A Comparison of Continuous-time Models for Scheduling Noncontinuous Plants

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Scheduling of batch plants has received considerable attention in the past two decades. With the primary objective of scheduling being the determination of the start and end times of batch operations, researchers have used two different types of time representation, namely, the discrete- and continuous-time representations. While the former can be effective for small-scale problems with fixed batch processing times, the latter has proven to be more effective for larger problems with fixed/variable batch processing times. This is because the continuous-time representation requires, in addition to being more accurate, fewer binary variables than the discrete-time representation. Hence, over time, the discrete-time representation has lost favor to the continuous-time representation. The three most prominent scheduling approaches based on the continuous-time representation are the slot-, the sequence- and the event-based approaches. As there have been several reservations or claims among the researchers regarding these approaches, there is a long-standing need to compare and analyze their efficiencies and nuances on a variety of batch plants. More importantly, the comparisons available in the literature are piecemeal and in several cases lack rigor and fairness. In this work, we make a first effort to compare the effectiveness of these approaches on several types of batch/semicontinous plants: single-processor systems, serial multiproduct plants, single-stage plants with parallel units, and multipurpose batch plants. In addition, we consider scheduling problems with single and multiple due dates.

In the case of serial multiproduct batch plants, we start with systems with a single semicontinuous production line. We consider features such as minimum run lengths and multiple due dates and show that some approaches are unable to deal with them properly. In the case of serial batch plants, we show that the event-based formulation can be simplified to match the slot-based formulation, and hence, we compare only the slot- and sequence-based models. We propose and evaluate many alternatives and combinations of slot- and sequence-based models and show that the slot-based models can be up to sixty times faster than some sequence-based models.

For the single-stage batch plants, we consider various features such as multiple orders per product, demands at the end of the horizon as well as at multiple due dates and so on while comparing the performance of all three approaches. Since Lim and Karimi (2003) have shown that slot-based models are better than the sequence-based models, we compare only the slot- and event- based models for single-stage batch plants in this study.

In the context of continuous-time representation, scheduling of batch plants has been done using two types of assignment binaries: one with the decoupling of tasks from units and the other without. The former relies on the postulation that decoupling the tasks from units reduces the number of assignment binaries. In this work, we shed some light on the strategy of decoupling for any batch scheduling problem and prove that it is impossible for any batch scheduling model to reduce the number of binaries by decoupling tasks from units without losing optimality. We then compare a slot-based model with the best existing model (Maravelias & Grossmann, 2003) that decouples tasks and units and show that our slot-based model without decoupling uses fewer binaries and performs faster (by almost an order of magnitude in most cases studied) than the former. We also compare our slot-

based model with the event-based model (Ierapetritou & Floudas, 1998) existing in the literature.

We present several examples both from the literature and of our own to perform the comparison of each type of batch plant. We solve the models for various objectives such as profit-maximization, makespan-minimization, cost-minimization, and so on. For the sake of a fair comparison, we implemented all the models using the same hardware and software. Finally, we make a few remarks on the effectiveness of different formulation strategies.

Keywords: scheduling, batch plants, serial multiproduct, single-stage, multipurpose, continuous-time formulation

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