Supply Chain Management in the Pulp and Paper Industry

Dick Carlsson
Södra Cell International AB, SE-351 89 Växjö, Sweden

Sophie D'Amours
FOR@C, CIRRELT, Université Laval, G1K 7P4, Québec, Canada

Alain Martel
FOR@C, CIRRELT, Université Laval, G1K 7P4, Québec, Canada

Mikael Rönnqvist
The Norwegian School of Economics and Business Administration, NO-5045 Bergen, Norway

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Interuniversity Research Center on Enterprise Networks, Logistics and Transportation

(CIRRELT),

Université Laval, Québec, G1K 7P4, Canada

DE LA FORÊT AU CLIENT

Abstract

The pulp and paper industry depends on a long and integrated supply chain. It starts in forest harvest areas as trees and ends as multiple products used in all persons daily usage. The lead time from the first step to the last is long and it involves many steps operated by several companies and organizations. In this overview paper we describe the overall supply chain, its participants and the planning problems arising along the chain. We divide the planning problems into strategic, tactical and operative in a supply chain matrix and describe their characteristic and provide applications as illustrations. We discuss the need for information and decision support for planners in each of these areas. This relates to planning within a single company as well as integrated planning across several. A number of tailor-made systems has been developed and published in the literature and we describe these tools/systems together with their characteristics and results. To conclude with a discussion around current issues and outline future research areas.

1. Introduction

The pulp and paper industry produces a great number of paper and other cellulose based fibre products. The total quantity of cellulose-based products consumed every year world-wide exceeds 360 million tonnes. News papers, copy papers, various types of tissue, bottle labels, cigarette papers, and coffee filters are just a few examples of products regularly used in our everyday life. There is a large number of activities involved in the chain behind these products; from planting of the seeds of the trees producing the cellulose, until the product is used by the final consumer, and subsequently disposed of or recycled. Such a network of activities is known as a supply chain (SC) in the management and operations research literature. The interest for the supply chain perspective has increased over the recent years. Information systems, such as Enterprise Resource Planning (ERP) systems, are now crucial for the management of most companies by providing updated information about the various parts of the chain within a company. The information flow between organizations is an area which still needs further attention. Having information available is, however, not sufficient for appropriate management. Managing the supply chain involves a great deal of planning on different levels. Many of the ERP-systems offer some planning and decision support, and in addition there are commercial packages specialized for the purpose. However, commercially available planning support is not able to deal with all the planning problems of the pulp and paper supply chain. In addition there are research and development projects reported in the Operations Research (OR) literature to support the development of advanced Decision Support Systems (DSS).

Stadtler and Kilger (2005) provide an overview of supply chain management and planning systems. They give definitions and describe the structure of the supply chain. Different advanced supply chain planning concepts are explored and different commercial advanced planning and scheduling systems (APS) are given as examples. The authors also give some implementation examples, however not from the pulp and paper industry.

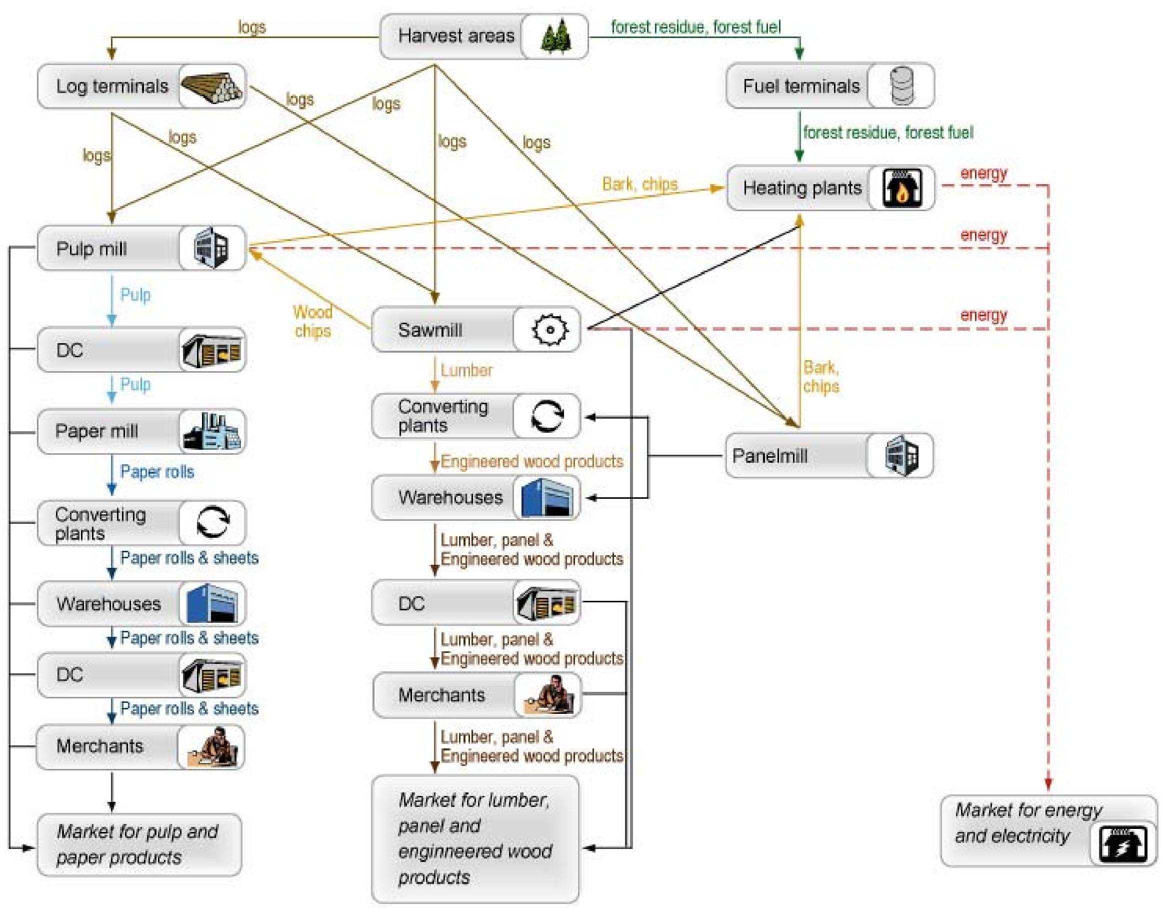
Stadtler (2004) also gives a, condensed, overview of supply chain planning and management. Recommendations for the future development of advanced planning systems are also offered. Demand planning is identified as being crucial for the supply chain planning and it is stated that models used so far could be improved. Another potential improvement is support for lot-sizing decisions in the master planning, which is claimed to be not fully solved yet. The author likes to see examples of event based planning being implemented which could prevent everything from being re-planned when the planning horizon is moved forward. Stadtler also identify uncertainty as a weakness in the supply chain planning of current APS. In the case of the pulp and paper industry, uncertainty at the supply level adds complexity as compared to discrete manufacturing. This because the properties of the logs (which in fact is unique for each) is not known until the harvesting is carried out. The fact that the production is a many-to-many process is another particularity which added to this uncertainty at the supply and demand level raises the complexity of the problem.

Rönnqvist (2003) and Weintraub and Romero (2006) gives examples of how optimization models and techniques have been used to solve supply chain planning problems arising in forestry. The reviews include forest management, harvesting, and transportation to wood consuming industries. The former also includes also examples of production and distribution planning at saw and pulp mills. The latter also include discussion about environmental and implementation issues.

Shah (2005) makes a review of the process industry and more specifically the chemical industry (excluding pharmaceuticals, food and drink, and pulp and paper). One of the conclusions drawn is that the modeling of the manufacturing process is often fairly rough, and that the actual implementation of the solution needs to be evaluated. The author would like to see combined revenue management and production-distribution models developed, and he argues that the scope should be broadened for coordination across the extended supply chain including suppliers and customers. Another need for integration that Shah identifies is that between the design of the production processes and the supply chain operations. Shah also points out that uncertainty is neglected in current literature.

Meixell and Gargeya (2005) reviews literature on global supply chain design, in view of changes that are going on in the global environment. They develop a classification scheme and analyze how well the literature deals with practical global issues. The authors find that existing models do not address outsourcing, integration and strategic alignment. The paper is primarily directed towards finding future research directions.

There is a vast literature on SCM in general. However, due to the special characteristic of the pulp and paper industry there is a lack in this area. The purpose of this paper is to provide an overview of available decision support for the planning and management of the pulp and paper supply chain and discuss issues and further research. In Figure 1 we illustrate the overall forest supply chain. We will focus on the pulp and paper supply chain which is indicated in the left part of the figure. Our starting point is the wood available in the forests (harvest areas) after harvesting has taken place. We then follow the wood from harvest areas until the production facilities where the wood is processed into pulp, and onwards to the paper manufacturing and the converting facilities. Thereafter we include the distribution of the finished products to merchants and/or retailers and the market for pulp and paper products.



The pulp and paper industry is described in the left part.

Figure 1. The forest industry supply chain.

The remainder of the paper is organized as follows. First, we define and describe the pulp and paper supply chain in Section 2, and then we present a supply chain planning matrix and different specific pulp and paper planning tasks in Section 3. In section 4 issues are discussed relating to availability of information for planning and the efforts made to integrate different parts of the supply chain in order to enhance the transfer of information. In section 5 advanced planning support is reviewed and planning models presented in the literature. We review the literature to find out the state-of-the-art of tailor-made planning models specifically dealing with the pulp and paper supply chain. Finally we discuss our findings and future directions for pulp and paper supply chain planning and management.

2. The Pulp and Paper Industry Supply Chain

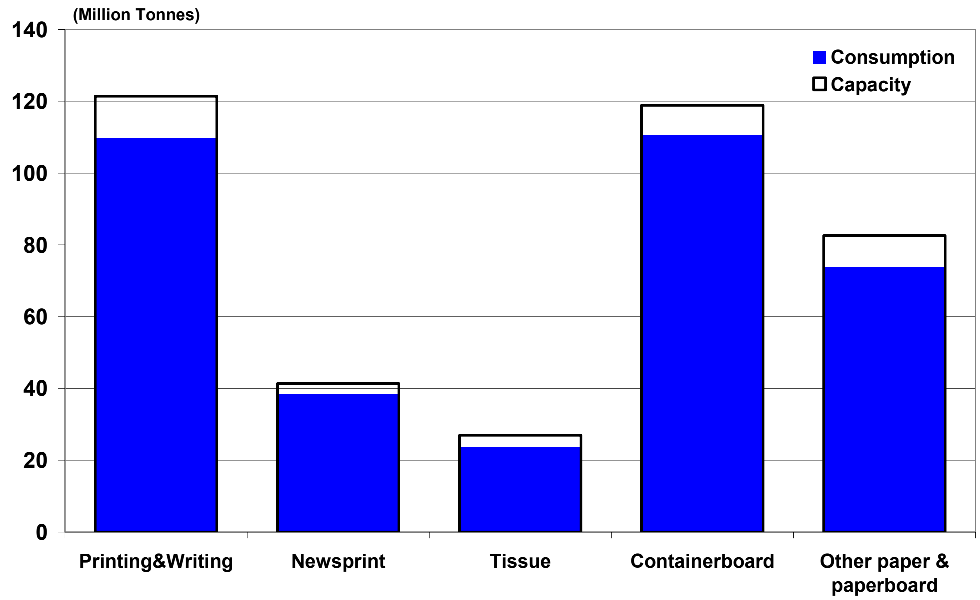
2.1 Paper Products and Usage

The paper consumption world wide amounts to roughly 360 million tonnes per year (RISI 2005). The paper consumed can be divided into five main segments based on end-use:

- Printing & Writing (e.g. catalogues, copy paper, book paper and magazines)
- Newsprint (e.g. newspaper)
- Tissue (e.g. toilet- or kitchen rolls, facial tissue)
- Container board (e.g. packaging box)
- Other paper & paperboard (e.g. paper boxes, paper bags, filters)

Figure 2 shows the annual consumption within different paper segments. Notable is that the capacity utilisation in the business is generally very high (91%). Paper companies normally run continuously except for regular maintenance stops.

The cellulose fibre accounts normally for more than 80% of the weight content of the paper. The properties of the cellulose fibre itself are therefore crucial for the resulting properties of the paper. This constitutes a strong link backwards in the Supply Chain to the very origin of the fibre used in the paper-making. The right fibres need to be identified already in the beginning of the chain and kept separated in different wood assortments and pulp products along the chain. It is also very important that the pulping and paper making processes do not destroy the properties needed further down the chain.



(Source: RISI)

Figure 2. Consumption and capacity for the year 2004 within different paper segments.

The desired properties for different types of paper vary. In tissues, for example, softness is often the most important feature. In the case of toilet rolls the softness should be paired with a high strength. Softness can be achieved with a high degree of short-fibre pulp (e.g. *Eucalyptus*), but in order to get the strength a certain degree of long-fibre is needed. However, it is important that the long fibres are flexible offering both maintained softness and reinforcement. This type of long-fibre properties can be found in Spruce (*Picea abies*) harvested in thinnings. Other papers, such as paper sacks, calls for a high tear strength. This property can be achieved by using a high content of long-fibre pulp based on residue wood from lumber production (e.g. Spruce chips). The reason for this is that sawmill chips comes from the "surface" of the logs used in the lumber production, where the fibres are longest and has the thickest walls.

2.2 Fibre Sources

The vast majority, more than 95%, of the fibres used for pulp and paper production originates from wood. Table 1 shows the three main pulp grades and their demand in 2004. Hardwood kraft pulp based on Eucalyptus is the grade that is growing fastest. This grade is used in many kinds of papers. In printing&writing this pulp makes the paper opaque and gives it a smooth surface and thereby good printing characteristics. In tissue, it contributes to the softness of the paper. In most papers softwood kraft pulp is still needed to make the paper strong enough. The strength is needed during the paper production itself as well as in subsequent converting and printing operations, and sometimes also when the paper is used. Mechanical pulp is mainly used in newsprint and other wood-containing papers such as papers for catalogues etc.

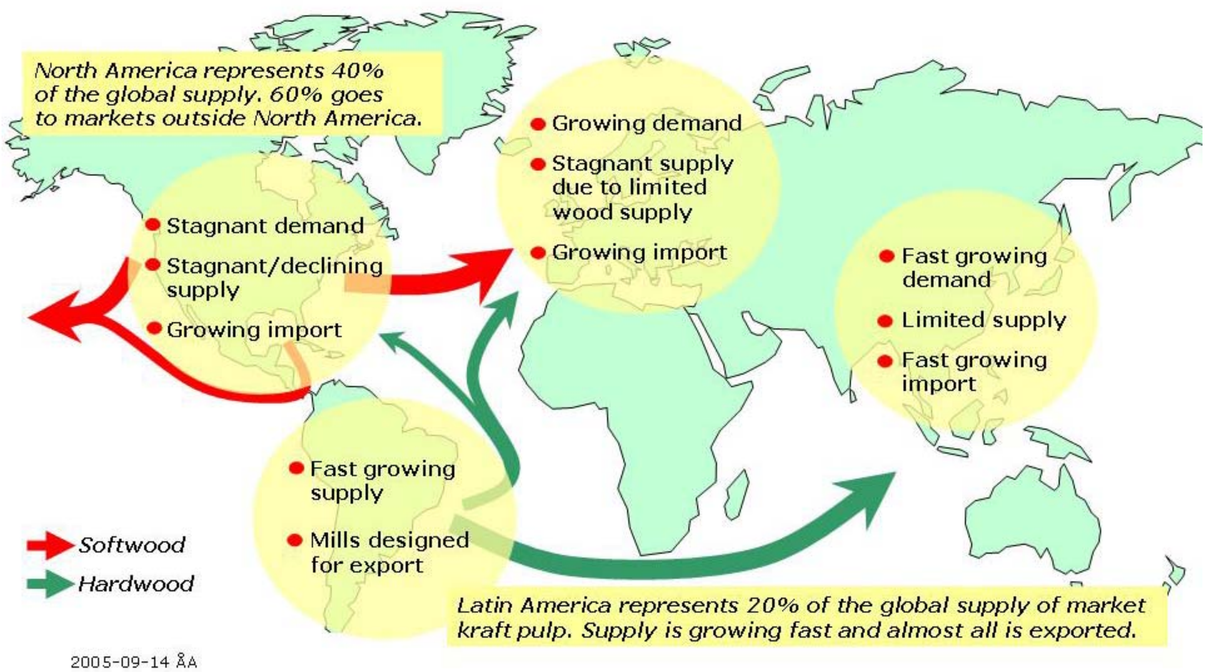
Table 1. Consumption (in millions of tons) of different pulp grades 2004 (Source: RISI 2005)

Pulp grade	Consumption
Bleached hardwood kraft	52,0
Bleached softwood kraft	39,0
Mechanical	37,0

It should be noted that it is the properties of the fibres that matters for the use in different papers. It is because the eucalyptus fibres are short that they contribute to a smooth surface of the paper. Softwood (conifer) fibres are long and acts therefore as reinforcement in the paper. The properties of the fibres differ also within the single tree. At the surface of the lower part of the conifer tree the fibres are longest and most robust (mature wood, thick walls). At the top the fibres are somewhat shorter and the fibre walls are thinner which make the fibre more flexible, and results therefore in a softer paper (juvenile wood). The causal relationships between some of the wood properties such as wood density, fibre length and fibril angle and several important pulp and paper properties were illustrated for juvenile eucalyptus globulus trees in a paper from Wimmer et al. (2002). Another study by Wilhelmsson et al. (2002) based on 62 Norway spruce and Scots pine trees sampled from a wide range of growth sites spread throughout Sweden, proposed models for predicting certain bulk wood properties based on three macro-level properties (tree diameter, tree age and growth conditions). These two research projects propose ways to bridge fibre characteristics, growth site quality and final product properties together and contribute to better plan the usage of the forest in the pulp and paper supply chain.

When converting the wood into pulp, the inherent property of the cellulose fibres of the wood is in principle not changed. In fact, the main achievement for a pulp producer is to make as small damage to the fibres as possible while maintaining the highest possible production speed. So, to end up with a paper of desirable properties depends to a large extent on finding the appropriate trees in the forest containing the right fibres for that purpose.

The pulp and paper business are currently undergoing major structural changes (see Figure 3). The major change from a demand perspective is the fast growing paper market in Asia. The availability of wood in the area is scarce so therefore the increase in demand of paper products is satisfied through imports of either finished products, but mainly through imports of pulp to be used in the expanding Asian paper industry. The major source of fibres for the future can be found in Latin America. Large land areas have been planted with Eucalyptus which has a typical rotation period of 7-10 years. The old markets such as North America and Europe are stagnant or growing slowly. The exception is Eastern Europe, which shows a fair growth.



(Source: Axelsson, Södra Cell AB)

Figure 3. Anticipated development of the global flow of wood fibres

2.3 The Pulp and Paper Industry

The pulp and paper industry can be viewed as a large network of production units which gradually refines the wood into consumer products (see Figure 4). It is very rare that all the refinement is made in one single company. The production network is linked to a procurement network which starts in the forest. This network may contain several locations (wood yards or other storage points) where logs are just stored or transhipped before it goes to production units. The production network is also linked to a distribution network ending at merchants or retailers, which together with the final customers constitutes the sales network.

As a matter of fact there is actually a connection from the sales network back into the pulp and paper supply chain again. Almost half (47% in 2004, RISI 2005) of the paper that is consumed is recovered and used to produce paper again. This volume amounted to 168 million tonnes in 2004, and made up 45% of the fibre furnish in the total paper production. Roughly the same amount, 170 million tonnes (46% of the paper furnish), of wood pulp is produced every year based on virgin fibre. The remaining content (less than 5%) of the total fibre furnish is mainly non-wood pulp such as pulp made from different grass species. The world's biggest buyer of recovered paper is China. In 2004, it imported another 12.3 million tons of recycled paper, with the U.S. providing about 60% of the total (McIntyre, 2005).

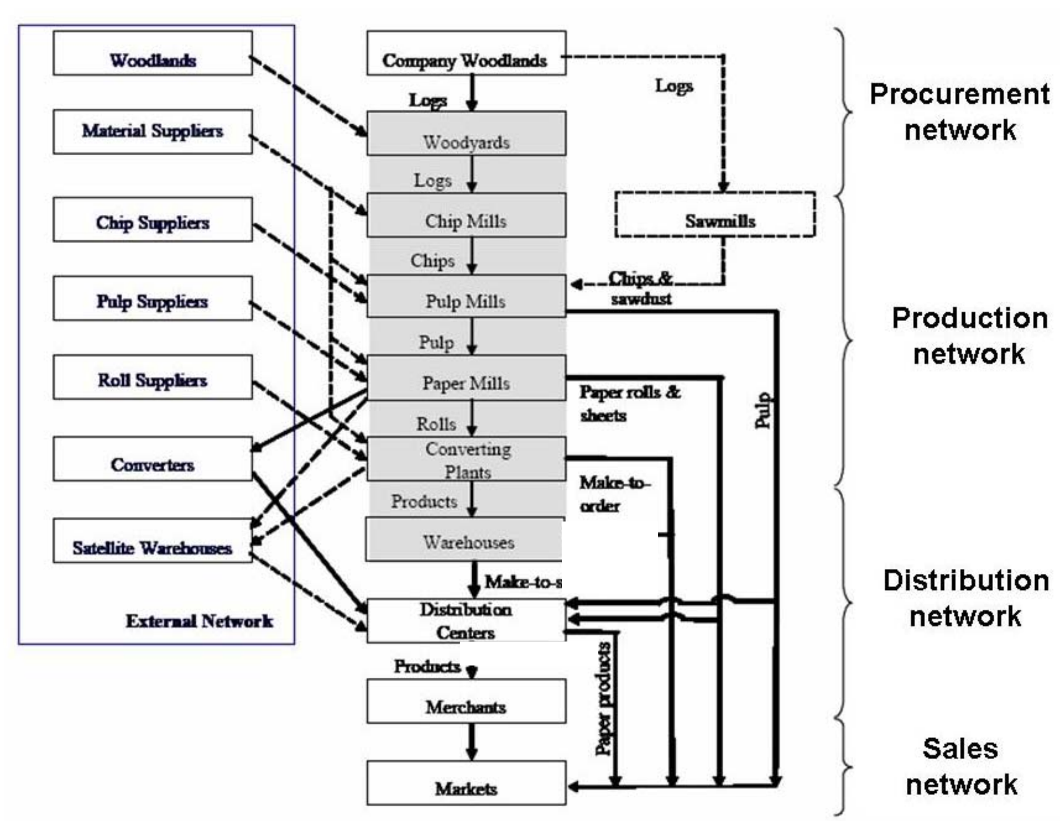


Figure 4. The pulp and paper supply chain. (Source: After Martel et al. 2005)

A mill which produces paper as well as the pulp needed for the paper production is said to be integrated. A majority of the world's pulp consumption, 72%, is integrated. The remaining volume, almost 50 million tonnes is market pulp. It is either sold by integrated producers that has an excess capacity or by non-integrated suppliers. Purchasers of market pulp are integrated producers not having enough capacity (or not producing a certain grade) or non-integrated paper producers.

We have three major processes; harvesting, pulp making and paper making. The harvesting consists of the following major stages.

- The trees are cut and branches are removed. Thereafter the tree is bucked (or cross-cut) into logs (with specific dimensions and quality). This process is typically done directly at harvest areas.
- Logs are transported from harvest areas directly to mills or through intermediate storage at terminals.

The harvesting is done by a set of harvest crews and the transportation by one or several transport companies. The overall harvest and transportation planning is often integrated. However, operational planning e.g. routing of logging trucks is done independently of the e.g. the bucking process.

The pulp making process involves the following steps:

- Conversion of pulp logs to chips. Chips from different species are mixed according to recipes with sawmill chips depending on the pulp quality produced.
- The chips are boiled and washed. Here, the fibres and lignin are separated.
- The fibres are then in a number of steps where chemical is added bleached in order to produce fibres with a certain brightness.

This is a continuous process where the time from chipping to production of pulp is about 12 hours. At integrated mills, the fibre is transported directly to the paper machines. In pulp mills, sheets of pulp is produced for further distribution to paper mills. The later paper making process involves the following major stages (see Figure 5):

- Fixed width reels of a given paper grade, also referred to as jumbo rolls, are produced on a paper machine.

- The reels are put on a winder and sliced into several rolls of smaller diameters and widths (trimming). The part of the reel not cut into rolls is trim loss.
- Finally, the rolls are shipped to customers, or converted into cut-sheet finished products on a sheeter, which may also generate some trim loss. The rolls sheeted into finished products are known as parent rolls.

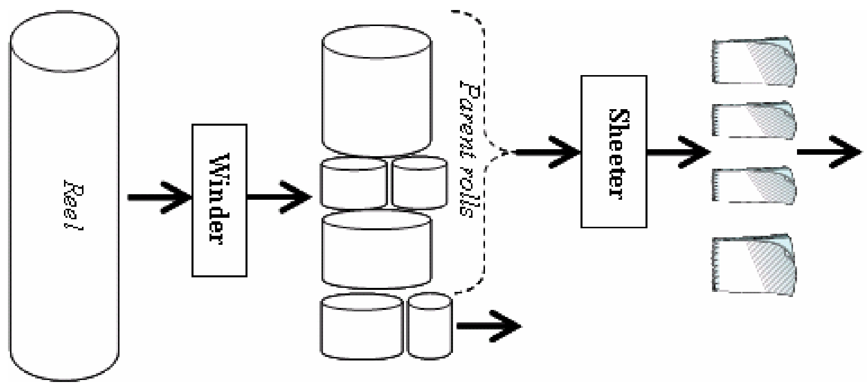
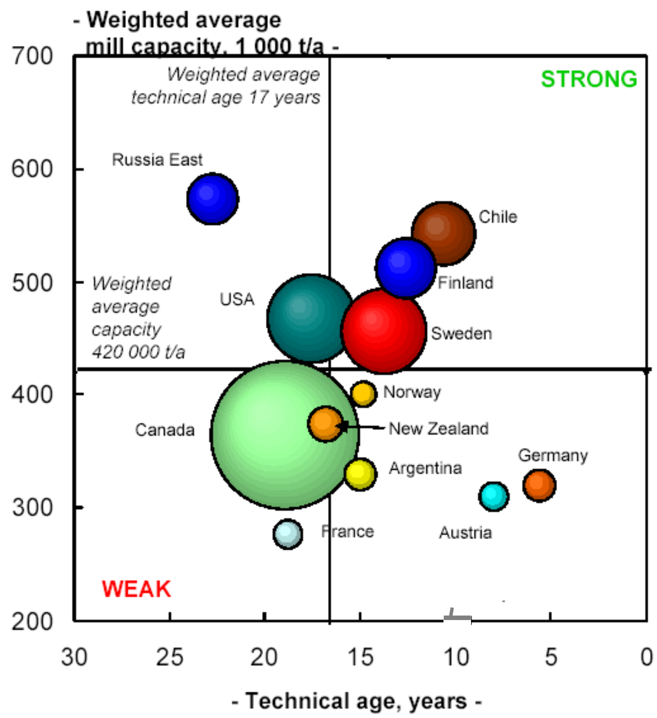


Figure 5. Paper manufacturing process

In some sectors of the industry, like Tissue, all these steps can be found at one single location and the products are then directly packaged for distribution to the consumers through merchants and/or retailers. In other sectors, the products are delivered to printers or additional converting plants before entering the sales network.

An important aspect is the current production capacity of the industry and how it is likely to change. Figure 2 did show that global capacity was higher than demand. In Figure 6, Jaako Pöyry illustrates, by country, the capacity and the technical age for market kraft pulp. Given the anticipated flow of fibres (Figure 3) it can be argued that countries with old smaller mills on a stagnant market, such as Canada, will have a weak position on the market as compared to countries like Chile with large modern mills with increasing demand and supply if pursuing a positioning in commodity segments.

The actual global distribution of capacity raises some interesting consolidation perspectives. These are also supported by the positive impact of consolidation on price control. Figure 7 illustrates the relationship between prices fluctuation and the level of consolidation in North America of the different pulp and paper product segments.

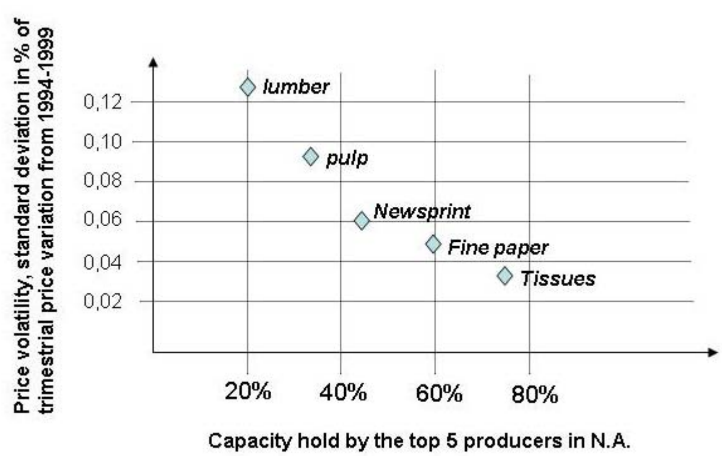


The bubble size reflects the market capacity of market kraft pulp (including export captive pulp).

The vertical axis represents the average mill capacity and the horizontal the average technical age.

(Source Jaako Pöyry)

Figure 6. Illustration of the global producers by country



(Source: Consolidation de l'industrie des produits forestiers en Amérique du Nord, Ministère des ressources naturelles du Québec, Avril 2003)

Figure 7. Illustration of the impact of consolidation on price volatility in North America

3. Pulp and Paper Supply Chain Planning

The above description of the pulp and paper supply chain shows that it involves many operations. It typically involves different modes of transportation over a great geographical distance. The planning horizon stretches from almost half a century (e.g. new capacity) down to hours and minutes (operative truck routing). The physical lead-time ranges normally between 5 to 12 months. Planning this chain is enormously complex. We will describe the different planning problems that occur. Thereafter, we will discuss how commercial advanced planning and optimization packages may be used to solve some of the planning problems that occur in the pulp and paper supply chain. Then we will describe how these planning problems have been dealt with in the literature

3.1 The Supply Chain Planning Matrix

Fleischmann et al. (2002) divides the supply chain into four main stages or processes. *Procurement* involves the operations directed towards providing for the raw material and resources necessary for the production. In the case of pulp and paper the most important raw material is wood. *Production* is the next process in the chain. In this process the raw materials are converted to intermediary and/or finished products. Thereafter, the *distribution* includes the logistics taking place to move the products either to companies processing the product further or to distribution centers, and finally to retailers. The *sales* process deals with all demand planning issues including customer or market selection, pricing strategy, forecasting and order promising policies. Figure 8 shows a matrix with typical planning problems that can be identified for the different processes of the pulp and paper supply chain. These planning problems are classified also based on the planning horizon.

3.1.1. Strategic

Long-term planning in the pulp and paper industry is indeed very long-term. An investment in a new pulp or paper mill is normally intended to last for more than 30 years. Strategic decisions would relate to opening and closing of mills, location of new or to be acquired mills, products and markets development, financial and operational exposure, planning strategy (e.g. decoupling point) and inventory location. Defining the planning approach has a major impact on all the investment decisions. It will fix important parameters in terms of needed technology and capacity as well as inventory levels and maximum distance to customers. Such decisions involve naturally an evaluation of how the investment will fit into the whole supply chain. Which markets are available for the products based on anticipated market trends? How will the distribution of the products be carried out and at what cost? And finally how should the production be supplied with the necessary wood fibres (wood or pulp)? Other supplies such as energy might also be a crucial factor.

	Procurement	Production	Distribution	Sales
Strategic	• Wood procurement strategy (private vs public land) • Forest land acquisitions and harvesting contracts • Silvicultural regime and regeneration strategies • Harvesting and transportation technology and capacity investment • Transportation strategy and investment (e.g. roads construction, trucks, wagons, terminal, vessels, etc.)	• Location decisions • Outsourcing decisions • Technology and capacity investments • Product family allocation to facilities • Order penetration point strategy • Investment in information technology and planning systems (e.g. advance planning and scheduling	• Warehouse location • Allocation of markets/customers to warehouse • Investment in logistics resources (e.g. warehouse, handling technologies, vessels) • Contracts with logistics providers • Investment in information technology and planning systems (e.g. warehouse execution	• Selection of markets (e.g. location, segment) – customer segmentation • Product-solution portfolio • Pricing strategy • Services strategy • Contracts • Investment in information technology and planning systems (e.g. On-line tracking system, CRM)
Tactical	• Sourcing plan (log class planning) • Harvesting aggregate planning • Route definition and transshipment yard location and planning • Allocation of harvesting and transportation equipment to cutting blocs and • Allocation of product/bloc to mills • Yard layout design • Log yard management policies	• Campaigns duration • Product sequencing in campaign • Lot-sizing • Outsourcing planning (e.g. external converting) • Seasonal inventory target • Parent roll assortment optimization • Temporary mill shutdowns	• Warehouse management policies (e.g. dock management) • Seasonal inventory target at DCs • Routing (Vessel, train and truck) • 3PL contracts	• Aggregate demand planning per segment • Customer contracts • Demand forecasting, safety stocks • Available to promise aggregate need and planning • Available to promise allocation rules (including rationing rules and substitution rules) • Allocation of product and customer to mills and distribution centers
Operational	• Detailed log supply planning • Forest to mills daily carrier selection and routing	• Pulp mills/paper machines/winders/ sheeters daily production plans • Mills to converters/DCs/ customers daily carrier selection and routing • Roll-cutting • Process control	• Warehouses/DCs inventory management. • DCs to customer daily carrier selection and routing • Vehicle loads	• Available to promise consumption • Rationing • Online ordering • Customer inventory management and replenishment

Figure 8. The Pulp and Paper Supply Chain Planning Matrix.

3.1.2 Tactical

The next step in the hierarchical planning structure is mid-term or tactical planning. Tactical planning addresses allocation rules which defines which resource or group of resources should be responsible for realizing the different supply chain activities. It also addresses the definition of the usage rules defining production, distribution delays, lot sizing and inventory policies. An important contribution of the tactical planning is to define those rules through a global analysis of the supply chain. This planning serves as a bridge from the long-term strategic level to the detailed operative planning which has a direct influence on the actual operations in the chain (e.g. routing of trucks, definition of when to change from one product to another in the production process etc.). The tactical planning should ensure that the subsequent operative planning is not sub—optimized due to a shorter planning horizon, but rather that the direction which has been set out in the strategic planning is followed. Typical decisions here are allocation of customers to mills and definition of necessary distribution capacity. The requirement of advance planning of the distribution depends on the transportation mode. Typically vessel, and rail transportation needs to be planned further in advance than trucks.

An important reason for tactical planning is the need for advance planning if there is seasonality in the supply chain. In the case of the pulp and paper supply chain, seasonality influences greatly on the procurement stage, i.e. the outbound flow from the forests. One reason is shifting weather conditions over the year which may make it impossible to carry out transportation during certain periods because of lack of carrying capacity on the forest roads due to thaw. In many areas of the world, there is also seasonality prevailing in the harvesting operations. In the Nordic countries, for example, relatively less of the annual cut is carried out during the summer period (July-august). During this period operations are focused on silvicultural management such as regeneration, cleanings, etc. During the winter relatively more is harvested, when the ground is frozen and there is little risk of damages during forwarding of the logs out of the forest. All this makes availability of wood vary considerably over the year. After the summer, wood stocks are low with restricted availability of specific assortments, whereas in the spring, there are plenty of most assortments.

Example of a tactical planning task is production scheduling of pulp mills with regards to wood availability, and vessel distribution. The time horizon may vary in this planning between 6 to 12 months. Crucial is to account for the period during the year when wood availability is scarce to ensure not to run out of certain assortments. In a chemical pulp mill the cost of changing from one product to another is relatively high; therefore the number of product transitions is not that large (somewhere in the range of 6 to 24 per year). This makes it important to account for the scheduling of the production already at the tactical level. When it comes to paper, production transition costs are normally considerably smaller. This is why the scheduling sometimes is not explicitly accounted for at the tactical level. The purpose of this plan is to define guidelines on monthly levels for the subsequent short-term planning. The wood supply department is given target volumes of different assortments to deliver to different mills the following month. This planning task stretches over several stages of the chain: procurement, production and distribution. There are also tactical planning tasks which are more restricted to one of the stages. In the procurement stage, for example, one planning task is to define catchment areas for the supply to different mills. A catchment area denotes the geographical area in which the wood from different harvesting locations is hauled to a certain mill. Often there is more than one mill requiring the same assortment. The problem in this case is normally to ensure that all mills are sufficiently supplied while the total transport cost is minimized.

In most companies, an important task is the annual budgeting of the following year. During this planning exercise, the company decides which products to offer to customers and in what quantities. In the process of elaborating these decisions, their implications on the whole supply chain (procurement, production and distribution) needs to be evaluated and net profit maximization should be the aim. In that regard, Shapiro (2001) suggests that the tactical planning models be derived from the strategic planning models where the 0-1 variables related to the strategic decisions be fixed and the planning horizon be extended to a multi-period (multi-seasonal) horizon.

3.1.3 Operative

The third level of planning is the short-term or operative planning, which is the planning that precedes and decides real-world operative actions. Because of that, there are very high demands on this planning to adequately reflect in detail the reality in which the operations take place. The precise timing of operations is crucial. It is normally not adequate to know which week or month a certain action should be taken, it has to be defined in terms of days or hours. The operative planning is normally distributed to the different facilities or cells of the facilities because of the enormous quantity of data that needs to be manipulated at that level (e.g. SKU and specific resources).

One operative problem is the roll cutting problem in paper mills, see Figure 5. Once the reel (or tambour) has been produced in the paper machine it must be cut into the rolls demanded by internal and external customers. The reel may be 5-10 meters wide and 30 km long. The customer orders are for products that may be 0.5-1.0 meter wide and 5 km long. The problem is to decide cutting patterns, and the number of each, in order to satisfy the customer order while minimizing the number of reels required during a given period of time.

Another large area of operative planning problems is within transportation. Routing of vessels appears between several segments of the supply chain. There are routing issues for the truck fleet used for haulage of wood from the forest to pulp mills. There is routing of trucks for the distribution of finished products from mills to customers or distribution centers.

Within the production process, scheduling of the different products on the pulp and paper manufacturing lines are also typical operational planning tasks. Finally, the process control of pulp and paper manufacturing involves real time operative planning decisions.

3.2 Order Penetration Point and Customer Relationship

Although the decisions presented in the Supply Chain Decision Matrix all have to be taken at some point of time within the supply chain, the models supporting the decision making may vary greatly depending on the strategy of the enterprise in terms of the order penetration point location within the production-distribution network, the customer relationship strategies and the use of inter-enterprise collaboration. Here we address a set of business models used by the industry and discuss their impact on the supply chain decision process.

3.2.1 Order penetration point (OPP)

The order penetration point is normally defined as being the semi-finished product (e. g. pulp, parent roll) inventory decoupling a push planning approach from a pull planning approach. The semi-finished product at the OPP is built-up based on matching demand forecasts with production capacity forecasts (make-to-stock) whereas the rest of the production-distribution process is planed just-in-time, pulled by firm orders to the producer. Defining the location of the order penetration point is a strategic decision because of its impact on capacity deployment and technology decisions. Normally, the push process would be supported by high capacity equipment providing important economies of scale, while the pull process would be supported by agile manufacturing equipment providing high flexibility and responsiveness. The OPP also has a direct impact on the nature of the supply chain planning and control decisions.

Order promising requires checking the availability of the semi-finished products needed to be transformed just in time to the specificity of the customer as well as the availability of the capacity to conduct the just-in-time transformation. Demand planning therefore does not limit itself to inventory management but it also involves real-time or fast scheduling decisions. If the OPP is far within the supply chain, then scheduling challenges are increased since more resources are to be scheduled on a just-in-time mode.

The positioning of the OPP is limited by the response time accepted by customers. For example, if a next day delivery offer is guaranteed to the market then the OPP can only be at the distribution center. If customers allow a few days of delivery, then the OPP can move into the production process. In the paper industry, in practice, the OPP has been set at three different locations: before the paper machine (***make-to-order)***, after the winder (***convert-to-order***) and at the warehouse (***deliver-to-order***). Specific planning applications have been provided in the literature for each of them and Martel et al. (2005) provides a comprehensive discussion of most of them.

3.2.2 Customer relationship

Adding to the decision on the OPP, the offer made to the customer influences greatly the nature of the decision support models used for the supply chain planning. Different customer relationship approaches are used in the industry. The most common one is the order-based relation, where a customer just places an order and the producer promises a price and a delivery date. Over the last years, a vendor managed inventory (VMI) approach appeared. Under a VMI agreement, the producer is responsible for managing the inventory of its customer. The customer provides the daily consumption to the producer so it can build a production-distribution plan that meets the fixed service level as well as optimize the usage of its production-distribution resources. The VMI approach showed to the industry that some collaboration between the producer and the customer is possible. Since then, companies have explored new approaches such as Continuous Replenishment models based on carrier capacity or production capacity. The replenishment is structured around a pre-scheduled reservation of capacity. For example, the collaboration may set a one truck per day delivery to the customer. Then, the customer is responsible for setting the mix of products to be in the truck every day. This approach smoothes the needs of the customer over time and it reduces the pressure on the producer. The same approach applies with capacity reservation. Finally, the Collaborative, Planning, Forecasting and Replenishment (CPFR) business model is also slowly penetrating the pulp and paper industry. In that model, demand and production-distribution capacity are dealt up-front in order to define a win-win unique plan for both parties.

3.2.3 Inter-enterprise collaboration

Inter-enterprise collaboration seems to raise more and more attention in both the academic and industrial worlds. Companies are working together to reduce logistics and procurement costs. There are examples for the collaborative planning of log supply and chips supply where companies are willing to consider logistics constraints of competitors in order to generate globally greater economy. Other examples of collaboration have been seen in transportation planning. These new approaches are usually contributing at the tactical level by improving the allocation of products to mills or at the operational level by integrating the need of a set of mills in the planning process. Typically at the operational level, the collaboration is supported by an electronic platform which can plan and negotiate the needs. These new practices request from the decision support systems that they can deal with distributed and restricted information and that they can propose collaborative solution to all participants. The objective of the models used is therefore to provide a better solution to all participants. Often, the optimal solution is not feasible because of an uneven distribution of the benefits. As for the constraints, they integrate the logistics constraints of all participants.

All these business models impose different constraints and driving objectives, and they therefore lead to different planning models for the supply chain. They raise the need for a deeper comprehension of the interaction between the OPP, customer relationship strategies and emerging collaborative planning approaches. Advance planning systems are expected to evolve so they can deal more efficiently with collaborative practices such as information exchange and collaborative planning.

4. IT in the Pulp and Paper Supply Chain

A basic requirement for proper management and planning of the supply chain is information about the current state of the system, and anticipated business needs and opportunities. In this section we review the status of IT for supply chain management, in the pulp and paper industry. For a thorough review of literature on information systems in supply chain integration and management the reader is referred to Gunasekaran and Ngai (2004).

Often information technology is viewed as the sole solution to supply chain management problems. It is however crucial to ensure that the planning and control processes and the relations between partners are adequate before a large investment is made in an IT-system. De Treville et al. (2004) indicate that such investments can be counter-productive. They refer to a major Nordic pulp and paper company that, despite substantial investments in an ERP-system, could not improve their on-time delivery performance despite the fact that they had high inventories. The authors argue that in order to benefit from improved information transfer, the lead-times in the supply chain has to be reduced so that the information can be used in planning the production and distribution for a specific order. Otherwise the information might even cause, or worsen the so called bullwhip effect in the supply chain. The bullwhip effect refers to the amplification of the variation of demand as it is passed down the supply chain. Lee et al. (1997) wrote one of the greatest studies on this effect proposing four causes for it: demand forecast updating, order batching, promotions and rationing and shortage gaming. The negative impact on the pulp and paper supply chain was raised in Carlsson and Fuller (2000) estimated the importance for the paper industry by stating that for a 300 kton North-European paper mill the costs incurred by the bullwhip effect are 200-300 MFIM 940-60 millions USD) annually.

Today most companies in the pulp and paper industry have an ERP-system installed containing much of the information necessary for planning. There are however still data integrity and availability problems that needs to be addressed. The ongoing consolidations in the industry make it inevitable that different ERP-systems are used within a company. To change system is both costly and time-consuming. Therefore some companies choose to maintain different systems. The big challenge in this situation becomes the integration between the systems, especially if customer orders must be managed consistently, regardless of which part of the company will delivery the order.

Another source for problems is that ERP-systems are designed for handling large volumes of real-time transactions. This information is very specific and stored in a way that is streamlined for the management of the individual transactions. ERP-systems are normally not suitable for making analyses based on the stored transactions. For this purpose data has to be flexibly aggregated on different dimensions. For planning purposes data also has to be extrapolated into future time periods.

In the paper industry there has since a number of years been a strive towards simplifying the flow of information between companies, i.e. mostly between suppliers and customers. The type of information subject to these efforts has primarily been order and delivery messages. This development started with the creation of EDIPAP, an EDI-standard for electronic business transactions between paper suppliers and their customers (merchants and printing houses). In the late nineties the development of an XML-standard was initiated. This later became the papiNet™-standard (www.papinet.org). The scope of the standard has widened to include not only the printing&writing sector, but also packaging, label stock and pulp.

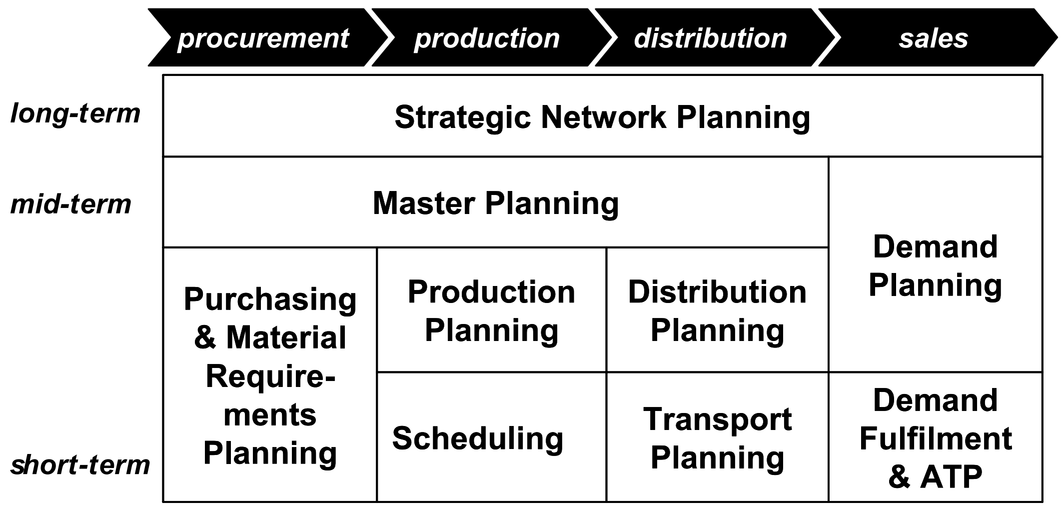
Whereas EDIPAP never became widely used in practice, papiNet™ is currently showing a fairly quick growth (www.papinet.org), both in Europe and in North America. In addition to being used for integration between companies, the standard is also often used for internal integration of a central ERP-system with mill-specific production planning systems. Generally the integration from suppliers to customers is either carried out in direct links business-to-business (B2B) or passes through a hub. An example of a hub is *Expresso* (www.expressopaper.com), which has been established for integration between fine paper producers and merchants. Another example is *Elemica* (www.elemica.com) which originally was created for integration between chemical suppliers and their customers, among others companies in the pulp and paper industry. Subsequently, customers linked to the Elemica hub wanted other types of suppliers integrated through the same hub (e.g. pulp). Generally speaking, the pricing policy of the hubs has so far not been clearly advantageous compared to B2B-integrations. However, further on when the costs involved in maintaining numerous B2B-connections becomes clearer, the business case for the hubs may be more attractive on the integration-market.

5. Supply Chain Planning Support

In this section we present and discuss decision support for the planning problems presented above. We will first very briefly cover the planning support typically available in commercial packages that is relevant for our case, and the problems these packages might face when dealing with pulp- and paper supply chain planning. Thereafter we will review the operations research literature which specifically is dealing with supply chain planning in the pulp and paper industry.

5.1 Advanced Planning Systems

Most ERP vendors like SAP (www.sap.com), Oracle (www.oracle.com), etc. also provide solutions for supply chain planning and management. In addition a number of companies, such as i2 (www.i2.com), Manugistics (www.manugistics.com) and SLIM (www.slimcorp.com), have specialized in providing supply chain optimization solutions. These software packages are commonly called advanced planning systems (APS). Most APS have a common structure which relates to the supply chain planning matrix described earlier. Fleischmann et al. (2002) gives a thorough review of the typical structure of an APS. The APS-systems are structured into a number of different software modules. Each module is dedicated to solving a specific problem in the supply chain planning matrix. Figure 9 shows the modules normally found in an APS.



(from Fleischmann et al. 2002)

Figure 9. APS modules covering the SCP-Matrix

There are many cases when the standard APS-module have limitations in solving the actual problem at hand. This has often to do with the methods used in the modules being designed to deal with a generic planning problem formulation. When the actual problem does not fit into the generic problem formulation the APS-module will be less suitable. Examples of this includes that operational aspects need to be accounted for explicitly in the mid-term planning, or that two or more stages along the supply chain has to be planned together also at the operative level in order to achieve a relevant result. In some cases it is even necessary to use an operative planning model to analyze the impact of a strategic decision. An example is that to understand the implication on the transport fleet of changed service hours for loading/unloading, an operative routing model is necessary in order to capture the essential aspects. An aggregate flow model will not be able to reveal what actually happens. To deal with all these cases tailor-made planning support has to be developed. In the next section we review the scientific literature which specifically deals with the pulp and paper industry.

5.2 Advanced Planning Models from the Literature

Our review of the literature is based primarily on the planning horizon adopted in the respective articles. We start with the strategic planning support and then move to the tactical and conclude with the operative articles. In Figure 10 we indicate where in the Supply Chain planning matrix each article can be located in terms of planning horizon and the scope along the chain it covers.

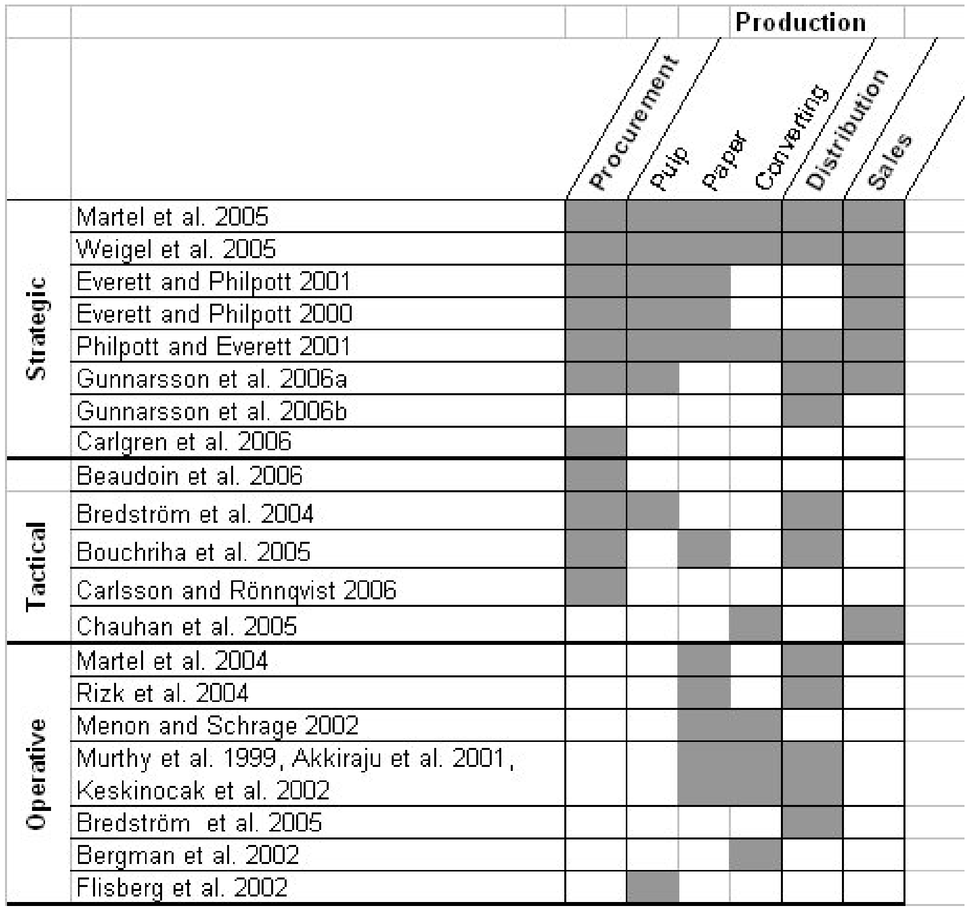


Figure 10. Planning horizon and scope of the reviewed literature

5.2.1 Strategic models

Martel et al. (2005) presents an OR model to optimize the structure of multinational pulp and paper production-distribution networks. The authors aim to identify the main international factors having an impact on the industry and show how they can be taken into account in the design of the supply chain. The main factors necessary to account for on the international level includes national taxation, transfer price regulations, environmental restrictions, trade tariffs and exchange rates. Adding these features to the model, however, adds considerably to the complexity of the problem. Martel et al. suggest how this can be done based on a general production-distribution network model.

Weigel et al. (2005) presents a model that optimizes the wood sourcing for different final products, through the whole value chain. As an alternative strategy, the end-product range is also tailored to make use of existing market conditions with respect to available fibre supply. The objective of the model is to maximize the contribution margin of the supply chain, i.e. sales revenues minus various fixed and various costs. The model assumes that wood available in aggregated supplies can be sorted in different ways into distinct grades. Each pulp and paper product can be made according to a set of viable recipes involving the wood grades in different proportions. The authors show, using a test case, that substantial improvement in objective value can be achieved by optimally allocating fibre types to the right process stream and at the same time optimize the output of the supply chain into different end-products.

Philpott and Everett (2001) present the work carried out within Fletcher Challenge to develop a model (PIVOT) for optimization of the paper supply chain. PIVOT is used to optimally allocate suppliers to mills, products to paper machines, and paper machines to markets. The core of the model is a fairly generic supply chain model formulated as a mixed integer program. In addition a number of restrictions are added to model mill specific conditions such as interdependencies between paper machines in a mill, and distribution cost advantages in certain directions due to backhauling opportunities. The successful implementation of PIVOT led to further development of the model by the authors in cooperation with the management of Fletcher Challenge. In Everett et al. (2000) the SOCRATES model is described which was developed for planning investments on six paper machines at two mills located on Vancouver Island in Canada. The main features distinguishing SOCRATES from PIVOT is that capital constraints are introduced and that a multi-period planning horizon is used. Due to the expansion of the model it became difficult to solve it with the most straight forward formulation, mainly because of the large number of binary variables. The authors therefore present how the formulation could be strengthened to make it solvable, using the specific properties of the problem. A further development of the model was achieved in the COMPASS model (Everett et al. 2001), which was implemented for three Norske Skog mills in Australia and New Zealand. The objective function was modified to account for taxation in the two countries. The other main feature added was that the paper furnish was allowed to vary, in terms of different wood pulps used, depending on capital investment decisions. The intention was to evaluate possibilities to use a less costly furnish based on capital investments done on the paper machine.

Gunnarsson et al. (2006a) develops a model for strategic planning of Södra Cells kraft pulp supply chain. The main purpose of the model is to optimize the allocation of the various products to mills. Södra Cell has four pulp mills, three in Sweden and one in Norway, producing kraft pulp. The whole pulp supply chain is described using a mixed integer programming model. On the demand side of the model all potential contracts with individual customers are defined together with the expected net prices to be achieved. The user can define whether a certain contract has to be taken to its full extent or if the model can choose to take it or not. Various different means of transportation can be selected to deliver the pulp to the final destination. Pulp recipes are allowed to vary within a min/max-range in terms of the share of different wood assortments used to make different products. The model is used by Södra Cell's management to evaluate different scenarios of wood availability and cost. Another typical use of the model is to optimize the composition of the product portfolio. A kraft pulp mill suffers very much from having to produce many different products, since transition costs are relatively high, especially when mixing hardwood and softwood on the same production line. Gunnarsson et al. (2006b) deals with strategic design of the distribution network. Södra Cell operates three long term chartered vessels dedicated to the pulp distribution only. How well the routing of these vessels can be done depends on the terminal structure. With a few terminals each having a large volume turnover, there is a great chance that the vessels can be unloaded at one single terminal, whereas if many small terminals are used, the vessel probably has to pass two or several terminal to be unloaded. The authors develop a model in which terminal location is combined with vessel routing. This is an example of planning on a strategic level where it is important to account for the operative aspects, i.e. the routing.

A crucial part of the pulp and paper supply chain is the procurement of appropriate wood fibres for the different final products eventually being produced. For that purpose wood is sorted into different assortments with specific properties. Sorting into more assortments is however costly, and is a decision that normally not can be taken independently by one single party on the wood market. Carlgren et al. (2006) develops a model in which sorting decisions for the southern Swedish pulp wood market is optimized. The model accounts for backhauling possibilities as described in Carlsson and Rönnqvist (2006). The model was used to analyze what would be the effect of modified wood demands at one or several mills in the region. Results from the model could among other things show in what way the wood composition would change for the mills when wood demands changed at one of the mills.

5.2.2 Tactical models

A tactical planning model for Södra Cell is developed in Bredström et al. (2004). The main focus of the model is the production planning of the three Swedish kraft pulp mills of Södra Cell. The model stretches from individual wood sources through the mills until aggregated demand sinks, and it produces individual production schedules for the mills. The combination of optimizing the flow in virtually the whole supply chain with production scheduling makes it challenging for the authors to solve the model. Two different approaches are adopted; one using column generation with one variable for each production plan and one explicit mixed integer formulation with a branch and bound strategy as the solution method. Both approaches prove to be successful for solving the problem. Based on a test case presented, the second formulation could provide a solution faster, whereas the first one was able to find the best solution in terms of objective value. In comparison with manual planning, the model generated production schedules with a larger number of product changes, while on the other hand reducing incurred storage and logistics costs.

Bouchriha et al. (2005) develops a model for production planning in a context where the production campaigns have a fixed duration. The aim is to fix the campaign duration on a single paper machine of a North American fine paper mill. The planning model is used to anticipate the cost of planning under different fixed duration production campaigns. The problem is solved using a three step procedure. In the first step the cycle length is determined based on historical demand data. In the second step the lot-sizing of each product is optimized subject to a fixed sequence of products in the cycle, i.e. all products are made in every cycle. The volume produced may however vary between cycles. The fixed sequence restriction is relaxed in the third step in order to obtain a lower bound on costs, to be compared with results from the second step in order to ensure the quality of those results.

A tactical planning problem for the wood procurement stage of the supply chain, is dealt with in Carlsson and Rönnqvist (2006). The problem here is to find optimal wood catchment areas for a number of plants in a region. The catchment area constitutes the geographical area from which a specific wood assortment is delivered to a certain mill. The destination thus designated to each wood pile subject to being transported is used in the subsequent operative transport planning. The formation of the areas will therefore affect the potential of efficient routing of the truck collecting the wood. The authors suggest how this can be accounted for in a model where backhauling possibilities are included. The model is formulated as a column generation problem and solved iteratively to optimality, or near-optimality. A large number of implementations of the model in the Swedish forest industry are reported. The model has primarily been used to analytically evaluate the potential for increased productivity in truck routing based on backhauling. The authors however also report a case in which it has been implemented as an integrated part of a web-based wood-transport management system.

A similar problem has been studied by Beaudoin et al. (2006), although in this case the wood procurement problem is viewed from a multi-company perspective. They proposed a mixed integer programming model that allows for wood exchange between companies. Furthermore, the material flow through the supply chain is driven by both a demand to satisfy (Pull strategy) and a market mechanism (Push strategy), enabling the planner to take into consideration both wood freshness and the notion of quality linked to the age of harvested wood into demand. A test case shows that it is possible to manage the wood flow from the stump to end market in such a way as to preserve its freshness and to extract higher value from the logs processed in the mills. Also, results for the test case show that the proposed planning process achieves an average profitability increase of 8.8%, as compared to an approach based on a deterministic model using average parameter values.

Chauhan et al. (2005) deals with tactical demand fulfillment of sheeted paper in the fine paper industry. The authors adopt a *sheet-to-order* strategy, which means that parent rolls are produced to stock. The sheeting occurs subsequently upon receipt of customer orders. A model is proposed to find the assortment of parent rolls to keep in stock in order to minimize expected inventory holding and trim loss costs. The model is a nonlinear integer program which for large problem instances is difficult to solve. A couple of heuristics for solving the problem are however presented. When tested on real data from one of the largest fine paper mill in North-America the model proved capable of reducing inventory holding costs substantially while at the same time achieve a slight reduction in trim loss cost.

5.2.3 Operative models

A number of operative planning models have been developed for the paper industry.

Rizk et al. (2006a) present a model for planning multiple machines in a single mill, integrated with distribution to a single distribution centre. The production of intermediate products and final products is coordinated. The production of intermediate products is considered to be the bottleneck in the production line, whereas no capacity constraint is considered for the converting to final products. Economies of scale in transportation is accounted for through a piecewise linear function. The authors formulate the model as a mixed integer programming model. Different formulations are tested with regard to the piecewise linear distribution cost function. In addition a number of "artificial" but logical restrictions (cuts) are proposed in order to enhance solvability of the model by use of the commercial solver Cplex. Results presented from a real case coming from one of the largest uncoated free sheet producers in North-America shows that the model can be solved within reasonable time when the suggested cuts are included. It also showed considerable savings when production and distribution decisions are optimized all together as compared to optimize distribution planning first, and then, constrain the optimization of the production planning. In Rizk et al. (2006b) the previous model is expanded to include multiple distribution centers. The authors report that the large model obtained can be solved more effectively by using adequate cuts. They also propose a heuristic sequential solution approach to solve large problem instances efficiently.

Another case in which multiple stages of paper manufacturing is planned simultaneously is presented in Murthy et al. (1999). In this case the planning includes allocation of orders to machines (possibly at different locations), sequencing of the orders on the machine, trim scheduling for each machine, and load planning. To solve the problem a heuristic framework based on an agent-based architecture is developed. One set of agents are responsible for adding new tentative plans to a shared population of solutions (Constructors), another set (Improvers) work on existing solutions in the population, and a third set (Destroyers) limit the population by removing non-attractive solutions. The agents are specialized for the different aspects of the plan, order allocation, sequencing etc. Multiple objectives are used by the agents based on transition costs, distribution costs or due dates. More about the agents and how they are constructed can be found in Akkiraju (2001) and Keskinocak et al. (2002). The authors report several real-world implementations of the planning system in the US based company Madison Paper Inc with substantial savings in trim loss and distribution costs. Correira et al. (2004) also contributed to this idea of integrated scheduling and cutting approaches in a make-to-order strategy.

A model specifically dedicated to the combined order allocation and trimming problem in the paper industry is developed in Menon and Schrage (2000). The model is formulated as an integer programming problem. It is solved, by the use of linear programming based bounds in an iterative procedure. The authors report from successful use of the model on real-world and generated test problems.

Bredström et al. (2005) deals with a planning support model dedicated to operative planning of pulp distribution. The model focuses on routing and scheduling of vessels which are coordinated with other available means of transportation: truck, rail. The problem is solved heuristically by a genetic algorithm. The algorithm works on a pool of potential solutions, the population, which is evolved through generation of new generations (combinations of two solutions) and mutations (random modifications of existing solutions). A crude selection of the fittest individuals in the population is done by the use of a simplified LP-formulation of the distribution problem in which restrictions on the overall consistency of flows are relaxed. The individuals thus selected, are finally evaluated by a full LP-formulation. Computational results reported by the authors show that the genetic algorithm performs well compared to a mixed integer approach.

Bergman et al. (2002) deals with roll cutting at paper mills. Roll cutting is a well known academic problem for which there are efficient solution methods. However, in an industrial setting there are many practical issues to consider e.g. limited number of knives in the winder, products needs to be in the same pattern or not, different due dates for products, limited inventory space etc. Another practical issue is given a minimum number of rolls needed there is an objective to use as few cutting patterns as possible. This to limit set up costs and times. In this article a system taking into account these issues is described and tested on a set of case studies. It is based on a combination of Lagrangian heuristics, column generation and limited branch & bound strategies. Other roll cutting models particularly suited for the paper industry are presented by Goulimis (1990), Sweeney and Haessler (1990) and Westerlund et al. (1998).

Flisberg et al. (2002) describes an online control system for the bleaching process at a paper mill. The problem is to decide the chemical charges in a number of bleaching steps. The objective with the system is to support operators to minimize the chemical usage (i.e. cost of chemicals) and improve the spread of the brightness of the pulp before it reaches the paper machines. The solution approach is to construct approximate models describing the individual process steps and then formulate an overall optimization model that comes up with the control i.e. chemical charges in each of the steps. The models are nonlinear and the system is implemented in an online system where the control is recomputed every five minutes.

6. Discussion

The pulp and paper industry has some characteristics that makes it unique. The volumes and quality of the supply is stochastic and hard to predict with high accuracy. The planning horizons are ranging from very short (seconds) to very long (decades). The industry has a divergent flow i.e. there are many more end products (several hundreds) as compared to the raw material (a few species of trees). The industry has a tradition of using manual planning in a push-based system and there are many practical problems when this is turning into a pull-based system. The relations with customer are often based on spot and contracts. The industry is very capital intensive with small margins. Due to the specific characteristics in the industry it is difficult to use standard planning systems. Hence, there is a need for more tailor-made DSS. Below we discuss some areas where there is a large need for further research.

There is an increased competition with other industries. In recent years, the use and importance of bio-energy fuel has increased. Escalating prices for fossil fuels has boosts the development of alternative energies, among which wood fuels are the most promising in the short term for medium- and large scale heat and electricity production. Due to governmental policies the wood fuel is now making a substantial share of the energy supply in countries like Sweden, Finland and Austria. Several fuel types exist that can be used and one important type is forest fuel. Forest fuel can be forest residues that are chipped (converted into small pieces), by-products arising from sawmill such as sawdust, or wood without other industrial use. With the increased energy prices, trade in emission rights and different tax systems the usage of pulp logs directly at heating plants have increased. This competition between pulp and paper producers and heating plants is expected to grow in the future. Competition on the supply of pulp logs is also increasing with saw mills and panel industry.

Beside the industrial competition, there are also issues related to environmental aspects. There is an increased need to consider endangered species, set of areas to preserve biodiversity and to increase to area for recreational usage. These rules are often based on governmental policies and they set limits for the procurement. How this affect the pulp and paper industry is difficult to address without tools that include such aspects and restrictions.

Transportation corresponds to a large proportion of the total raw material cost. Large volumes and relatively long transport distances together with increasing fuel prices and environmental concern makes it important to improve the transportation planning. In many regions, several forest companies operate and the transportation is carried out by a large number of transport organizations and hauliers. Supply, demand and companies are geographically evenly dispersed in the region and there is generally a high potential for coordination of the wood flow. Examples and methods for coordination are found in Forsberg et al. (2005). The potential for cooperation is often in the range 2-20%. When there are several companies planning becomes more difficult. Planners do not want to reveal supply, demand and cost information to competitors. Also, how should the saving be divided among the participants? In a study by Frisk et al. (2006) eight companies were included in a case study. Here an optimization system was used to find the optimal transportation for each company as well as the coordinated case. In the paper different cost allocation models are studied in order to split the savings among participating companies. These studies illustrate interesting collaboration potential within the pulp and paper supply chains. However, many questions remain unsolved as the collaboration involves defining stable coalitions, composed of companies which have no incentive to quit the collaboration and therefore propose a sustainable solution.

7. Concluding remarks

We have made a description of the pulp and paper supply chain and the planning tasks found therein. Thereafter we made an overview of commercially available planning support off-the-shelf as well as the state-of-the-art of relevant research. We can conclude that support is available for most planning tasks. Of-the-shelf commercial systems will however not always be sufficient. For certain problems tailor-made models are necessary. The specific pulp and paper literature is not abundant, which in itself can indicate a need for additional research.

What improvements would we like to see in future planning support? Initially we mentioned improvement areas identified in reviews of general supply chain planning literature. Some of these are relevant in our case as well. One factor that was mentioned by several authors was that uncertainties typically were neglected. This is potentially a serious deficiency since a planning model that would incorporate uncertainty could lead to substantially different results and thereby eventually lead to a completely different management decision. Incorporating uncertainty in planning models typically support decisions that lead to the maintaining of as much flexibility as possible for the future. If there is uncertainty in the relative demand and/or prices of different products, a model that optimizes the product portfolio would give higher priority to maintaining several products than would a model that assumes demand and prices at some average and fixed level. This aspect is of course most important for strategic planning when long term decisions are taken, which influence the ability of the organization to adapt to changes in the future. The reason for not taking uncertainty into account is however obvious in many cases; it would make the planning model at hand virtually explode in size and make it impossible to solve. Even though it was technically possible there are reasons that make the issue complex. Uncertainty can be incorporated in many different ways and a number of assumptions have to be made regarding the nature of probability distributions which often can not be derived from historical data. In addition a stochastic model is generally more difficult to explain to decision makers, which need to trust the planning model to act on the results generated by it. Based on this discussion we conclude that more research should be carried out on the implications of uncertainty to supply chain planning before it is incorporated into practical systems. More about incorporating uncertainty in strategic supply chain planning can be found in Shapiro (2004).

A weakness we identified in the mid-term master planning of the commercial APS's was a lack of ability to integrate lot-sizing or campaign planning for individual mills (also mentioned by Stadtler 2004). This relates to the fact that the different APS lack ability at integrating the

different decision levels (tactical versus operative, or operative versus execution). This is mainly due to the problem of aggregating and disagreeing the needed data.
This is crucial in a production system where transition costs are high and cycle times therefore long. Due to this weakness tailor-made models have been developed (e.g. Bredström et al. 2004).

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