582d Hierarchical Approach for Production Planning and Scheduling under Uncertainty

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In any production plan planning and short-term scheduling are the most predominant decision making stages. Production planning determines the optimal allocation of resources within the production facility over a time horizon of few weeks up to few months whereas short-term scheduling provides the feasible production schedules for every day operation of the plant. The integration of planning and scheduling has received a lot of attention in the last decade. The published articles can be generally categorized into two approaches (Bose and Pekny, 2000).

The first approach emphasizes that planning and scheduling decisions need to be simultaneously considered in order to achieve the optimality. These approaches consider a large scheduling problem over the planning time horizon (Orcun et al. 2001, Bassett et al. 2000). Due to the complexity and size of the problem these models are reported to be hard to solve without decomposition. Periodic scheduling is developed in the context of campaign-mode operation (Schilling and Pantelides 1999, Castro et al. 2003). The resulted model determines optimal duration of the operating cycle and detailed schedule in each cycle. Wu and Ierapetritou (2004) present an efficient continuous-time formulation for periodic scheduling problem, resulting in less variables and constraints. However, cycle operation is more appropriate for plants operating under stable demand conditions, thus limiting the applicability of the periodic scheduling.

The hierarchical approaches involve the problem decomposition into planning and scheduling level problems. McDonald and Karimi (1997) proposed production planning and scheduling models considering single stage processor. Papageorgiou and Pantelides (2000) presented a hierarchical approach attempting to exploit the inherent flexibility of the plant with respect to intermediate storage policies and multi-usage of the equipment. Harjunkoski and Grossmann (2001) presented a bilevel decomposition strategy for a steel plant production process. Other research includes Bose and Pekny (2000), who used model predictive control ideas for solving the planning problem. Zhu and Majozi (2001) proposed an integration of planning and scheduling problems as well as a decomposition strategy for solving the planning problem. Rolling horizon approach has been widely considered to reduce the computational burden (Dimitriadis et al., 1997, Van den Heever et al. 2003). This strategy only makes decisions for a shorter planning time period than the planning time horizon, which moves as the model is solved. Most of the existing approaches however are limited due to overly simplified planning level problem, the lack of uncertainty and task sequence feasibility consideration.

This work proposes a general hierarchical framework for the solution of planning and scheduling problems. At the planning level, a multi-stage planning model is presented to account for future uncertainty. The planning time horizon is decomposed into three stages with various durations. The first stage with the smallest duration is denoted as “current” period where operating parameters are considered deterministic. The second stage with larger duration is subject to small variability of demands and prices, and the final stage with largest duration has higher level of fluctuations regarding demands and prices. Uncertainty is expressed by incorporating a number of scenarios at each stage. More scenarios are considered towards the last stage in order to represent the increasing level of uncertainty. Each scenario is associated with a weight representing the probability of the scenario realization. Since the planning model essentially considers the material balance, a parameter denoted as sequence factor is introduced to simplify the computational complexity and account for sequence constraints. The sequence factor discounts the time horizon in the planning problem in order to reduce the infeasibilities at the scheduling level. In this work, a general procedure is presented for estimating the sequence factor. Since a gap always exists between the planning problem solution involving the sequence factor and the short-term scheduling problem, an iterative procedure is developed within the planning and scheduling framework, which adjusts the sequence factor. It is also assumed that each unit will process a certain number of batches at a full capacity and a single batch at flexible size at every stage in the planning model. The objective function consists of minimizing the overall cost during the whole planning time horizon including raw material cost, backorder cost and operating cost.

The scheduling problem is solved after the solution of planning model to ensure a feasible production schedule for the current period. Since planning takes into consideration the future time periods, the production required in the scheduling period could exceed the orders imposed by the market. In this case, not only all the orders are required to be satisfied by their due dates, but the additional production from the planning solution needs to be considered. Assuming that parameters in the current period are deterministic, the scheduling problem is solved using a continuous-time formulation modified from that of Ierapetritou and Floudas (1998). The objective function minimizes the cost of raw materials, inventory cost, backorder cost, and operating cost as well as the penalty for not finishing the additional production. The overall hierarchical framework is based on rolling horizon strategy. The planning model takes into consideration a number of periods with aggregated orders although only the decisions for the current period are implemented. The solution of the planning model could result in the following two cases: 1) the production for the current period could not satisfy the aggregated demand in this period; 2) the production meets or exceeds the aggregated demand. Generally we need to further identify if this is due to capacity limitation or inaccurate parameters in the planning model. Therefore, the demands are disaggregated and the short-term scheduling problem is solved in order to obtain a feasible production schedule. The scheduling results are compared to the market orders and the planning results, and strategies are determined accordingly. The following cases can be obtained: 1) the production schedule is optimal and all the orders are satisfied; 2) the backorder happens and needs to be produced in the next period; 3) the planning and scheduling results are not consistent, thus the sequence factor needs to be updated and models are resolved. This iterative procedure continues until convergence is achieved between the planning and scheduling problems. Demand and inventory are updated and the same procedure is followed for the next time period based on the rolling horizon approach.

The proposed hierarchical approach has been applied to a planning problem where thirty 8-hour schedules need to be determined dynamically. There are demand peaks appearing at the beginning and later periods, which exceeds the production capacity of the plant. By applying the proposed framework, we leverage the storage capacity such that a smooth production schedule can be generated for the entire time horizon with the minimum amount of backorders. Compared to two other scheduling approaches, the proposed approach significantly reduces the number of backorder periods and decreases the backorder cost. It is also shown in this example that the iterative procedure can effectively adjust the sequence factor to reflect the real production capacity. The proposed framework can effectively considers a long-term trend in the planning model while optimizing the detailed production schedule for the current period.

References:

Basset, M.H., Doyle III, F.J., Kudva, G.K., Pekny, J.F., Reklaitis, G.V., Subrahmanyam, S., Zentner M.G. and Miller. D.L. (1994). Perspectives on Model-based Integration of Process Operations. Proc. fifth Int. Symp. on Process systems Eng. Kyongju, Korea.

Bose, S. and Pekny, J. (2000). A Model Predictive Framework for Planning and Scheduling Problems: A Case Study of Consumer Goods Supply Chain. Comput. Chem. Eng., 24, 329-335

Castro, P., Barbosa-Povoa, A. and Matos, H. (2003). optimal Periodic Scheduling of Batch Plants Using RTN-based Discrete and Continuous-time Formulations: A Case Study Approach. Ind. Eng. Chem. Res., 42, 3346-3360

Dimitriadis, A.D., shah, N. and Pantelides, C.C. (1997). RTN-bases Rolling Horizon Algorithms for Medium Term Scheduling of Multipurpose Plants. Comput. Chem. Eng., S21, S1061

Harjunkoski, I. and Grossmann, I.E. (2001). A decomposition approach for the scheduling of a steel plant production. Comput. Chem. Eng., 25, 1647-1660

Ierapetritou, M.G., and Floudas, C.A. (1998). Effective Continuous-time Formulation for Short-Term Scheduling. 1. Multipurpose Batch Processes. Ind. Eng. Chem. Res., 37, 4341.

McDonald, C.M. and Karimi, I.A. (1997). Planning and scheduling of parallel semicontinuous processes. 1. Production planning. Ind. Eng. Chem. Res., 36:2691-2700

Orcun,S. and Altinel,I.K. and Hortacsu,O. (2001). General continuous time models for production planning and scheduling of batch processing plants: Mixed Integer linear program formulations and computational issues. Comput. Chem. Eng., 25:371-389

Papageorgiou,L.G. and Pantelides, C.C. (2000). A hierarchical approach for campaign planning of multipurpose batch plants. Comput. Chem. Eng., 17, S27-S32

Schilling,G. and Pantelides, C.C. (1999). Optimal periodic scheduling of multipurpose plants. Comput. Chem. Eng., 23:635-655

Van den Heever, S.A. and Grossmann, I.E. (2003). A Strategy for the Integration of Production Planning and reactive Scheduling in the Optimization of a Hydrogen Supply Network. Chem. Eng., 27, 1813-1839

Wu, D. and Ierapetritou, I.G. (2004). Cyclic Short-term Scheduling of Multiproduct Batch Plants Using Continuous Time Representation. Comput. Chem. Eng., 28, 2271-2286

Zhu, X.X. and Majozi, T. (2001). Novel continuous time MILP formulation for multipurpose batch plants. 2. Integrated planning and scheduling. Ind. Eng. Chem. Res., 40:5621-5634