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Production scheduling problems of steelmaking-continuous casting process in dynamic production environment

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ABSTRACT

A concept of production scenario for the steelmaking-continuous casting production process and the mathematical description of such concept were proposed. The production scenario was described with the variation of the equipment status and the production material properties based on the executing production schedule. Then, the dynamic characteristics of the production process could be described with the evolution process of production scenario. Through analyzing the influence of the dynamic production scenario on production scheduling, three key points about the scheduling problems were identified: the problem for integrating the schedules of different batches that is non-neglected when making a schedule, the problem for matching the material flow with the schedule that should be solved when implementing a schedule, and the problem for eliminating the deviations between the initial schedule and implemented schedule that should be solved when rescheduling in a disturbed environment. Finally, a set of experiments were conducted, and the results demonstrated that making the production schedule and solving the rescheduling problem for steelmaking-continuous casting process with addressing the above three problems improve the adaptability of the schedule in dynamic environment.

1. Introduction

For the sustainable development of modern Iron and Steel Corporations, it is very important to realize the multi-species, small-batch and low-cost production. The steelmaking-continuous casting (SCC) production process, which mainly contains the steelmaking, refining and continuous casting stages, has a dominant influence on the variety, quality and shape of the final products. In addition, the production process is also a typical hybrid flow shop that contains both the discrete and continuous processes. Therefore, how to make an effective schedule for the SCC process is significant for the high-efficient production of steel plants[1,2].

In the last decades, many researchers have studied the SCC scheduling problems, including the SCC static scheduling[3-9] and SCC dynamic scheduling[10-15], and they have made considerable headway. More and more mathematical models and algorithms have been proposed for these scheduling problems. However, for easily solving in the dynamic production environment, some important assumptions have been considered in the models. As a result, most of schedules made by the current scheduling systems in steel plants cannot be put into use directly, and the scheduling decisions of the practical production process are still determined depending on workers′ experience in practice. For example, Pan et al.[6] proposed a mixed integer mathematical model for the SCC scheduling problem, designed a heuristic algorithm to obtain a rough schedule, and then used the artificial bee colony algorithm to find a better solution. However, the casting starting time of continuous casters is assumed to be predefined in their model, which neglects the problem that the casting starting time of the continuous casters should be dynamically determined based on the current batch plan, machine status and hot metal resources before making a schedule. Chen et al.[7] proposed a hybrid algorithm which integrated the constraint satisfaction and genetic optimization for the scheduling problem. The original problem was simplified firstly based on logical Benders decomposition, then the constraint satisfaction technology was employed to ensure the feasibility of

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solutions, and finally the iterative evolution of genetic algorithm was used to obtain the convergence of solution. However, since all the machines are assumed to be available when making a schedule in their model, the dynamic characteristics of the continuous production process have been violated. In the practical production process, tasks are unceasingly completed and new tasks are unceasingly carried out. Thus, the earliest available time of machines should be considered in the model for each scheduling decision.

As a consequence, in order to better understand the nature of the SCC scheduling problems in the dynamic production environment, the concept of production scenario was proposed in this paper. The production scenario mainly contains the information of three elements, which are the machines, the production materials and the production schedule. With the help of production scenario, the dynamic characteristics of the SCC process were described as the evolution process of the production scenario. Then, the key points of this study on SCC scheduling problems in the dynamic production scenario were analyzed. Finally, a set of experiments were conducted to demonstrate the effectiveness of addressing these key problems for the production scheduling and rescheduling in steelmaking-continuous casting process.

2. Description of SCC Dynamic Production Process

The SCC scheduling problem is solved to determine the machine allocations, starting time and ending time for all the operations of all the charges (the basic unit) from the steelmaking stage to the continuous casting stage. The obtained schedule is always used to guide the production process of the steel plant. Optimal scheduling can bring many profits such as production cost savings, customer satisfaction improvement and energy consumption reduction. How to express the dynamic characteristics of the SCC production process is important to the scheduling decision process. As a flow manufacturing industry, the SCC production process has strict requirements on time, temperature, quality and amount of the production materials. As for SCC process, a unit of production material refers to a ladle of hot metal and its molten steel that is converted in a basic oxygen furnace (BOF). In the practical production process, production materials continuously enter into the manufacturing system and leave after all the operations are completed. Therefore, the dynamic production process can be described as the evolution process of production scenario.

2.1. Definition of production scenario

In order to describe the SCC dynamic production process accurately, the definition of production scenario should be presented first. Based on a comprehensive analysis, the information of machines, production materials and production schedule are concluded as the three important elements in the dynamic production process. Therefore, in this paper, the production scenario is described with the variation of equipment status and the production material properties based on the executing production schedule. Then, the dynamic characteristics of the production process can be described with the evolution process of production scenario. At each moment, the information of the production scenario contains the status and the process information of machines, the property and the process information of production materials, and the information of the executing production tasks. Therefore, a triplet $M \mid L \mid J$ is used to describe the production scenario S_t at the moment t, where the M field, L field and J field describe the information of machines, production materials and production tasks, respectively. For ease of description, some subscripts are also defined to describe the production scenario, where i refers to the identification number, s refers to the current status, c refers to the duration of the status, q refers to the quality, r refers to the processing route, b refers to the starting time, and e refers to the ending time.

The M field for each machine contains the following entries: the identification number of machine (M_i), current status of machine (M_s) and duration of status (M_c). M_i is the unique identification number which makes the machine different from others. M_s represents the status of M_i at the moment t which is optional in the following three statuses: idle, busy and broken-down. M_c represents the duration of the status M_s of machine M_i until moment t. Note that M_c should be reset to zero once the status of M_i is changed.

The L field for each production material contains the following entries: the identification number of production material (L_i), current status of production material (L_s), current quality of production material (L_q), duration of the status (L_c), finished processing route (L_r) and associated identification number of charge (J_i). L_i is the unique identification number which makes the production material different from others. L_s represents the status of L_i at the moment t which is optional in the following three statuses: waiting, processing and transporting. L_q represents the quality of L_i at the moment t which includes the temperature information and the chemical composition information. L_c represents the duration of the status L_s of L_i until moment t. Note that L_c should be reset to zero once the status of L_i is changed. L_r represents the ordered set of M_i which has been used to process L_i until moment t.