Sonoco Uses a Stochastic Lotsizing and Scheduling Model to Optimize the Production of Coreboard

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Abstract

Since several years we have been working together with the European supply chain team of Sonoco, one of the largest global players active in the packaging industry, to solve a variety of supply chain challenges encountered in their industrial products & services division. In this work, we present the result from a pilot project related to production planning for which we developed a novel stochastic lotsizing and scheduling model and a solution approach tailored to their specific business environment.

Introduction

Sonoco, which has its headquarters in South Carolina, USA, is one of the largest producers of consumer and protective packaging in the world. Their current net sales are estimated at $5.39 billion, and they employ over 20,000 people in more than 300 operations in 33 countries. They are a member of the New York Stock Exchange (NYSE: SON), and are also included in the S&P 400 index.

The pressure on production efficiency in the paper mills of Sonoco is high, as coreboard is a low value density product the production of which requires capital-intensive machines. Furthermore, the time it takes to carry out a setup depends on the grade, which is determined by the amount of old corrugated containers that are added at the start of the production line, and the thickness (also known as the caliper) of the coreboard, and is hence contingent on the sequence in which the coreboard is produced.

The goal of the collaboration between Sonoco and the authors of this work is the development of a mathematical model and efficient solution approach that jointly optimizes lot sizes and production sequences for the production of coreboard in one of their European paper mills.

Development of a mixed-integer linear programming model

From a modelling perspective, the case at hand poses two challenges: the demand is considered stochastic, which introduces nonlinear expressions for the expected inventory on hand and for the backorder functions, and the changeovers are sequence-dependent, which enlarges the solution space and requires the inclusion of additional binary decision variables that increase the computational complexity of the mixed-integer linear programming (MILP) model.

A review of the available literature showed that previous research has studied either stochastic versions of the lotsizing and scheduling problem with sequence-independent changeovers or deterministic versions of the sequence-dependent lotsizing and scheduling problem, whereas both of these complicating factors have never been considered at the same time. Therefore, we developed a novel mixed-integer nonlinear programming (MINLP) model that can handle both the variability of the demand and the sequence-dependency in **?**.

The resulting model minimizes the sum of the expected holding, setup, and outsourcing/overtime costs while respecting a fill rate constraint and was first validated by using it on the broad set of instances introduced in **??** before its application to the case at hand. Via a tailored breakpoint selection strategy that transforms the MINLP into a MILP and a relax-and-fix with fix-and-optimize (RFFO) heuristic (**?**), an optimal production plan with a gap of less than 1% for the instance related to the paper mill in Rome with 24 products, 14 planning periods, and 40 line segments can be found in less than two hours.

Pilot project Rome

Overview of the supply chain

After the development and validation of the MILP model by using a benchmark dataset, we set up a pilot project at one of their European mills, for which we will assume that it is located in Rome, to assess the cost reduction potential.

The paper mill in studied in this work produces coreboard and supplies this coreboard directly to external customers and to two tube & core plants. Whenever, there is not enough capacity at the mill in Rome, there is one particular type of coreboard that can be sourced from a second paper mill at an extra cost to prevent a raw material shortage in the tube & core plants. In Figure 1, we present an overview of the supply chain network starting from the paper mill in Rome.

Data collection

In total, 24 types of coreboard are to be scheduled on the paper mill in Rome, for which the average historical weekly demand varies between 1 and 120 metric tons, with an estimated coefficient of variation of 30%. The setup times vary between 4 and 25 minutes depending on sequence in which they are produced and obey the triangle inequality.

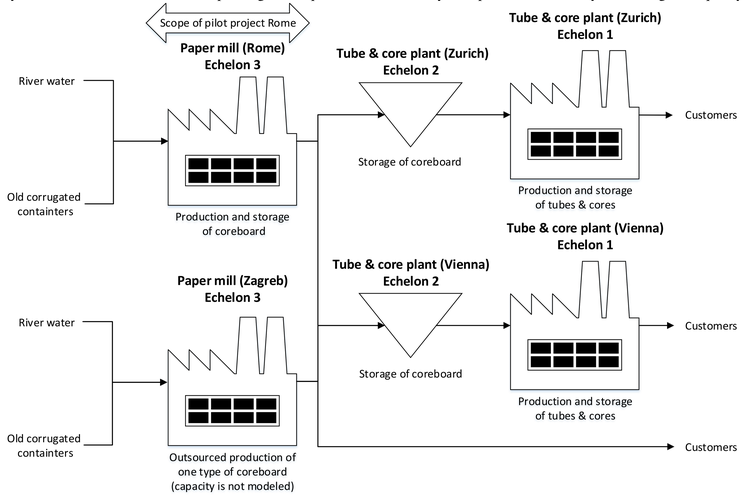

Figure 1: Overview tube & core supply chain starting from the paper mill in Rome

The highest changeover cost per minute is not more than twice as large as the lowest changeover cost per minute, and takes into account the value of the 'off-spec' material that is produced during a changeover. The holding costs are found by multiplying the production cost per ton with the weighted average cost of capital. The mill operates 24/7 with a 10% downtime for maintenance, the production time varies between 0.2 and 0.3 hours per ton.

Validation output model

To validate the model, we started from the historical production plan and selected a 14 week period for which we could collect data regarding the starting inventory, produced volumes and historical demand. Based on this data, we were able to derive the fill rate that was achieved for each type of coreboard, which was found to be 95.7% on average.

Besides the evaluation of a potential cost reduction by optimizing the production plan with an equivalent service level requirement, we are also interested to see by how much we can increase the fill rate for the same expense. To this end, we simulate three additional scenarios where the service level is equal to 96, 97, and 98%.

From Figure 2, we learn that the optimization model improves the objective value by more than 30%, and that the fill rate can be increased from 95.7% to at least 97% for the entire product portfolio before it exceeds the the cost of the historical plan. Even for a 98% fill rate requirement, the benchmark cost is only exceeded by 4.5% despite an increase of 2.3% in fill rate.

On top of the high-level production plan and cost overview, we provided the planners with a 'validation' spreadsheet that included a high-level overview of the potential cost savings shown in Figure 2, the historical plan, and the detailed results of the output of the MILP (see Table 1 for an overview of the reported data) for the matching service levels with the 96%, 97%, and 98% scenarios on a time period-product level.

The validation spreadsheet was found to be an ideal tool for engaging with the planning team. Not only did it lead to the final signing off on the model, but also to several insights related to the model and its input data: various master data corrections with respect to the changeover matrices were executed, to the extent that some changeovers that had been originally considered impossible by the ERP system were in reality only very small changeovers and hence had a significant cost reduction potential. Furthermore, the inclusion of starting inventory in the model increased the average fill rate for the historical plan from 73% to 95.7%, and the possibility to outsource the production of one type of coreboard prevented the model from going infeasible for high fill rate requirements.

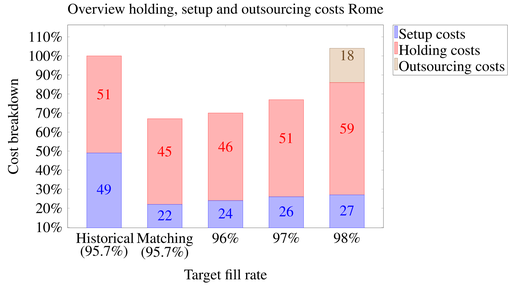

Figure 2: Overview tube & core supply chain starting from the paper mill in Rome

index	product name	position in sequence	previous product
production [kg]	production cum. [kg]	out. prod. [kg]	out. prod. cum. [kg]
demand avg [kg]	demand avg cum. [kg]	demand std [kg]	demand std cum. [kg]
setup time [min]	setup cost [€]	hold. cost [€/kg/year]	starting inv. [kg]
expected inv. [kg]	holding cost total [€]	expected backorder [kg]	

Table 1: Overview of the reported data per time period-product combination for the validation of the MILP model

Outlook

The novel MILP model that was specifically developed for Sonoco for tackling the stochastic lotsizing and scheduling problem with sequence-dependent changeovers in their paper mills and tube & core plants has now been running successfully for three months at the Rome paper mill along with the manual planning process, with thousands of euros in realized and projected savings, which is in line with the results that were found via backtesting, and which will be used to further strengthen the business case for a global roll-out.

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