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Using robust optimization for distribution and inventory planning for a large pulp producer

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ABSTRACT

Södra Cell is a world leading producer of pulp and has a large distribution network for its pulp products. This network includes production mills in Sweden and Norway, terminals in European harbours and inland locations, and many customers. The company uses several transport modes including long chartered vessels, spot vessels, trains, barges and trucks. The company uses a supplier managed inventory with a large proportion of its customers. This makes the logistic planning including transportation and inventory critical, as Södra Cell has direct responsibility of their customers' inventories. However, there is still some uncertainty regarding customer demand and Södra Cell has traditionally used a safety stock inventory approach to handle this. In this paper, we introduce a robust optimization approach to handle the uncertainty and to establish a distribution plan, together with related inventory management. With this approach there is no need for explicit safety stock levels. This is instead taken into account directly through the robust solution. In the proposed model, we can use practical characterization and historical information on the uncertainty. An important result with this is that we can avoid solutions that are too conservative and costly as in standard robust models. A large case study from Södra Cell is used to validate the proposed approach against the traditional approach with safety stock. The analysis is based on simulations and it shows that the robust approach is more cost efficient and can be used as a basis in a decision support system.

1. Introduction

Södra Cell AB is one of the world's largest pulp producers. It has five pulp mills: three in Sweden and two in Norway. The total number of pulp products is about 30 and these are delivered to about 150 customers located all over Europe. The majority of the pulp is transported on vessels from harbours close to the pulp mills to sea terminals in Europe. From these terminals, trains, trucks and barges are used for further transport to inland terminals and customers. Customers are typically paper mills which mix the pulp products in their own paper production. It is also possible to deliver by train or truck directly from the pulp mills to customers. This is used, in particular, for customers in the nordic countries and in cases of shortage.

Södra Cell is increasingly using a Supplier Managed Inventory (SMI), where Södra Cell takes full responsibility for the inventories of products at customer sites. In order to handle this, Södra Cell receives information on current inventory levels and production plans from its customers. One important decision is to manage inventory levels at terminals and of customers' to ensure that the SMI customers have enough products for their own paper production. At the same time, there is uncertainty in the final demand for products by customers and the transport capacity. The most difficult source of uncertainty is due to changes in the customers' own demand and production. Another source is the availability of spot ships, trains and trucks. However, this can somewhat be controlled by contracting enough capacity ahead of transports. As the proportion of SMI customers and their total volume has increased it is very important for Södra Cell to establish robust inventory and distribution plans which guarantee that customers do not run out of pulp products. The distribution planning at Södra Cell is done in a weekly rolling horizon environment.

A traditional solution approach is to formulate a deterministic model with safety stock levels at terminals and with customers. The purpose of the safety stock is generally to take into account uncertainty in demand and transportation capacity. The main problems are determining the level of the safety stock and the distribution or allocation over several terminals. An advantage with this approach is that the size of the planning problem can be kept small, as uncertainty is handled through safety stock levels.

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Another planning approach is to use stochastic programming. However, such models require full knowledge of the distributions of the uncertain data and such information is rarely available in practice. In addition, such models are generally very large and difficult to solve, even for small instances. These challenges have led to widespread use of robust optimization methods.

Robust optimization deals with situations where the decision maker wants to be protected against parameter uncertainty and, in particular, against the worst-case scenario. A robust solution is a solution that is feasible for any realization of the uncertain parameters (Bertsimas et al. [3], Ben-Tal et al. [1]). Much work has been done on static robust optimization where no recourse action can be done. However, when planning is dynamic on a rolling horizon, the solution can dynamically be adjusted as more information is known. In the dynamic planning situation there are two sets of variables. One set must be determined before all the parameters are determined (business decisions), and the other set of variables model future decisions that need not be determined until a later stage (anticipation decisions). Recently, there has been a large interest for robust optimization (See and Sim [12], Bredström et al. [4]) where the uncertainty set is kept small. The main problem with robust optimization is that solutions are over-conservative and often very costly. Thiele [13] discusses this over-conservatism in robust linear optimization and Bredström et al. [4] show that the cost to protect against a general uncertainty description is very expensive. However, by introducing an uncertainty description where practical considerations are included, the solution can be greatly improved. These ideas are used in Bredström et al. [4] where the case study (network distribution model) examines uncertain annual (monthly periods) demand at heating plants due to changing outside temperatures. These heating plants have annual contracts for a given energy consumption. The monthly demand is modeled as min and max levels around an expected level as is standard in robust optimization. However, by using additional information based on long term average annual temperatures it is possible to limit the uncertainty set. For example, even if the demand for a given month may fluctuate by $+/-10\%$, the precise demand numbers for one year are known (due to contracts and the stable average temperature), i.e., no uncertainty. This implies that any over-demand must be compensated with an equal under-demand. This type of constraint is not standard in robust optimization but it improves the performance considerably, as the uncertainty set can be reduced considerably. The same approach was also used in Bengtsson et al. [2] where uncertainty in arrival times for tankers at a refinery is studied. The problem is creating production and blending plans such that storage tanks do not get full or empty. The exact arrival times of the tankers are uncertain. However, from experience not more than every third tanker is delayed. This can be used to reduce the overall uncertainty as compared to when individual uncertainty intervals for each tanker are used.

In this paper, we use the solution approach proposed in Bredström et al. [4], in which the uncertainties can be described with an arbitrary polytope. No assumptions are required about the underlying distribution to describe the uncertainty in this formulation. Instead, the characteristics in uncertainty are formulated with affine constraints. In our application the demand from customers on a monthly basis is known accurately. However, the short term use of products is more uncertain. The reason for this is that customers may change, on the short term, the production campaigns and, hence, their use of products from Södra Cell. One aspect of our application which is not accounted for in Bredström et al. [4] is that decisions in the so-called business period may impact many periods in the anticipation planning periods. In the original method, transportation could be done within the same time period and the coordination between business and anticipation periods was done through the inventory level at the end of the business period. However, as transportation by vessels may take many days, this assumption is no longer valid. There are three main contributions in this paper.

- First, we implement the robust method to facilitate business decisions directly impacted in the anticipation periods.
- Second, we develop a solution methodology that can solve large problems efficiently.
- Third, we apply the proposed robust approach on a large industrial case and compare it with a traditional deterministic approach using a safety stock policy.

The structure of the paper is as follows. In Section 2, we describe the distribution and inventory problem in detail, together with the main issues to consider in planning. In Section 3, we state the deterministic version of the planning model and how the uncertainty can be described and modeled. In Section 4, we describe the proposed robust method. We use two cases for the numerical computations in Section 5. One smaller case is based on the data in Bredström et al. [4]. This is used to validate and analyze the extension with transports over several time periods. The second larger case is based on the problem faced by Södra Cell AB. The planning period for this problem is 30 days with daily planning periods. In order to evaluate the proposed robust method, we compare it with a traditional deterministic approach with safety stock levels. We also compare it with an oracle which is the solution found once all demand information is known. This corresponds to a theoretical limit of the other approaches when this is uncertain. We provide concluding remarks in Section 6.

2. Description of distribution and inventory problem at Södra cell

The terminals used for distributing pulp to customers in Europe (see left part of Fig. 1) are contracted from terminal operators. These are mostly specialized in handling forest products such as pulpwood and paper. Contracts with a terminal operator are usually valid for three to five years. The agreed handling rate covers a certain period of storage without extra charge (e.g. 60 days). After that time a storage rent is charged. The storage capacity of these terminals is agreed upon in the contract and is normally at least 30 days of regular throughput. There are two kinds of terminals; sea and land terminals. The demand for pulp products is mainly located across Europe including domestic demand in Sweden and Norway. Södra Cell deals with roughly 150 customers and delivers to some 250 paper mills/destinations in Europe (see right part of Fig. 1).

The distribution from pulp mills to customers use several transport modes. Södra Cell uses three long time chartered vessels to transport pulp to European terminals. Each vessel has a loading capacity of 5600 tonnes of pulp. Two of them are normally used for calling Northern European ports and the third is almost exclusively used for calling Genova, Italy. The routes to North Europe take 6–7 days (return trip) and the routes to Genova roughly 28 days (weather permitting). These vessels are chartered for 5–6 years and account for approximately 60% of the total need of vessel capacity. In addition, vessel capacity is contracted on an annual basis with shipping companies. Vessels under such contracts can normally be called-off with two-three weeks notice. From terminals, it is further transported with barges, trains and trucks to the customers. Some customers are delivered to directly by truck or train from the pulp mills. Customers normally delivered to through terminals can, as an alternative, be delivered to directly by trains or trucks, often at a higher cost. Roughly 60% of the delivered volume is transported by vessel and through terminals. The remaining