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Efficient multi-product multi-BOM batch scheduling for a petrochemical blending plant with a shared pipeline network

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ABSTRACT

We present an effective scheduling heuristic for realistic production planning in a petrochemical blending plant. The considered model takes into account orders spanning a multi-product portfolio with multiple bills of materials per product, that need to be scheduled on shared production facilities including a complex pipeline network. Capacity constraints, intermediate storage restrictions, due dates, and the dedication of resources to specific product families have to be respected. The primary objective of the heuristic is to minimize the total order tardiness. Secondary objectives include the minimization of pipeline cleaning operations, the minimization of lead times, and the balanced utilization of filling units.

The developed algorithm is based on a dynamic prioritization-based greedy search that schedules the orders sequentially. The proposed method can schedule short to mid-term operations and evaluate different plant configurations or production policies on a tactical level. We demonstrate its performance on various real-world inspired scenarios for different scheduling strategies.

Our heuristic was used during the construction phase of a new blending plant and was instrumental in the optimal design of the plant.

1. Introduction

In this paper we present a heuristic to solve a batch scheduling problem in a real(istic) multi-product petrochemical blending plant. In this competitive semi-process industry, expected customer service level is high and delivery lead-times are short. Non-performance is penalized with high fines. The number of different products produced, as well as the high cost of liquid bulk storage forces the plant to focus on a make-to-order (MTO) production strategy. This in turn renders the On-Time In-Full (OTIF) delivery of customer orders a challenging task. For these reasons, the efficient planning and operating of such a high-performing blending plant needs decision support systems based upon powerful planning and scheduling algorithms.

This research was motivated by a research project executed in collaboration with a petrochemical company. The focus of this project was not on the development of an operational scheduling tool to handle the day-to-day planning of the plant; for this purpose, the company used a commercial software package. Rather, the aim was to develop a planning heuristic that could be used as the scheduling component of tactical analysis tools. For this reason, the heuristic needed to be both very fast and very flexible, being able to plan, e.g., the expected order set of an entire year in a reasonable amount of time, while taking into account multiple objectives.

As a result, the generic heuristic we propose is appropriate for short-term scheduling, but its design allows it to be integrated in tools for strategic or tactical decision support on plant layout (number, capacity and location of production facilities), and plant configuration (dedication of production facilities to product families, availability of personnel, opening or closing pipeline connections, etc.). Our heuristic was used during the startup phase of a new petrochemical blending plant to simulate the efficiency and determine the expected capacity of the plant design. To this end, it was expected that the heuristic should be able to schedule a realistic set of customer orders for a whole year in a reasonable amount of computing time. The performance of our heuristic made it possible to test new scenarios for both plant layout and plant configuration, which was important to determine the best possible configuration of the new plant. A detailed discussion of this validation phase follows in Section 5.

The heuristic considers raw material availability, production capacities, intermediate storage limitations, customer order due dates, as well as the several characteristics proper to the

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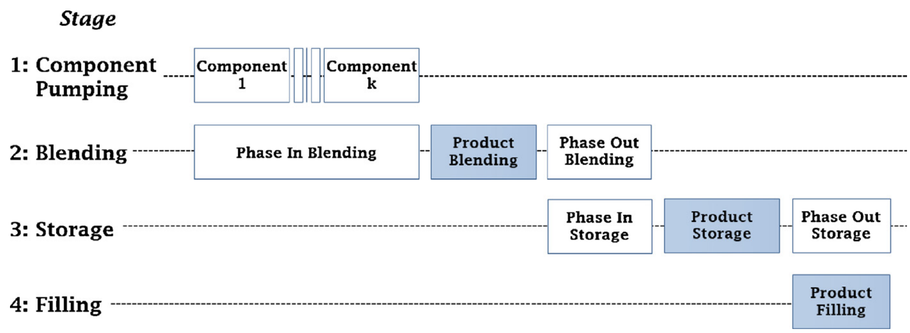

Fig. 1. The stages of a typical blending production process and their operations.

production process. Additionally, it takes into account the complex pipeline network that regulates the material flows between all production facilities. In fact, the layout of the pipeline system is designed to limit multiple direct end-to-end connections, but the shared pipelines generate supplementary resource availability constraints and a higher risk for contamination between production batches.

1.1. Industrial application

Although the scheduling problem described in this paper applies to semi-process production plants of different size, capacity and industry (e.g., specialty chemicals, pharmaceutical, food sector), the target in this paper is an industrial petrochemical blending plant with a yearly capacity of 100 000 m^3. The plant completes circa 80 000 customer orders annually, of which 80% are delivered in bulk and 20% in drums. It produces about 500 different products, independent of further labeling or packaging.

Regarding production facilities, the target plant counts about 60 component tanks for base oils and additives, 20 blending tanks, 50 intermediate storage tanks, 12 loading arms, and 3 packaging lines. The plant's pipeline system uses 4 manifolds that control the access to 400 pipelines. To avoid contamination in the pipelines, a state-of-the-art cleaning system pushes a pressure-driven PIG (Pipeline Intervention Gadget) through the pipes in order to clean or empty them when needed. The use of the PIG should be minimized.

Characteristically for this industry each blending product has its preferred formula, but on top of that it can be produced according to multiple Bills-of-Material (BOM), using different base oils and additives depending on their price and availability. As a result, the total number of different BOMs used over a year amounts to 5000. Since most of the BOM-components can be stored in multiple component tanks, the accessibility of the component pipelines must be considered when choosing the BOM and the related component tanks for each production order.

As mentioned earlier the majority of products are produced to order (MTO). Even though a limited number of fast-moving products are produced to stock (MTS), the heuristic does not treat these products differently, as this would require it to take into account the full complexity of MTS replenishment policies, which in turn would force it to consider continuous or periodic review, safety stock levels, target stock levels, optimal replenishment periods, and economic order quantities. In this paper, we therefore assume that all products are MTO and that every production order corresponds to a customer order. The only distinction made between products is that, before loading or packaging, customer orders can always be stored one by one in a *single-order* tank dedicated to the corresponding product family, but that for a few fast moving products the customer orders are preferably stored in a dedicated *single-product* tank, possibly simultaneously with other customer orders for that product.

Finally, production and logistic personnel work in a one-, two- or three-shift pattern depending on the seasonal demand. As a consequence the use of component and blending tanks, pipelines and finishing lines is limited to these working hours.

1.2. Production process

The stages of the production process needed to blend a product are illustrated in Fig. 1. The white rectangles represent transfer operations through pipelines, during which the source and destination tanks are occupied too, but no other value-adding activity occurs. In Stage 1 (Component Pumping) all necessary BOM-components such as base oils and additives, are pumped sequentially out of their individual component tanks into a blending tank. Scarce or low-volume additives are injected via a decanting unit that can be considered as a special type of component tank. During the pumping of a component, the component tank, connecting pipelines and the blending tank are occupied. The component tanks are replenished when needed.

Throughout Stage 2 (Blending) the product components are mixed in a blending tank. These tanks have different sizes and are dedicated to one or more product families. A blending tank is occupied during component pumping (Phase-In Blending), heating and blending (Product Blending), and during the transfer of the product into a storage tank (Phase-Out Blending). The duration of the heating and blending process is independent of the product volume but can depend on the product type and blending tank. The duration of Phase-In and Phase-Out Blending depends on the pumping capacity and product volume transferred.

During Stage 3 (Storage) the product is stored into a storage tank. Like blending tanks, storage tanks have different sizes. Moreover, a *single-order* tank is dedicated to a product family, a *single-product* tank is dedicated to one specific product. During the transfer from the blending tank, both the storage tank and connecting pipelines are occupied (Phase-In Storage). The product remains in the storage tank (Product Storage) until the pumping towards a filling unit starts. A minimum dwell time is necessary in the storage tank for quality control. During the filling (Phase-Out Storage) the storage tank and the transfer pipelines to the filling unit remain occupied.

Finally in Stage 4 (Filling) the product is bulk-loaded or drummed via a filling unit (Product Filling). Filling can start immediately after the minimum dwell time in the storage tank, but ideally it should be finished immediately before the customer order due-date, i.e., at the date it has to leave the factory. In case of (too) early production a maximum dwell time is imposed, after which the production order is filled in a costly additional container to free up space in the storage tank.

Using the description of the blending process above, the operations needed to schedule a production order while taking into account the finite capacity of the main production facilities can be summarized as follows (see also Fig. 2).