Planning a Distribution Chain
- a case from the Swedish Pulp Industry

Henrik Andersson
Linköping University
Department of Science and Technology
SE-601 74 Norrköping, Sweden
email: henan@itn.liu.se

Abstract

In this extended abstract, two different planning philosophies for a distribution chain management problem are analyzed and compared. The distribution chain is taken from a real world case in the pulp industry, and the main focus is mainly on the ship routing and scheduling.

Unlike many other models for marine distribution chains, the customers are not located at the discharge harbors in this case. This means that the model proposed also incorporates the distribution planning from the discharge harbors to the customers. All customers are not served from the discharge harbors; some are served directly from the mills using trucks and trains to distribute the pulp and these decisions are also included in the model.

The problem is modeled as a mixed integer linear program and solved using a branch and price scheme. Due to the complexity of the problem, the solution strategy is divided into two phases, where the first emphasizes the generation of schedules for the fleet operated by the company while the second deals with the chartering of vessels on the spot market.

1 Introduction

To remain competitive in today's business, a company needs to be efficient in all parts of its organization. This means cutting costs in the production processes by using advanced production technologies, increasing sales by effective marketing and using decision support tools to better coordinate the decision making. Here, two different planning philosophies, cyclic and demand driven planning, concerning the ship routing and scheduling are analyzed and compared. In cyclic routing, each vessel uses a cyclic schedule, i.e. performs the same route over and over again, while in demand driven routing, the vessels are routed based on the customers demand. The advantage with a cyclic schedule is that the functions around the vessels, such as loading and discharge operations, are easier to plan. The drawback is that the fleet may not be utilized as effectively as possible, resulting in a higher cost for chartering vessels on the spot market. It is the other way around with demand driven schedules, the utilization of the fleet may become higher at the expense of a more difficult planning situation.

The literature on ship routing problems is not as well recognized as other routing and scheduling problems. As far back as 1983, (Bodin et al., 1983) listed over 600 references on routing and scheduling problems, but only a few among them concerns ship routing. One reason for this might be traditions and resistance towards changes in the shipping industry. Another reason might be that the research is done within the companies or sanctioned by the companies and is therefore not published in regular scientific journals. When it comes to the routing problem itself, there are some important differences between ship routing problems and standard routing problems. For a general discussion about these differences as well as many other issues concerning planning in maritime transportation, the interested reader is referred to the surveys (Ronen, 1983), (Ronen, 1993) and the survey (Christiansen et al., 2004) for further examples.

An interesting thread to follow through the works in the earlier mentioned surveys is the decomposition of the ship routing and scheduling problem into one master problem where a number of pregenerated schedules are selected, and one subproblem where the schedules are generated. The first papers using this idea are (Appelgren, 1969), (Appelgren, 1971) where cargo constraints and convexity constraints are in the master problem and the subproblem becomes an ordinary shortest path problem. In (McKay and Hartley, 1974), the schedules are embedded in a more complex model, and all schedules are generated beforehand. An interesting aspect of this paper is that the products to be transported are not specified as cargos, i.e. with a given loading port, discharge port, time of delivery and so on, instead any supply of the given product can be used to fulfill a demand. (Ronen, 1986), (Brown et al., 1987), (Fisher and Rosenwein, 1989), (Perakis and Bremer, 1992) and (Bremer and Perakis, 1992), and (Kim and Lee, 1997) all use cargos and generate the feasible schedules beforehand.

In (Christiansen, 1999) and (Christiansen and Nygreen, 1998a), (Christiansen and Nygreen, 1998b) the ship scheduling problem is one part of a larger distribution chain problem. Besides information about the visits, the ship schedules also include information about the load quantities and arrival times. The schedules are then matched with harbor visiting schemes in the master problem.

Recently, (Fagerholt and Christiansen, 2000), (Fagerholt, 2001) and (Christiansen and Fagerholt, 2002) all use cargos and generate the feasible schedules beforehand. (Persson and Göthe-Lundgren, 2005) do not use cargos and do not include information about quantities in the ship schedules. Instead, the loading and discharge decisions are taken in the master problem.

The problem analyzed in this extended abstract is modeled according to these ideas, using a column based approach, where each column represents a schedule. Since the customers are not located at the discharge harbors, the model also incorporates the distribution planning from these harbors to the customers. All customers are not served from the discharge harbors. Some are served directly from the mills using trucks and trains to distribute the pulp, and these decisions are also included in the model. These extensions are not commonly addressed in the ship routing literature.

2 Problem description

The extracted distribution chain is part of Södras pulp supply chain. Södra is one of the world's leading producers of pulp for the open market, and a large actor on the timber, wood products and biomass fuel markets as well. The industrial operations of Södra are divided into four different business areas, Södra Skog (forestry), Södra Cell (pulp), Södra Wood Products, and Södra Skogsenergi (biomass fuel).

Södra Cell has five pulp mills, three in Sweden and two in Norway, and a total yearly production of around two million tons of pulp. Many of Södra Cell's costumers are European paper mills, meaning a long and complex supply chain from the forests to the customers.

The supply chain mainly starts in the forests in southern Sweden owned by the members of Södra. Besides hard and soft wood from these areas, Södra Cell also imports raw material mainly from Russia and the Baltic states. Some wood is also bought from non-member forests in Sweden, although Södra Cell prefers foreign deliveries. Wood from domestic suppliers is transported by trucks or trains to the pulp mills. Imported wood is transported by vessels to harbors close to the mills. Another important raw material is wood chips, which is a byproduct from sawmills. The pulp mills have limited storage areas for pulpwood, wood chips, and produced pulp. This makes it important to coordinate the production, the delivery of raw materials and the distribution of produced pulp.

After production, the pulp is transported to the customers. To domestic customers, the pulp is transported either by trucks or trains. Vessels are contracted to deliver the pulp to overseas customers. The distribution chain from the mills to customers in Europe is more complex. From the finished goods inventories at the mills, the pulp is transported to loading harbors and loaded onto vessels. Södra Cell operates three own vessels, but also vessels chartered on the spot market. The vessels travel to harbors in Western Europe and on the British Islands, and discharge the pulp. The customers may pick up the pulp at the harbors, or Södra Cell can deliver the pulp from the harbors to the customers using trucks or trains. A third possibility is to transport the pulp using barges and tugs from the harbors to inland terminals, and then from these terminals to the customers by trucks or trains. Some pulp is also transported from the mills to Central Europe using trucks or trains.

A schematic picture of the supply chain is shown in Figure 1.

Given this, the distribution chain management problem from the finished goods inventory at the pulp mills to the customers can be stated as *"Given fixed production plans at the pulp mills, minimize the distribution cost while fulfilling the demands of the customers"*.

In the distribution chain management problem, the production plans are considered fixed, and hence all activities upstream from the production are beyond the scope of this study. This is not always the case since the inflow of raw materials and the outflow of pulp can be coordinated, but here, no such coordination is considered. What happens

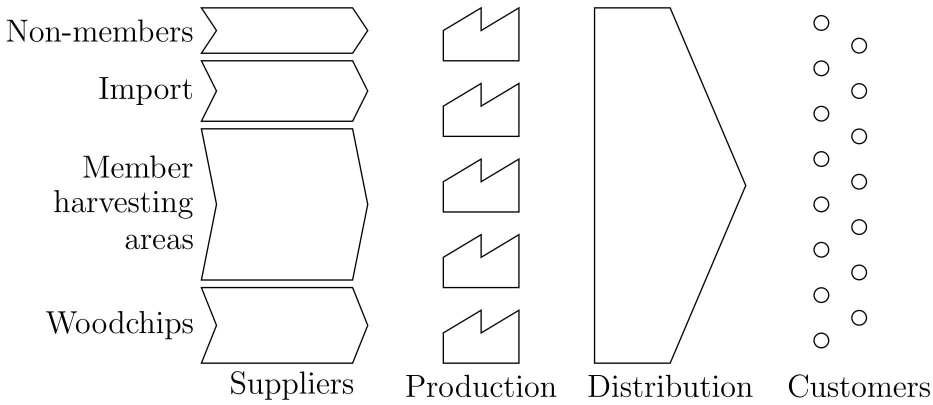

Figure 1: A schematic picture of the supply chain

after the pulp is delivered to the customers is also beyond the scope of this analysis.

Each mill has a fixed production plan, specifying the sort of pulp and the quantity produced each day. There is a limited storage capacity at each mill, but due to the tightness of the problem, the amount of pulp stored at the mills is so small that these capacity limits can be neglected. Because of technical limitations, such as the number of cranes that can be used to load and discharge pulp, a loading capacity per time period is associated with each mill, and a discharge capacity is associated with each harbor. The vessels in the fleet are all of the same size; the only thing that differs is their position and destination at the beginning of the planning period.

All domestic deliveries are considered uncomplicated. The assumption is that the cost of transporting one unit of pulp from a mill to a customer is fixed, meaning that the only decisions are when to deliver the pulp and from which mill the pulp should be delivered. The same assumption is made for all inland deliveries, i.e. from the discharge harbors to the inland terminals and the customers, and from the inland terminals to the customers. Södra Cell does not deliver to the overseas customers directly, but through a third party. Södra Cell only delivers the pulp to harbors in Scandinavia. Therefore, the overseas customers can be seen as domestic customers, and treated likewise.

3 Solution method

The problem is formulated as a mixed integer linear program and solved using a branch and price methodology. Branch and price is a combination of branch and bound and column generation, where each problem in the branch and bound tree is solved using column generation. Branch and price has been successfully used in many routing applications, see for example (Palmgren et al., 2003), and (Sarac et al., 2006). For a general introduction to branch and price, see (Barnhart et al., 1998).

Besides the columns used when describing the schedules for the fleet, additional columns are used to describe the possibilities of chartering vessels on the spot market.

Another key issue of the model is the way the flow of pulp is modeled. To model the flow an entity called *tie* is used. A tie is a pair of harbors, one loading harbor close to a mill and one discharge harbor close to the customers, representing a possibility to deliver pulp from the mill to the discharge harbor. This way of representing the flow is not very common, mainly due to the fact that cargos often are used and the schedules are generated beforehand. In the column based models where cargos are not used, (McKay and Hartley, 1974) use unconnected loading and discharge variables. (Christiansen, 1999) and (Christiansen and Nygreen, 1998a), (Christiansen and Nygreen, 1998b) discretize the load and discharge quantities and include information about the flows in the ship schedule. (Persson and Göthe-Lundgren, 2005) use a concept related to ties when they define their outbound voyages, but they associate one tie with each relation and voyage.

The algorithm iterates between the branch and bound scheme, where the ties are used in the branching decisions and column generation where new schedules for each vessel of the fleet as well as new chartering possibilities are generated. To generate the schedules, a network based on clusters of either loading or discharge harbors is constructed, and a modified k-shortest path algorithm is developed to solve the problem. The modified algorithm penalize the ties in the schedules already generated, making the schedules more diversified that general k-shortest path algorithms. By restricting the network used to generate new schedules, both cyclic and demand driven routing can be simulated.

4 Computational study

In the computational study, cyclic and demand driven routing will be compared and the differences between the different planning philosophies will be analyzed.

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