead time between casting and rolling. In CCR (Cold Charged Rolling) processing, SM-CC and HR processes are disconnected so that there is no relation between the sequence of casting and rolling. In the hot charged rolling (HCR) process, slabs from caster(s) are fed into the rolling process consecutively within a certain lead time, and the sequence of casting and rolling may not identical. Figure 2 depicts the characteristics of CCR, HCR, DHCR, and HDR comparing their processes and slab charging temperatures.



[Figure 2] CCR, HCR, DHCR, and HDR

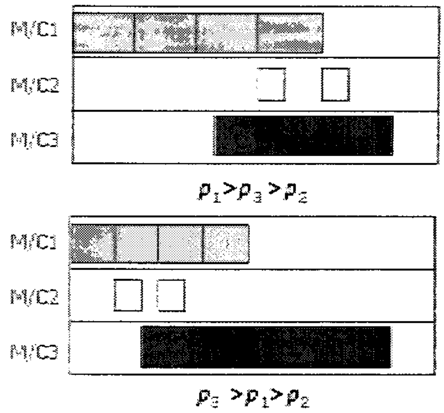
Throughout this study, only the HCR case is investigated because the case of CCR processing is included in the HCR case, and the HDR processing has very specialized production processes like Mini Mill. There could be various environments for the HCR processing, but hereafter the following two cases are investigated.

Case 1. Single machine at each process

Case 2. Parallel machine at SM and CC process

4.2. Case 1. Single machine at each process

When there is single machine at each process, the sequencing of charges in one cast can be considered as the instance of 3-stage flow shop scheduling. Practically, since the refining process has much shorter processing times than steelmaking and casting, this case can be reduced to the machine 2- dominated 3-stage flow shop problem. For this problem, a modified LPT/STP algorithm can be applied to minimize makespan. After sequencing lots in each machine, the exact time schedule of lots is obtained by a linear programming, in which the earliness and tardiness of lots are minimized, and machine conflicts and assuring continuous casting are constrained.



[Figure 3] SPT/LPT algorithm to F3/m2 dominated/C_{max}

The following procedure is proposed to this case.

Step 1. Matching application for roll grouping at CC-HR

Step 2. Priority rule for roll sequencing

Step 3. Modified Johnson's Algorithm for charge sequencing at SM-CC

Step 4. LP for time scheduling for SM-CC-HR

4.3. Case 2. Parallel machine at SM and CC process

If there are identical parallel machines in each SM and CC process, parallel machine scheduling problems occur for sequencing casts and charges. There are two cases of SM-CC processing, whether single or multiple converters feed a caster. Assuming Charges in one Cast can be processed on different machines. In this case, sequencing casts and charges on the parallel machines are regarded as a parallel machine scheduling problem. Thus, the following procedure is proposed.

Step 1. Matching application for roll grouping at CC-HR

Step 2. Priority rule for roll sequencing

Step 3. Parallel machine scheduling for cast and charge sequencing at SM-CC

Step 4. LP for time scheduling for SM-CC-HR

5. Proceeding of the Research

This research deals with the lot sequencing problem with process synchronization. Criteria of matching for roll grouping should be prioritized in advance and the detailed matching procedure also should be designed. And algorithms for assignments of casts and charges on the parallel machines are under consideration. After adopting the proposed procedure, a post processing procedure for improving the schedule is needed. To test the performance and conformity, implementation of the algorithms and numerical experiments are planned with real world and constructed data sets. The performance can be measured by their computation times and their conformity can be verified with the scheduling experts in the steel industry.

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