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State-of-the Art in Short-Term, Medium-Term, and Reactive Scheduling for Large-Scale Batch and Continuous Processes

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Abstract

Scheduling is a decision making process to determine when, where, how to produce a set of products given requirements in a specific time horizon, a set of limited resources, and processing recipes. The research area of batch and continuous process scheduling has received great attention from both the academia and the industry in the past two decades. This is motivated by the increasing pressure to improve efficiency and reduce costs and by the significant advances in relevant modeling and solution techniques and the rapidly growing computational power. In multi-product and multipurpose batch, semi-continuous, and continuous plants, different products are manufactured via the same or similar sequence of operations by sharing available pieces of equipment, intermediate materials and other production resources. The inherent operational flexibility of these plants provides the platform for great savings reflected in good production schedules.

In this talk, we will present an overview of the exciting developments in the scheduling of multi-product, multipurpose batch and continuous processes. In addition to the discrete-time approaches, pioneering continuous-time models will be presented. Based on the continuous-time representation, existing approaches were classified into slot-based, global event-based, and unit-specific event-based models. A comparative study of different continuous-time models will be presented with respect to some benchmark problems from the literature for short-term scheduling of batch and continuous plants. Important characteristics of batch and continuous chemical processes that pose challenges

to the scheduling problem are discussed. Using the unit-specific event-based continuous-time representation, we will focus on (i) short-term scheduling, (ii) medium-range scheduling, (iii) reactive scheduling, and (iv) scheduling under uncertainty. Two large-scale industrial case studies will illustrate the potential benefits of the proposed frameworks.

In the first case study, a large-scale multipurpose industrial batch plant is considered; and in the second case study an industrial continuous polymer compounding plant will be discussed. A key feature of the proposed formulation is the use of a decomposition model to split the overall scheduling horizon into smaller sub horizons which are scheduled in a sequential fashion. A rolling horizon based approach is proposed for solving the medium-range scheduling problem and two subproblems are solved. An upper-level model is used to find the optimal number of products, and length of the time horizon to be considered for solving the lower level short-term scheduling problem. At the lower level, novel mathematical models are proposed for short-term scheduling of batch and continuous processes using unit-specific event-based continuous-time representation.

The short-term scheduling model of the first case study for batch plants takes into account a large number of processing recipes and units and incorporates several features including various storage policies (unlimited, no intermediate, and zero-wait), variable batch sizes and processing times, batch mixing and splitting, sequence-dependent changeover times, intermediate due dates, and several modes of operation. In the second case study, the short-term scheduling model for continuous plants can rigorously handle various storage requirements such as dedicated, flexible, finite, unlimited and no intermediate storage policies. The formulation allows for unit-dependent variable processing rates, sequence-dependent changeovers and with/without the option of bypassing of storage requirements. The plant additionally has several other practical restrictions such as limitation on the usage of number of parallel units, restriction on product lifting on weekends, time-dependent limitation on raw material availability, and restrictions on changeover timings, which are handled efficiently using the proposed formulation.

We will also present a reactive scheduling framework that provides an immediate response to unexpected events such as equipment breakdown or the addition or modification of orders by taking into account the schedule currently in progress and planned productions that are not affected by the unexpected event. Additionally, for handling uncertain problem parameters, a novel robust optimization approach was proposed by introducing some auxiliary variables and constraints, where a deterministic robust counterpart problem is formulated that produces robust solutions that are immune against data uncertainty. The proposed frameworks are demostrated on industrial case studies.