An Improved Formulation For Scheduling Multipurpose Batch Plants Using Synchronous Slots

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Several continuous-time formulations in the literature address the most demanding problem of scheduling in multipurpose batch plants. These formulations can be broadly classified into two types based on the assignment binary variables. They are (i) Formulations with decoupling and (ii) ones without decoupling. The former rely on the postulation that decoupling the tasks from units reduces the number of assignment binaries. In contrary, the latter do not decouple the tasks from units but use the assignment binaries as such. In this work, we present a new, simpler and more efficient continuous-time mixed integer linear programming (MILP) formulation based on our proven opinion that formulations without decoupling necessarily require the same number of binaries that formulations with decoupling do.

Some recent attempts[1-3] at scheduling multipurpose batch plants have one thing in common. They all base their formulations on the idea that decoupling of tasks from units reduces the number of binary variables. The only difference between the non-decoupled binaries and the decoupled binaries is that the former display the unit information explicitly, while the latter hide the same. The number of necessary binary variables per event/time point must however be the same; otherwise the formulation cannot give the optimal solution. In this work, we prove that decoupling of tasks from units does not help reducing the assignment binaries. Furthermore, the proposed model of this work does not decouple tasks from units, but still has fewer binaries, constraints and nonzeros than the recent best decoupling-based model[3].

We consider a multipurpose batch plant or production facility (F) that produces multiple products using a number of shared production units that constrain the plant operation. We describe the production in F using recipe diagrams (RDs), which we feel are a more straightforward extension of Process Flow Diagram (PFD) concept to a batch process. In a RD, nodes represent the tasks, arcs represent the various materials, and arc directions represent the task precedence. In this paper, we present a basic formulation for scheduling multipurpose plants, in which all units are batch units, and no resources other than materials and equipment are required for tasks. We divide the scheduling horizon into a number of variable length slots. To handle the sharing of production units easily and ensure the material balance at any point in horizon, we synchronize the slots on all units.

Some features of our proposed formulation are noteworthy and distinct from the previous work. First, we use a novel balance on units besides that on mass and resource. Second, in contrast to all the existing continuous-time decoupling-based models[1-3], our formulation has absolutely no big-M constraints. We believe that this is significant, because our experience shows that eliminating the big-M constraints generally improves MILP formulations. Third, our model is much simpler (almost one third reduction in binaries, two third reduction in constraints as well as nonzeros) and faster (almost an order of magnitude in most cases studied) than the most recent and the best model[3] existing in the literature.

We consider several examples both from the literature and of our own to compare our model with the best recent model[3]. For the sake of fair comparison, we implemented both the models using the same hardware and software. Although, we solve both the models for only two scheduling objectives (maximizing the profit/revenue from the sales of finished products and minimizing the makespan using variable processing times) in this work, other objectives such as minimizing inventory, production, or setup costs and even minimizing the tardiness or earliness can readily be accommodated in the proposed formulation with minor modifications. From the performance evaluation, we conclude that our model is superior to the recent best decoupling based-model[3] irrespective of the scheduling objectives.

Keywords: scheduling, multipurpose, batch plants, continuous-time formulation, MILP, synchronous slots

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