Optimizing the production cycle

A new approach is helping schedule paper machines—a task traditionally done using manually-created block schedules

CONSTANTINE GOULIMIS

Paper machine scheduling is traditionally a black art, often delegated to planners with long experience.

The process is quite difficult because of non-constant demand; a continuum of make-to-stock vs. make-to-order strategies; a broad spectrum of sequence-dependent grade/basis weight transitions ranging from a few minutes to several hours; and occasionally, multi-machine capabilities allowing some grades to be sourced from multiple sources. As with project planning, paper machine scheduling also aims to balance production efficiency, inventory and customer service. Cynics might ask "which 2 out of 3 objectives shall I meet?"

Our studies with real data in North America and elsewhere demonstrate a vast source of previously untapped savings, ranging up to 30% in various key performance indicators.

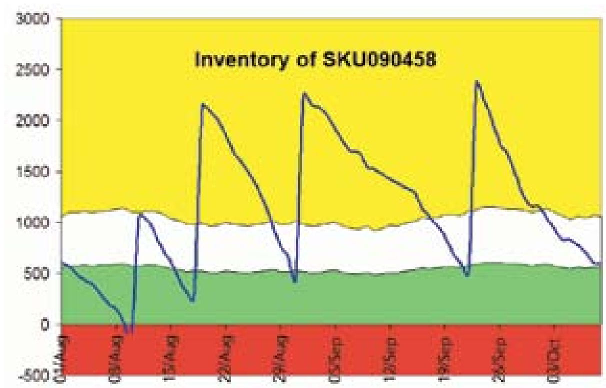

Figure 1: Inventory of an SKU over time, being replenished at certain times. Between replenishments, consumption is dictated by the forecast. Minimum desired inventory is in green and maximum is in yellow. Red shows negative territory and white shows the target zone called the *tunnel.*

AIMS

A practical solution to this problem needs to cover the following issues:

Make-to-stock Demand

This starts with an SKU-level forecast and an associated inventory policy probably driven by service level considerations (**Figure 1**). The values of an inventory policy are not necessarily constant, but can be time-varying. A common approach is to express them as days of cover, e.g., the minimum could be set to seven days and the maximum to 21 (several software vendors sell tools that allow this inventory policy to be optimized).

Make-to-order Demand

In practice, this consists of two components:

- Already existing firm orders with a desired delivery date. In practice, the presence of such orders diminishes as we move further into the future.
- MTO Demand Forecast: This should cover the remaining forecast demand. It can be at a higher level—in contrast to a make-to-stock SKU that can be down to width and diameter, this can be expressed down to grade and basis weight so as to reduce forecast errors. There is often a need for a complicated netting procedure (Is this order part of the forecast?).

Production Characteristics

Depending on the product family, a paper machine transition between two grade/basis weight combinations can take from a few minutes to several hours. The transition costs are sequence-dependent—A→B can be different from B→A. Other complicating factors include:

- Planned downtime
- Need to schedule some production at pre-defined times (trials, FDA certification)
- Time-varying production rates (machine clothing deterioration, machine upgrades)
- Minimum run lengths at machine/product level

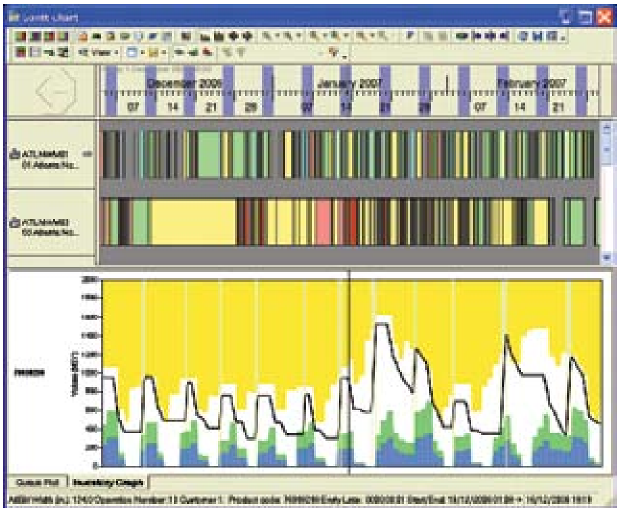

Figure 2: A 13-week view of the schedule. In the top half are the blocks, runs and replenishment orders. The user-configurable color coding of the replenishment orders is governed by the state of the SKU at the time the run starts: e.g. white indicates that at the time of the run the inventory is between minimum and maximum, yellow above maximum, etc.

Objectives of a Schedule

■ Minimize Inventory Policy Deviations: For make-to-stock items to be minimized, with particular attention to not go below zero inventory levels

■ Maximize Customer Service: Items made-to-order to be delivered as close as possible to the requested date

■ Maximize Production Efficiency: Focus attention on minimizing switchover costs and allocating demand to the most cost-effective manufacturing resource

As mentioned previously, these objectives are conflicting and must be balanced against each other.

CURRENT PRACTICE

In our experience, most companies schedule paper machines by employing a team of "master planners" responsible for defining a block schedule for each machine. The starting base for such block schedules is often a cycle (as in "We operate a six-week cycle"), although this term should be used loosely since not every grade/basis weight is made every time.

The creation of an optimal schedule is a very difficult combinatorial problem whose dimensionality overwhelms human capacity. People have, therefore, assumed that the problem is not amenable to optimization techniques. For instance, over a 90-day horizon there may be around 200 runs for 50 grades and 1,000 SKUs; we estimate that there are more than 1,080 possible schedules. In multi-machine situations, there are even more possibilities.

In the absence of optimization algorithms, planners must manually create a campaign schedule. The quality of this schedule is uncertain, but it is used in conjunction with the demand (forecasts and firm orders) to generate replenishment orders. Some systems are then able to determine customer service implications (predicted over- or under-stock and earliness or lateness) in the form of alerts. However, the process of handling these alerts and re-scheduling to eliminate them is left with the planner (and there is no prescriptive methodology for this). The situation is further exacerbated when the replenishment order creation process takes hours. This slowness makes the overall system unresponsive to external events.

AN OPTIMIZATION APPROACH

Greycon Ltd. has developed an optimization approach to address the problem described in the previous section. This solution, called D-Opt, generates two outputs:

■ An optimized block schedule

■ Replenishment orders for the make-to-stock part of the demand.

There are many ways to present the results, shown in **Figure 2.**

One interesting aspect is that the upward steps of the inventory curve are not vertical since multiple SKUs for a single product family are replenished during each run. Rather than use the end of the run as the time when product becomes available, the system proportionately distributes the quantities throughout the run. For a paper machine, where trim optimization is an issue, after the run has been trimmed the replenishment will be tied to the actual slitting patterns.

Integration with External Systems

This type of optimization technology follows obvious patterns of integration, as illustrated in **Figure 3.** Integration

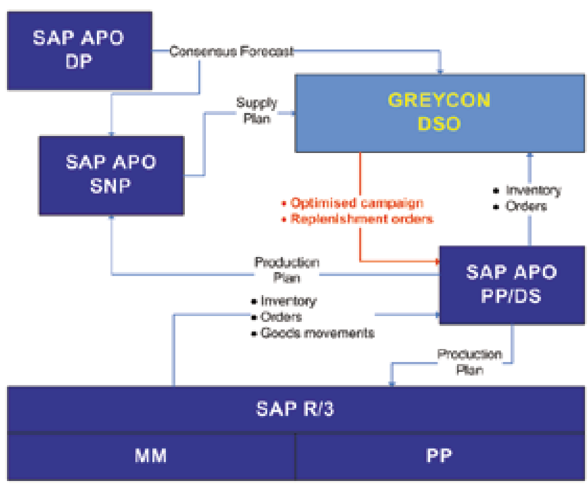

Figure 3: In an SAP context with APO, D-Opt complements SAP functionality dealing with multi-machine issues, treating the inventory tunnel as a target, and generating the appropriate planned replenishment orders and optimized campaign simultaneously.

with other systems is typically via XML messages, but other possibilities exist as well.

A CASE STUDY

The optimization technology was originally developed in association with a non-woven producer in North America, and the system is now in use at multiple sites.

Another North American paper company recently undertook an analysis of the potential benefits of the system as applied to a subset of their production. The model encompasses four large paper machines and demand data for 61 days. The annual sales value of these four paper machines is in the hundreds of millions of dollars.

The supplied data included the runs that were (manually) planned. This was particularly useful because it allowed a direct comparison of the schedules. The manual schedule was rather poor as shown in **Figure 4.**

A system parameter controls whether idle time is allowed. If not, the system will ensure that schedules completely use the available capacity within the horizon. This is done by inflating the demand as appropriate and, although it results in some sub-optimality (over-stock plus lack of detection of opportunities to either take downtime or go to the market with an incentive plan), this particular study was conducted under the no idle time assumption. The optimized schedule is shown in **Figure 5** with the same color coding as before:

The customer summarized the benefits as follows:

- From Red & Yellow to White & Green—Make what is needed, when it is needed. Demand-driven supply network (DDSN).
- Projected inventory reduction—20% in 90 days; US$700,000 annual carry cost; and US$2 million annual warehouse savings.
- Improved service, increased sales—US$400,000 increased margin, annualized (based on reduced stockouts by 1,000 tons in 90 days).
- Production costs are not materially changed.

Based on the above numbers, the system justifies itself in less than three months. But there are many additional benefits. The Friday before the presentation, one of the recovery boilers went down, resulting in the loss of five days of production for one of the paper machines. The effort to plan around this event to mitigate its consequences took many hours and generated a stack of paperwork, and the planners had little confidence that the final schedule best met the need. D-Opt's algorithm optimized these scenarios in 15 to 30 minutes on a laptop.

CONCLUSION

As with all nascent technologies, as systems are implemented new issues are discovered that will guide future product development. Some areas for possible development include:

Figure 4: Manual schedule. The color code is: red if the supplied item is below 0 at the time of the event, yellow if it is above maximum, green if it is below minimum, blue if it is below alarm and white if it is within the tunnel. Note that many items are produced when they are red (customer service failure) or yellow (over-stocking).

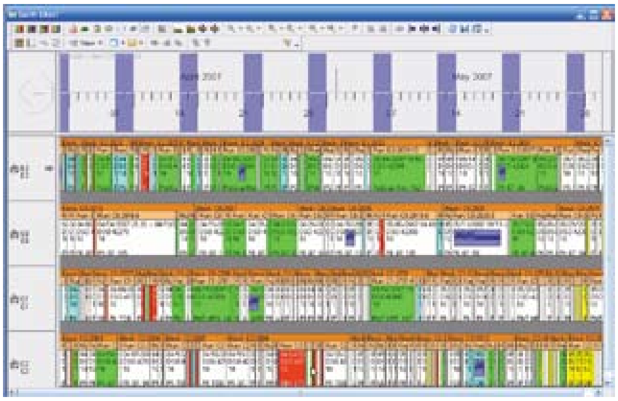

Figure 5: Optimized schedule. Note how the reds and the yellows have largely disappeared. The schedule contains 12% more runs than the manual schedule, but surprisingly they cost 5% less in total. This is because D-Opt was able to select better transitions than the planners.

Multi-site: With overlapping production capability, we need to consider transportation issues. Transportation impacts site selection in terms of cost and time. It is also common to encounter multiple transportation modes, which introduces another optimization degree of freedom.

Coupling Constraints: In some cases coupling constraints in multi-machine situations restrict the schedule construction process. Examples of coupling constraints include energy usage, pulp draw and effluent plant load. 360

Constantine Goulimis is one of the founders of Greycon Ltd., a London-based company specializing in applying advanced mathematical techniques to manufacturing, with emphasis in the paper industry. Contact him at cng@greycon.com.