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A mixed-integer linear programming model for the continuous casting planning

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Abstract

The development of optimization models for planning and scheduling is one of the most useful tools for improving productivity of a large number of manufacturing companies. This paper presents a mixed-integer programming model for scheduling steelmaking-continuous casting production. We first review the recent works in continuous casting planning. We focus on a model inspired from an application of steelmaking-continuous casting by Arcelor Group in Liege, Belgium. The process scheduling is characterized by several constraints: job grouping, technological interdependence, no dead time inside the same group of jobs and dynamic processing time of jobs. We present a formulation with mixed-integer linear programming which can be solved using standard software packages. Finally, we treat a few examples to illustrate this application and we conclude this paper with some comments and directions for future extensions.

Keywords: Steelmaking; Continuous casting; Mixed-integer programming; Production planning

1. Introduction

The development of optimization models for planning and scheduling is one of the most useful tools for improving productivity of a large number of manufacturing companies. Nowadays, factory management looks for high-quality, low-costs just-in-time (JIT), value-added products for specific purposes. In steel manufacturing, for example, many international iron and steel corporations are devoted to developing computer integrated manufacturing systems to improve their global competition, particularly with strong competitors in China, South Korea, etc.

Researchers and practitioners have developed and implemented many methods of planning and scheduling of steel production. Most of these methods use expert systems (Suh et al., 1998), heuristics (Cowling, 1995; Cowling and Rezig, 2000; Lopez et al., 1998) and mathematical programming (Chen and Wang, 1997; Lee, 2000) to generate feasible solutions.

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In this paper we study a model of steelmaking-continuous casting (SCC). The SCC is usually the bottleneck in iron and steel production; it is characterized by several constraints: job grouping, technological interdependence, no dead time inside the same group of jobs and dynamic processing time of jobs. We present a formulation with mixed-integer linear programming which can be solved using standard software packages. The rest of this paper is organized as follows. In Section 2 we will give a brief overview of the methods used for planning and scheduling in SCC production. In Section 3, we will describe the product environment for the SCC process. Section 4 proposes a mixed integer linear programming model for SCC planning. A few examples illustrate this model in Section 5 and the paper is concluded with some comments and directions for future extensions.

2. Literature review

Many researchers discussed and presented optimal planning models and methods for steel production. Several reviews with various production planning and scheduling techniques for steel production have been reported in literature, the more complete is the one by Tang et al. (2001). A thorough overview of mathematical programming applications in integrated steel plants can be found in Dutta and Fourer (2001). Another overview of non-mathematical programming techniques is given in Basu et al. (2004).

The research carried out in the area of the SCC with practical constraints is extremely complex. All the methods can be classified into four categories: (1) mathematical programming, (2) heuristics, (3) artificial intelligence, and (4) simulation.

For mathematical programming methods, Tang et al. (2000) formulate the SCC problem using a non-linear programming model to fix machine conflicts; it is based on the JIT idea and then converts it into a linear programming model, solvable using standard software packages. Harjunkoski and Grossmann (2001) present a decomposition strategy for solving large scheduling problems using mathematical programming methods. Tang et al. (2002) present a new integer programming formulation for the SCC problem. A solution methodology is developed combining Lagrangian relaxation, dynamic programming, and general heuristics.

For heuristic methods, Bellabdaoui et al. (2003) present a model for the flow management in SCC (it is the same problem as in this paper). This model is solved by using heuristic techniques based on eliminating machine conflicts; it is implemented in Matlab software. Lee et al. (1996) developed the scheduling system for the two-strand CC, adopted genetic algorithms to solve the problem and obtained satisfactory solutions meeting all the constraints. The SCC problem is formulated in Pacciarelli and Pranzo (2000) by means of the alternative graph which is a generalization of the disjunctive graph of Roy and Sussman and it is solved using a beam search procedure. De Schutter (1999) develops some techniques to design (sub) optimal timing and sequencing schemes of a continuous steel foundry. His method includes a mixture of linear programming, genetic algorithms, tabu search and heuristics.

For artificial intelligence methods, Nuamo and Morishita (1991) treat the problem at three levels: (1) sub-scheduling, which fulfills the scheduling of individual charge sets, (2) rough scheduling, which merges sub-schedules, and (3) optimal scheduling by an inference engine, which eliminates machine conflicts.

For simulation methods, Bekker (2001) discusses a simulation study of crane movement in the steel casting process. Facility layout changes are proposed and are compared to the initial operational scenario. Um (2002) describes a production control strategy for achieving the best level of operation in the process of steelmaking. It is analyzed with Arena simulator.

3. Problem definition

3.1. Process

Iron and steel production includes several phases (iron making, steelmaking, continuous casting and steel rolling). The steel process under