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Study of SCM in Paper Industries.

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Abstract—
The paper manufacturing organization depends heavily upon integrated supply chain. It begins in forest harvest areas and finally converts into final product with help of manufacturing processes. However the amount of time involved from initial stage to final step is high and it involves many stages operated by several intermediaries. 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. In this paper we discuss when scm is implemented it will have high impact on how to do business moreover the goals activities and organization of all functions within an organization will drastically changes. This relates to planning within a single company as well as integrated planning across several. To conclude with a discussion around current issues and outline future research areas.

1. INTRODUCTION

During last few decades many management techniques were launched. Some of this turned into hypes but disappeared almost as quickly as they came. However there is little doubt that supply chain is here to stay. Although everybody doesn’t release that but scm when implemented will have major impact on all the function within the organization. The paper industry manufactures a great number of papers. The total quantity of paper 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 stages behind these products; from planting of the seeds of the trees producing 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 paper industry supply chain. In addition there are research and development projects reported in the Operations Research. Steven stated that achieving an integrated supply chain require a three phase process : identifying customer needs, determining cost option, and organising options into a supply chain (steven, 1985).At a out this time the concept of supply chain gained much attention given to appropriate policies and procedures for supply integration (jones and riley,1987). By the 1991, the statement had been made that supply chain management had become a subject of increasing interest to academics, consultants and operational management and guidelines for strategic implementation were provided (Scotland west brook, 1991). When she stated that the philosophy of supply chain management extends the concept of partnership into multiform efforts to manage the total flow of goods. Ronnqvist (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 automobile industry (excluding pharmaceuticals, food and drink, and pulp and paper). One of the conclusions drawn is that the modelling 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 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 paper industry supply chain and discuss issues and further research. We will focus on the paper industry supply chain which is 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 remainder of the paper is organized as follows. First, we define and describe the paper industry supply chain, and then we present a supply chain planning matrix and different specific paper planning tasks. Lastly 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. Than 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 paper industry supply chain. Finally we discuss our findings and future directions for pulp and paper supply chain planning and management.

2. Paper Industry Supply Chain

2.1 Paper Products and Usage

The paper consumption worldwide amounts to roughly 360 million tonnes per year. 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)

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. 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 thinning. 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.

2.1 The Paper Industry

The paper industry can be viewed as a large network of production units which gradually refines the wood into consumer products. 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 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).

2.1.1 Paper Supply Chain Planning

The above description of paper manufacturing 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 paper industry supply chain. Then we will describe how these planning problems have been dealt with in the literature. 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. These planning problems are classified also based on the planning horizon.

2.1.2 Strategic

Long-term planning in the 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.

2.1.3 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.

2.1.4 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. One operative problem is the roll cutting problem in paper mills. 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 paper manufacturing involves real time operative planning decisions.

3. IT in the Paper Manufacturing 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 p 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 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 paper supply chain was raised in Carlsson and Fuller (2000) estimated the importance for the paper industry by stating that for a 300 kton paper mill the costs incurred was 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.

4. Supply Chain Planning Support

4.1.1 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 paper industry supply chain planning. Thereafter we will review the operations research literature which specifically is dealing with supply chain planning in the paper industry.

4.1.2 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.

4.1.2 Tactical models

A tactical planning model for Sodra Cell is developed in Bredstrom et al. (2004). The main focus of the model is the production planning of the three Swedish kraft pulp mills of Sodra 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 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 Ronnqvist (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.

4.1.3 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. 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.

5. Concluding remarks

We have made a description of the paper industry 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 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 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. Bredstrom et al. 2004).

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