Case study of a batch-production and inventory system

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Practice Abstracts

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Case Study of a Batch-Production and Inventory System

BASF is the world's leading chemical company. It serves customers in over 170 countries and supplies its approximately 8,000 products to almost all industries. These products present some common inventory-planning and production-scheduling challenges. First, process plant productivity is very sensitive to product transitions; sequencing these transitions properly is extremely important to improve yields and reduce changeovers. Second, because inventory and work-in-process material is often stored in tanks or silos, production planning for these tanks and silos must address both the operational time required and the volume of the material. The inflow from one operation and the outflow from the next dictate a tank's availability; upstream and downstream operations must be scheduled synchronously to ensure that the tank does not overflow.

We analyzed a BASF plant with two buildings (A and B), each with two available production lines. The two lines in building A can produce most products, whereas the lines in building B can produce only a small number of its products. All production takes place in fixed batch sizes. The layouts of the production lines in the two buildings have one major difference. The lines in building B start as two parallel lines but share a single resource at the end of the production process (i.e., postprocessing). This resource must be cleaned between the productions of any two different products; thus, setup times are incurred. However, in building A, the two lines are parallel during the complete production process. Products are produced in a make-to-stock fashion. A complicating factor, however, is the limited stock space for the individual products; i.e., a dedicated tank is assigned to each individual product. At the moment that a replenishment order is placed, BASF must ensure that the tank has sufficient space. Otherwise, the complete line is blocked and costly production capacity is wasted. Although product demand is highly uncertain, customer requests can arrive on short notice. Thus, batching current and future demand for a product to avoid small production runs and high setup frequency might be desirable. Combining several batches for a specific product in one production run is referred to as a *campaign*.

Each customer order is assigned a due date based on an agreement between the customer and BASF. Demand that cannot be delivered before or on this due date is backlogged until the product becomes available following production. We use the fraction of demand satisfied before or on the agreed due date to quantify the performance of the plant, where only complete deliveries are allowed. We obtain the inventory requirements such that given quality-of-service levels can be met. Last, we note that the vast production literature includes several problems related to this case study, yet the case that comes closest is the *stochastic economic lot-scheduling problem* (SELSP), which assumes a single production line (Winands et al. 2005).

Our planning model, which is used on a daily basis, consists of two parts. First, replenishment orders are placed by the planner according to an (s_i, nQ_i) inventory policy. When a product's inventory position falls below its *reorder level*, s_i, a replenishment order of amount nQ_i, $n = 1, 2, \ldots,$ is placed such that the inventory level is again between s_i and $s_i + Q_i$. The *inventory position* is defined as the physical inventory plus the stock on order minus the backorders. The quantity Q_i is called the *batch size*, whereas the amount nQ_i is referred to as the *campaign size*. Second, the production staff assigns these replenishment orders to the production lines and determines the sequence of production. These allocation and sequencing decisions are based on experience and future expectations. The above planning methodology has been previously studied in the open literature both by simulation (Kämpf and Köchel 2004) and by approximate analytical models that deploy restrictive assumptions, such as Poisson replenishment processes and a single production line (Zipkin 1986). These challenges motivated us to look for an analytical method to compute the performance of the system without making these restrictive assumptions, while also integrating production and inventory decisions into a single model.

We developed a fast, accurate, and easy-to-implement algorithm for the evaluation and optimization of batch-production and inventory systems. This algorithm is based on compound renewal customer-demand processes that permit us to model both general interarrival and demand processes with any probability distribution function. Furthermore, the algorithm, which can compute a wide range of performance measures, is also applicable to multiple, parallel, identical production lines. It is the main building block of the deliverable in the present study, i.e., the decision support tool OptStock. We applied OptStock to the BASF plant analyzed in this case study, and it enabled us to make recommendations on the required inventory levels and tank capacities.

The integrated batch-production and inventory model that we implemented has three stages. First, the (s_i, nQ_i) inventory policy is analyzed using (approximate) renewal techniques of de Kok (1987, 1991), whereas the sequencing strategies at the production lines are represented by $G/G/c$ queuing models analyzed by the highly accurate procedure of van Vuuren and Adan (2005). Building on the outcomes of the first two building blocks, the logistical performance measures are computed by asymptotic renewal results of de Kok (1987, 1991). We incorporated these three individual building blocks into a single integrated batch-production and inventory system. In the first step, the demand processes are translated, via the (s_i, nQ_i) inventory policies, into replenishment processes. Throughout this first step the reorders levels are kept unspecified. The second step aims to determine the sojourn times in the queuing model, which equal the delivery times for the inventory policy. Finally, the last step calculates the reorder level and thus also the required inventory levels for given service levels.

We collected data by analyzing production and sales data and interviewing people from various departments. The need for setup times in building B hindered a direct implementation of OptStock. That is, the inventory policy was driven entirely by the individual inventory positions. The implication is that too much costly production capacity might be wasted on setups in building B because of small replenishment orders placed by the (s_i, nQ_i) policy. In practice, the minimum campaign size in building B is therefore not a single batch but a multiple thereof. Throughout the implementation, we adopted these adjusted minimum campaign sizes for validation purposes. We made some important observations using our model. First, we concluded that the mean replenishment-order size for each product is approximately equal to the minimum campaign size. Second, the variability in order quantities was low. Finally, we saw that the two replenishment processes for the individual products differed significantly in their characteristics (e.g., order sizes and interarrival times). A related observation was that the interarrival times deviated considerably from negative exponential distributions as typically assumed in operations research (but which we did not assume in the present research).

In conclusion, we identified major opportunities for improving BASF's practice. Previously, no comparable tool or method had been available other than human intuition and experience. OptStock provided a systematic method for making tactical decisions and a valuable tool to support a wide variety of decisions (e.g., on inventory levels, tank capacities, and allocation). OptStock led to measurable improvements, including a 38 percent decrease in inventory with no reduction in the high quality of service offered to clients. Encouraged by this first positive application, BASF intends to apply OptStock in other plants. Although we took advantage of the specific setting we describe in this paper, this case study is generic in nature; i.e., many firms in the process industry face similar problems (i.e., stochastic demand, significant setup times, batch processing, and finite buffer capacities). The OptStock methodology (after some adjustments) recently proved its value in another project with different logistics characteristics.

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