International Factors in the Design of Multinational Supply Chains: The Case of Canadian Pulp and Paper Companies

Alain Martel,

Wissem M'Barek

and

Sophie D'Amours

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Research Consortium on e-Business in the Forest Products Industry (FORAC),

Network Organization Technology Research Center (CENTOR),

Université Laval, Québec, G1K 7P4, Canada

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Alain Martel[*], Wissem M'Barek and Sophie D'Amours

FOR@C Research Consortium,
Network Organization Technology Research Center (CENTOR),
Université Laval, Sainte-Foy, Québec, G1K 7P4, Canada.

Abstract: Factors such as tariffs, exchange rates, income tax legislations, national factors of production (e.g. natural resources supply, labour and infrastructure), transfer prices, trade barriers and competition (e.g. world wide distribution of capacity and demand) may have an important impact on company performance. In this paper, we discuss the international factors that may have an important impact on the structure of the value creation networks of Canadian pulp and paper companies, and we show how they could be incorporated in a global supply chain optimization model. To do this, we use a simplified production-distribution network structure in order to emphasize the role of international factors without complicating the analysis. The global network considered is composed of four echelons: fiber and pulp suppliers, pulp and paper mills, distribution centers and demand zones. We provide some modeling elements for the construction of a global optimization model through the synthesis of the existing literature on international network design. We conclude with a discussion of modeling extensions required to obtain network optimization models adequate for decision support in the pulp and paper industry.

Keywords: International factors, Supply Chain Design, Pulp and paper industry, Mathematical Programming.

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[*] Corresponding author e-mail: alain.martel@centor.ulaval.ca.

1. Introduction

Today, with the opening of markets, the emergence of commercial blocks (EU, NAFTA…) and the increased competition from abroad, companies cannot isolate themselves from international factors and, to improve their competitiveness, they must operate multinational supply chains. The Canadian pulp and paper industry does not escape this global context. Canadian pulp and paper companies are operating multi-echelon networks of production, distribution and retailing facilities located primarily on the North-American continent, but also elsewhere in the world. Although the industry has traditionally obtained the fibre resources required to make paper from affiliated North-American forestry and sawmilling operations, fibre resources are becoming scarce in some part of Canada, and the import of pulp from developing countries is now seriously considered. The industry is capital-intensive and it is characterized by a strong competition as well as an evolving demand. Maximizing returns in this industry is a complex task and international factors such as exchange rates, income taxes, access to resources and trade regulations may have a very significant impact on a company performance.

The aim of this paper is to identify the main international factors having an impact on the pulp and paper industry and to show how they can be taken into account to design superior multinational production-distribution networks. Although the problem is discussed from the point of view of the Canadian pulp and paper industry, the analysis and modeling approach proposed is general and it could be used in any other context. The literature on international factors and on network design models is also reviewed and research directions to improve the state of the art are identified.

The paper is organized as follows. In section 2, we discuss the international competitive context of the Canadian pulp and paper industry. Issues related to supply, demand, production, distribution and national factors are examined. In section 3, a mathematical programming model based on the current state of the art is proposed to optimize the structure of multinational pulp and paper production-distribution networks. Finally, in section 4, the extensions necessary to take all relevant factors into account are identified and the existing literature on these factors is reviewed.

2. Industry Context

Canada has been producing paper for 200 years and, since the beginning of the 20th century, it has been one of the largest exporters of pulp and paper in the world. In 2004 the Canadian industry produced 10.5 million tonnes of market pulp, 8.2 million tonnes of newsprint, 6.9 million tonnes of printing and writing paper, and 3.9 million tonnes of paperboard. Only 17% of this production was shipped in Canada. The rest was exported mainly to the U.S.A. (52%), to Asia (17%) and to Western Europe (10%). The value of these exports is 20.5 billion dollars[1], which represents a 70% export intensity[2], the highest in the Canadian manufacturing sector. The trade balance of the sector was on average $17.9 billion during the last decade, which is more than 50% of the country's commercial trade balance. The industry employs close to 100,000 persons and it is capital intensive. In 2002, the accumulated capital investment reached 62.6 billions. The dominant costs in the sector are materials (70%), production salaries (16%) and energy (14%)[3].

The manufacture of pulp involves separating cellulose fibers from other impurities in wood, used paper or other fiber sources. The manufacture of paper involves matting these fibers into a sheet. Converted paper products are produced from paper and other materials by various cutting and shaping techniques. These manufacturing processes, are embedded in complex supply chains, as shown in *Figure 1* for printing and writing paper. The main components of these supply chains are their supply network, their manufacturing network, their distribution network and the product-markets targeted. Different companies are structured in different ways. Some are vertically integrated and they possess and control all the facilities involved in this value creation network, from woodlands to markets. Others are not integrated and they rely on outsourcing to fulfill part of their commitments to their customers. For example, some companies buy pulp on

[1] Canadian Pulp and Paper Industry Key Statistics, PPPC, 2004.
[2] Export intensity = Domestic exports / Manufacturing shipments
[3] Canadian Industry Statistics, Industry Canada

the market, produce the paper and convert it through a network of external converters, before distributing the final products. All these possibilities are illustrated in *Figure 1*. The links between the external network and the internal network define outsourcing alternatives.

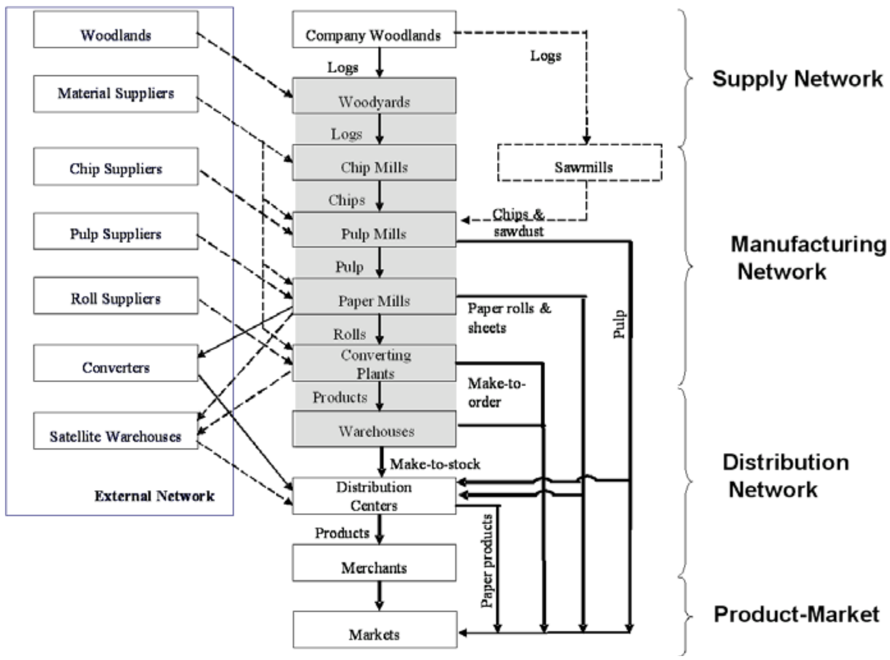


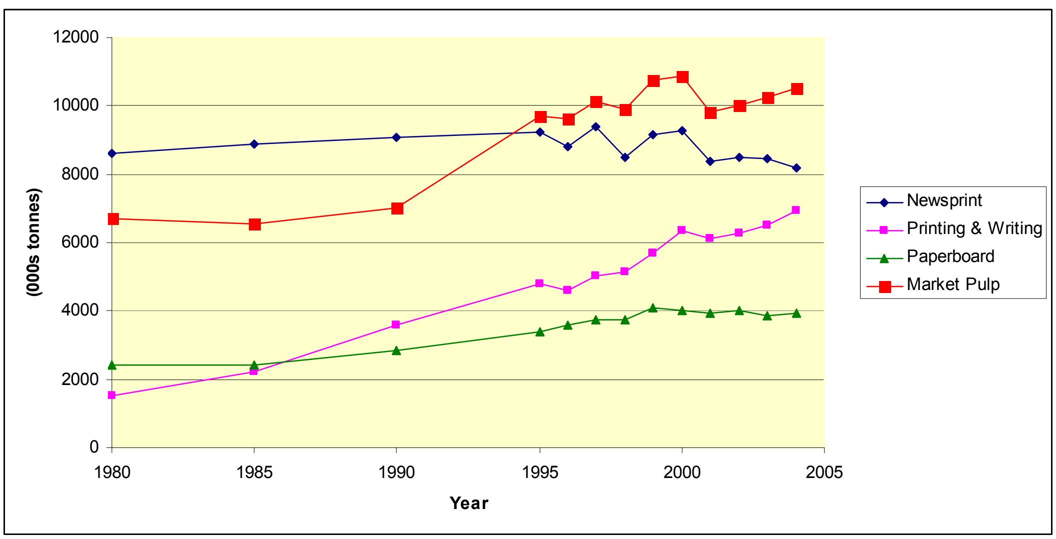
Figure 1: The Printing and Writing Paper Supply Chain

The supply chain of most large players in the industry is multinational. The largest companies in the world are based in the U.S.A., Japan, Finland, Sweden, Norway and Canada. However, large Canadian companies have mills in the U.S.A., Europe and Asia. Similarly, several of the pulp and paper mills located in Canada are owned by American and European companies. The industry has seen a lot of mergers and acquisitions over the past years and its global consolidation is expected to continue, with the result that it is gradually becoming dominated by a relatively small number of multinational enterprises.

In this section, we discuss the four major sub-networks of the pulp and paper supply chain as well as the environment in which the companies compete. We start with a description of global product-markets and of global raw material supply sources. We then examine some production capacity and technology issues and discuss distribution channels. We conclude the section with a discussion of country factors and global factors which are critical for pulp and paper companies' success.

2.1 Global Product-Markets

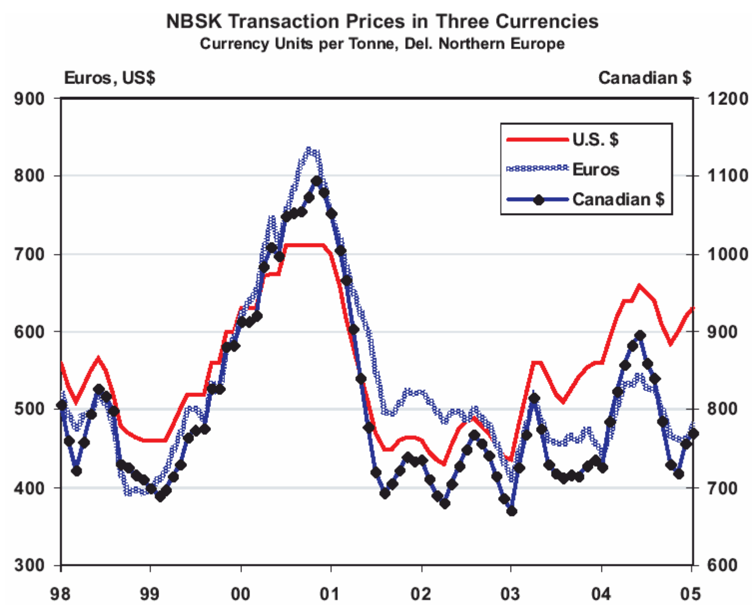
There exists a wide range of paper products that can be aggregated into four main families: newsprint, printing and writing paper, paperboard and tissue. In addition, some of the pulp produced is sold directly on the market. According to Juslin and Hansen (2002), in 1998, the global market share for paper product segments was of about 30% for printing and writing products, 12% for newsprint, 40% for paperboards, 6% for tissue and 12% for others. This is changing, however. Current long term trends indicate that the demand for coated papers, woodfree papers and tissue will increase significantly whereas demand for newsprint will continue on the downward trajectory that began in 2000. In the long term, printing and writing paper is also expected to loose market share to e-paper and the Internet. This is consistent with the position of these products on their life-cycle curves: coated papers, woodfree papers and tissues are in their growth or early-maturity phase, while printing and writing papers are approaching their maturity phase and newsprint is in its decline phase. These trends are also partially explained by the facts that demand for green products such as woodfree papers is increasing due to environmental considerations. These trends are visible in the yearly shipments of the Canadian pulp and paper industry illustrated in *Figure 2*.



Source: Canadian Pulp and Paper Industry Key Statistics, PPPC, 2004

Figure 2: Total Canadian Pulp and Paper Shipments

The demand for several paper products is cyclical and it varies significantly in time. This is also true for pulp and paper prices, as illustrated for NBSK pulp in *Figure 3*. The main consumers of paper and paperboard are the U.S.A., China, Japan and western European countries. Japan is self sufficient, but the U.S.A., China, Germany, the UK and France import large quantities of paper. Around 29% of paper and paperboard production is exported globally. Canada is the largest exporter with 22% of world's exports and the U.S. is the largest importer with 24% of world's imports: roughly 15% of global paper trade is between these two countries. More than 60% of Canadian pulp and paper exports are destined to the U.S.A. However, paper consumption in Asia is expected to increase faster than in America and in Europe in the coming years, which constitute an interesting opportunity for Canadian pulp and paper firms. A good discussion of global pulp and paper market trends is found in Juslin and Hansen (2002). These trends show that market opportunities are changing significantly, which forces a rethinking of company supply chain structures.



Source: RISI World Pulp Monthly, Jan 2005

Figure 3: Northern Bleached Softwood Kraft (NBSK) Pulp Prices

2.2 Global Raw Material Supply Sources

Manufacturing costs in the pulp and paper industry are dominated by the costs of materials and energy. According to Industry Canada, the costs of materials and supplies increased from \$8.1 billion in 1993 to \$10.9 billion in 2002 for the Canadian pulp and paper industry, or at a compound annual growth rate of 3.4%. Also, the industry fuel and electricity costs increased from \$2.1 billion in 1993 to \$2.9 billion in 2002, or at an average rate of 4.0%.

Canada has 10% of world forests, a real comparative advantage for the forest industry, and so it is not surprising that, over the years, it has become the world's largest exporter of forest products. Also, Canada has 20% of the worlds freshwater which is another natural comparative advantage since the paper industry is the largest water-using industry with about 40% of total water intake in the manufacturing sector. Having abundant water is synonym with abundant energy since an important part of the Canadian energy is hydroelectric. The paper industry is the first energy-consuming industry in Canada with 26.7% of total industry consumption in 2002. Fortunately, and thanks to biomass energy, the pulp and paper industry source approximately 53% of its energy needs from wood waste and pulping liquor coming from its own operations. The remainder comes essentially from electricity (24.5%) and natural gas (13%) and that's why many companies in the sector are equipped with their own electric central[1]. Even if energy cost has increased by about 15% in the last decade, Canada's energy is still competitive compared to many industrialised countries such as the United-States, Germany and France, and the energy cost by dollar of production has remained unchanged in the paper manufacturing sector.

The economical and political environments have changed, however, and several historical Canadian advantages are gradually eroding. With the development of thermomechanical pulping (TMP), the efficient use of low cost fibre from eucalyptus hardwood found in south-eastern USA and in several developing countries, such as Mexico and Brazil, becomes possible. Also, the development of production technology and recycling programs allow for the increasing use of recovered paper in fibre production (26% of the Canadian fibre), which is economically available in the USA. Therefore, Canada's advantage of having huge natural resources is not as significant as before, mainly when coupled with the tremendous appreciation of the Canadian dollar in recent years.

Moreover, Canadian forests are mainly located in the north and their distance from the mills is continually increasing, which adds a substantial transportation cost especially when compared to Brazilian companies which can grow eucalyptus in the backyard of their mills. The main reasons of this contrast are inherent to differences in climatic conditions and tree species. In Canada, a coniferous tree takes 30-40 years to regenerate and large forest areas are needed in

[1] Statistics are collected or computed from the 'Energy use database', Natural Resources Canada.

order to provide the industry with a sufficient supply of wood. Conversely, eucalyptus trees found in Brazil take on average 5 years to regenerate and hence only small areas are needed for fibre production. In addition, several stringent measures are taken in Canada in order to ensure reforestation of harvested areas. In fact, Canadian forest companies plant up over 500 million trees annually to regenerate areas they harvest. Canada is a leader in certifying operations for sustainable forest management. All Canadian companies must have their operations certified by the end of 2006. Also, new environmentally driven regulations in Canada restrict the accessibility to the forest: in Quebec, for example, a new law has just forced forest industry companies to decrease their wood harvesting volumes by 20%. All this to say that the distribution of global raw material sources is changing rapidly, which forces a reengineering of the industry supply chain structures.

2. 3. Production-Distribution Networks

Whereas product-markets and raw-material supply sources are affected by forces largely outside the paper company's control, the location of their production-distribution capacity is an internal strategic decision which has a very significant impact on company competitiveness. In fact strategic maneuvering to remain competitive mainly involves adapting the structure of production-distribution networks to evolving supply and demand conditions. Large capital investments are required to implement and to adapt pulp and paper production networks. In addition to that, labor costs and transportation costs are two important factors to take into account.

While the Canadian pulp and paper industry is large, its typical mill is relatively old and relatively small, with the consequence that its manufacturing costs are relatively high. To illustrate this, the global position of Canadian bleached softwood kraft pulp (BSKP) mills is plotted in *Figure 4*. Also, the position of Canadian newsprint mills on the global newsprint industry cost curve is illustrated in *Figure 5*. Mills on the left of this curve are competitively strong while those on the right are unprofitable. Note that this curve reflects the situation in December 2000, when the Canadian dollar was worth US$0.66. With the dollar at US$0.80, as it currently is, the bulk of Canadian mills (marked by a dot on the curve) are now located in the third and fourth quartile. Given that there is currently excess capacity globally and in particular in Canada for some pulp and paper grades, there is a clear need to rationalize production. This rationalization involves closing older inefficient mills, transforming mills dedicated to declining markets, such as newsprint, into mills for increasing demand value added papers, the adoption of new technologies, and mergers and acquisitions to increase Canadian companies size.

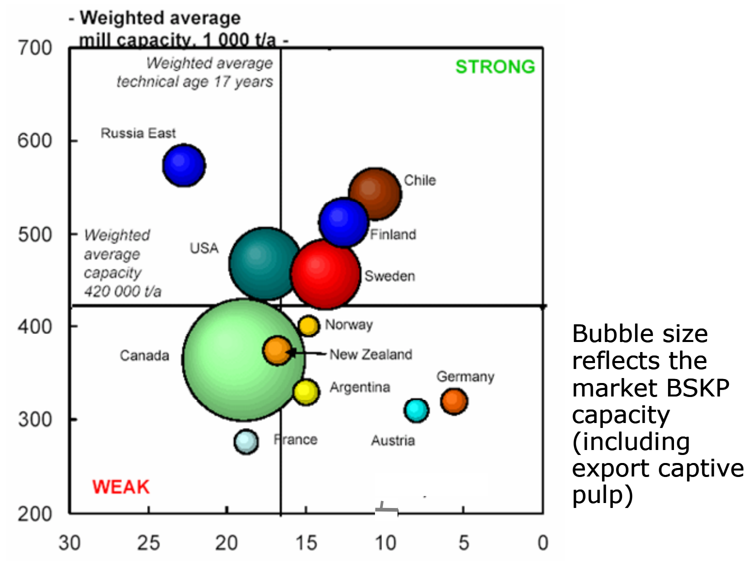


Figure 4: Market Pulp (BSKP) Global Producers by Country

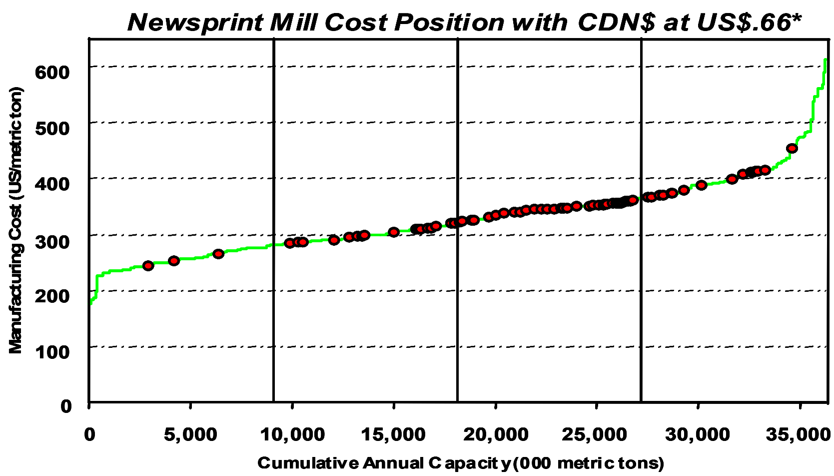


Figure 5: Global Newsprint Industry Cost Curve

Some of these actions require important capital investments. Although the industry has seen several mergers and mill shutdowns in recent years, in North-America, as illustrated in *Figure 6*, capital expenditures have been decreasing steadily since the early 1990s. Currently, new mills are under construction in Latin America, Europe and China, but most American capital spending is devoted to mill upgrades and/or conversions. Current low investments are explained partly by excess capacity, as indicated before, but also by the fact that the industry has difficulty raising new capital. The return on capital employed (ROCE), a key measure of performance for capital-intensive industries, averaged 3.9% in 2003 for the Canadian forest and paper industry, the same as for Europe and behind the United-states (4.7%), while the industry average was 4.2%[1]. With the cost of capital at 10-13%, it is not surprising that the industry has been marginalized in the capital markets. Also, Canadian forest companies have the highest debt/capital ratios in the basic materials sector and thus they have limited financial flexibility (Roberts, 2005).

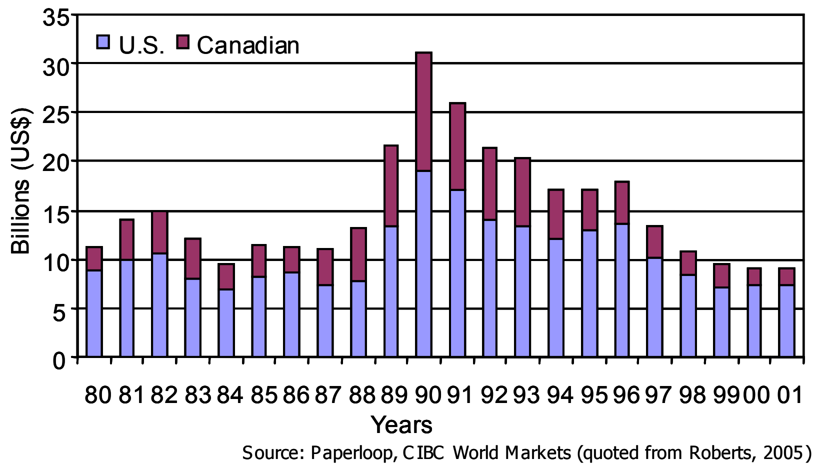


Figure 6: North American Pulp, Paper and Paperboard Capital Spending

With its long lasting involvement in the industry, Canada has developed highly qualified personnel in all trades related to pulp and paper manufacturing. The total number of employees in the Canadian pulp and paper industry decreased on average by 2.5% per year since 1993, which lead to a decrease of the rough wage bill from $3.5 billions in 1993 to $3.4 billions in 2002[2]. Currently, the average industry wage is 70% higher than the national average. Despite this, the current regional shortage of skilled people is expected to worsen. A large portion of the forestry workers are nearing retirement and they will be difficult to replace.

Pulp and paper companies make some products to stock and others to order. To simplify, there are three main channels between the mills and the converters, printers or end-users. When

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[1] Price Waterhouse & Coopers, "Global Forest and Paper Industry Survey", 2004 Edition – Survey of 2003 results.
[2] Canadian Industry Statistics, Industry Canada

large tonnages are involved, the mill ships directly to the customer. This would be typical for pulp sold to industrial users, paper rolls sold to newspaper printers and linerboard sold to corrugated container manufacturers. When intermediate or small tonnages are involved, mills ship to company owned distribution centers or to paper merchants. These intermediaries store the paper, sometimes break it down into smaller units, and sell to converters, OEMs, wholesalers, retailers or institutional users. There is a trend for paper companies to get closer to their end-users and the merchant's share of paper distribution is gradually decreasing. Several merchants are now owned by paper companies. Small users have traditionally obtained their supplies from retail stationers. More recently, there has been an increasing choice of alternatives such as superstores (Office Depot, Staples…) and e-stores.

In the production-distribution network, products are transported by ships, trains and truck. In North-America, large tonnages are transported by train, but otherwise truck transportation dominates. The warehousing and transportation costs in the pulp and paper supply chain can easily exceed 20% of company sales dollar. In addition, customers expect improved service levels and, in several product-markets, they are demanding next-day delivery. All this to say that in this low margin sector, the structure of a company supply chain can make the difference between sustained profitability and bankruptcy.

2.4 Country Factors

In addition to the numerous regulations already discussed, the Canadian pulp and paper industry suffers from a non-competitive tax system. As of 1997, Canada's tax burden as a percentage of GDP (36.8%) was significantly higher than that of many of Canada's trading partners such as the U.S.A. (29.7%), Japan (28.8%) and Mexico (16.9%) (Porter et al., 2001). Also, the effective marginal tax rate applied to new capital investments in Canada, which takes into consideration aspects such as depreciation, tax credits and capital taxes levied by various levels of government, is substantially higher than in any major forest-producing nation. Thus the Canadian tax system discourages investment in capital which is critical to the sector's future success[1].

[1] Forest Products Association of Canada: 2004 annual review.

A 2003 survey made by Ernst & Young revealed that 86% of the 641 multinational parent companies and 93% of the 200 subsidiary corporations interviewed identified transfer pricing as the most important international tax matter they are currently dealing with. Transfer prices are the prices at which good and services are traded across international borders between subsidiaries of a multinational company. Transfer pricing policies are one of the major multinational concerns since they affect subsidiary's sales value directly and therefore have a significant impact on performance evaluation and motivation. In addition, multinationals can use transfer prices to shift profits from one subsidiary in a relatively high-tax country to another located in a low-tax country in order to minimize their global tax liabilities and maximize their global after tax profits.

Governments are currently tightening their transfer pricing regimes: they consider it as a source of additional tax revenue since intra-firm transactions are becoming more and more important. The transfer pricing legislation of most countries, including Canada and the U.S.A., is inspired by the OECD's arm's length principle published in 1995. The application of this principle is based on a comparison of the prices, or margins, of non-arm's length parties with those of arm's length parties engaged in similar transactions. The OECD recommends five alternative transfer pricing methods which can produce a range of values that are acceptable by governments. Although this flexibility is decreasing continuously, the impact of small changes in transfer prices on the profits of a company can be substantial. Company transfer prices, however, are subject to increasing tax authorities' scrutiny. According to the Ernst & Young Survey, 71% of all US-based multinationals were subjected to a transfer pricing audit since 1999. Since 1998, steep penalties may also be imposed for transfer pricing adjustments. The Canadian act imposes a penalty equal to 10% of the net result of certain adjustments defined by the law. According to Lakhal et al. (2005), the penalty applied is 40% in France, 40% in Denmark, 100 000 DM in Germany and can reach up to 40% in the United States, 50% in Australia and 200% in Belgium. In order to avoid penalties and double taxations, an Advance Pricing Arrangement Program was set up in Canada and the United States.

Canada is also characterized by strong regulations to protect the quality of air, water and wildlife. Canada adopted several policies to lower greenhouse gas emissions by reducing the use of fossil fuels and increasing biomass energy consumption. Toxic chemical usage is closely monitored and severe regulations are imposed to ensure effluent quality and to protect fish habitat. The industry is a leader in water recycling and discharging with about 44.2% of total recycled water and 40.2% of total discharges within the manufacturing sector in 1996. This enviable position costs the industry about $372 million dollars for the year 1996[1]. Also, Canada is implementing programs to ensure wildlife habitat is maintained. These strong regulatory regimes place Canada among the world's leader in progressive forestry practices and efficient resource utilisation but they are not without costs.

2.5 Global Factors

The Uruguay Round of the General Agreement on Tariffs and Trade (GATT) concluded in 1994, as well as the North-American Free Trade Agreement (NAFTA), signed also in 1994, had a profound impact on the Canadian pulp and paper industry. Indeed, for the period of 1994-2000, the industry recorded an average annual growth of 9% in its total exports and 13.5% in its total imports with its NAFTA partners (the U.S.A. and Mexico). An important result of the Uruguay round's negotiations was the elimination of tariffs on "paper and paperboard" and "paper articles"[2]. This also had positive effects on the industry trade with other nations (excluding the U.S.A. and Mexico) since an average annual growth of 8.5% in exports and 15.9% in the imports was recorded. However, although import duties have been eliminated, several non-tariff measures are still creating barriers to trade liberalization. Some of these measures such as antidumping duties and special taxes can in fact be considered as disguised tariffs and they are often the subject of international trade disputes. Other barriers such as quotas, local contents rules, administrative barriers and ecological constraints can still severely limit the exchange of goods between countries.

The Canadian pulp and paper industry is very sensitive to exchange rate fluctuations since it exports on average 85% of its total production with about 60% going to the United-States. *Figure 7* shows the Canadian-US dollar exchange rate fluctuations from 1994 to 2004. Not surprisingly, Canadian exports are strongly correlated with the value of the dollar. With the high competition in the pulp and paper market, Canadian producers cannot pass the exchange rate appreciation through their prices without losing sales and the result is earnings' cut. This problem

[1] "Industrial water use, 1996 survey report", Environment Canada.
[2] Source: GATT 1994

is particularly severe for manufacturers for which the major costs are incurred in Canada. A direct consequence of exchange rate fluctuations is therefore to encourage companies to redeploy their production-distribution networks globally, which makes them less vulnerable to sudden changes in the Canadian dollar value.

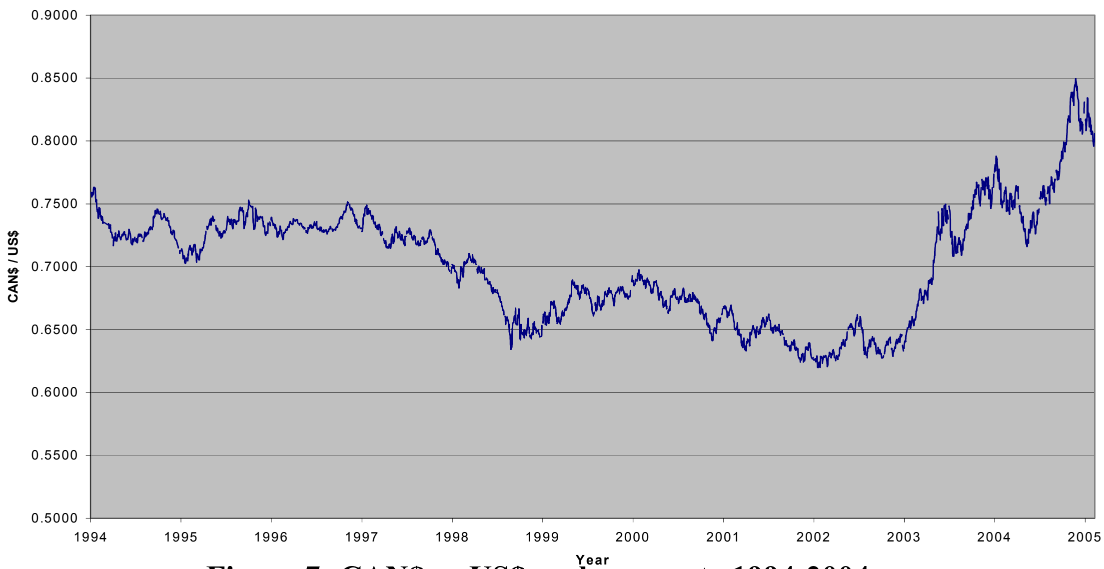

Figure 7: CAN$ vs US$ exchange rate 1994-2004

3. Modeling the Supply Chain

Based on his study of 60 leading enterprises, Lee (2004) concluded that superior companies do not stick to the same supply networks when markets or strategies change: they keep adapting their supply chain to changing needs. Our previous discussion of the pulp and paper industry indicates that its supply and demand structures are shifting and that the traditional comparative advantages of Canada in this sector are eroding. If Canadian pulp and paper companies want to remain competitive, they must follow Lee's recommendation and adapt their supply chains to the new global business environment. Reengineering a company's supply chain is a very complex task however. In order to facilitate it, supply chain optimization models can be used. In this section, we review the models proposed in the literature to optimize global logistic networks, as well as the models developed for the pulp and paper industry, and we present a simplified version of a global model which would be suitable for the industry.

Logistics network design problems integrate location, capacity acquisition and technology selection sub-problems. The first location-allocation model proposed (Geoffrion and Graves,

1974) was a single echelon single period model to determine the distribution centers to use, as well as the assignment of products and clients to these centers, in order to minimise the total cost of the system in a domestic context. Several extensions to this model were subsequently made to take into account multiple production-distribution echelons (Cohen and Lee, 1989), multiple seasons (Dogan and Goetschalckx, 1999), capacity acquisition and technology selection (Eppen et al., 1989; Paquet et al., 2004) and economies of scale (Cohen and Moon, 1990, 1991; Martel and Vankatadri, 1999). In an international context, two types of models have appeared. Some models are concentrating on the impact of demand and exchange rate randomness on simple plant location problems (Pomper, 1976; Hodder and Jucker,1985; Hodder and Dincer, 1986; Haug, 1991) and others cover broader production-distribution network design decisions with the objective of maximizing after tax net revenues, but for a deterministic world (Cohen et al., 1989; Arntzen et al., 1995; Vidal and Goetschalckx, 2001; Bhutta et al., 2003; Martel, 2005). Several of these papers and other related publications are reviewed in Goetschalckx et al. (2002) and in Bhutta (2004).

A few network design models were also developed for the pulp and paper industry. Benders et al. (1981) explain how International Paper, the largest pulp and paper company in the world, analyses and solves its network design problems with mathematical programming models. Philpott and Everett worked with managers of Fletcher Challenge subsidiaries located in Australia and Canada to develop three models known as PIVOT, SOCRATES and COMPASS published, respectively, in Philpott and Everett (1999), Everett et al. (2000) and Everett et al. (2001). The need for the PIVOT was felt following the acquisition of Australian newsprint mills in 1997 and its objective was to rationalize pulp and paper production costs and to exploit possible synergies that might emerge from this acquisition. The model considers several mill-specific constraints. The successful implementation of PIVOT led to the development of SOCRATES and COMPASS, which are concerned with strategic decisions to upgrade and convert existing paper machines in order to improve quality and to be able to produce different grades of paper. SOCRATES and COMPASS provide capital and production plans that maximize discounted annual earnings over a planning horizon. These models were developed within a national context and they do not include any international feature, even if they are used by a multinational corporation. Weigel (2005) also proposed a design model for pulp and paper plants with multiple fiber suppliers, technologies and recipes. A review of advanced planning approaches for the industry is found in Martel et al. (2005).

In what follows, we present a general modeling framework that may be applied to the pulp and paper industry. Without loss of generality, we voluntarily use a simplified version of an adaptation to the pulp and paper industry of the model proposed by Martel (2005). The model covers the main strategic decisions relevant for the industry and it incorporates the main international factors to take into account. It is however assumed initially that the business environment is deterministic. The extensions necessary to make the model more realistic are discussed in the next section. The potential logistic network of the multinational corporation considered is illustrated in *Figure 8*. This network is composed of fibre and chemical product suppliers, pulp and/or paper mills, converters and distribution centers (or merchants) dispersed geographically throughout the world. The production centers receive raw materials from external suppliers and they perform transformation, separation and/or assembly operations to manufacture semi-finished and finished products. These products are the sent to various distribution centers and merchants to be stored or forwarded to demand zones in order to be consumed.

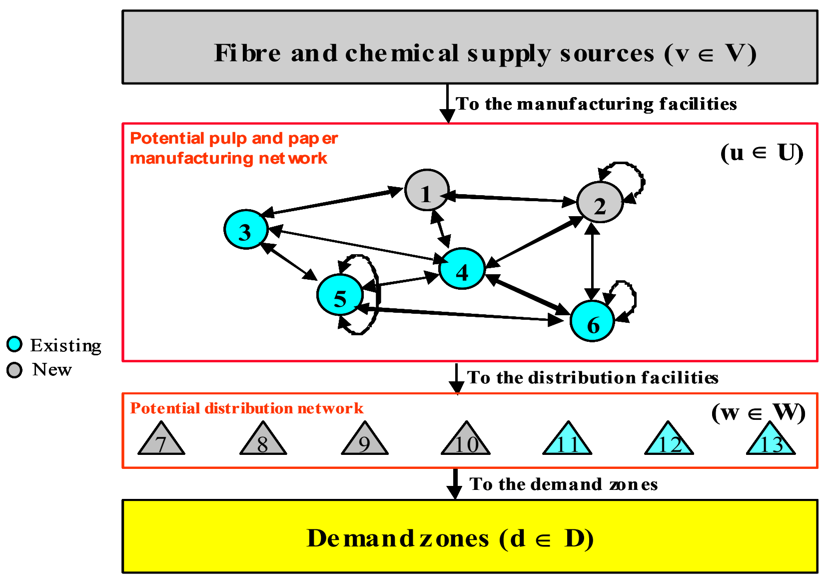

Figure 8: Potential Logistics Network

The model presented is based on the following assumptions:

- The logistic network nodes correspond to existing installations, to sites where it would be possible to build an installation or to installations of potential partners, but the structure of the network and the mission of each installation are decisions to be taken.

- Products are aggregated in families requiring the same technology. A *technology* k ∈ K is defined by the set of products it can manufacture, and it is assumed that the bill-of-materials is independent of the technology used. As illustrated in *Figure 9*, the capacity required to produce one product can be provided by either flexible or dedicated technologies. Dedicated technologies are associated with only one product family whereas flexible technologies can be used to make several product families.
- The aggregate bill-of-material of the products manufactured is similar to that illustrated in *Figure 9*. The number associated with arc (p'p) of the bill-of-material graph indicates the quantity of product family p' required to manufacture one unit of product family p. We take for granted that the nodes of this graph are numbered in topological order so that, for each directed arc (p'p), one has p > p'.

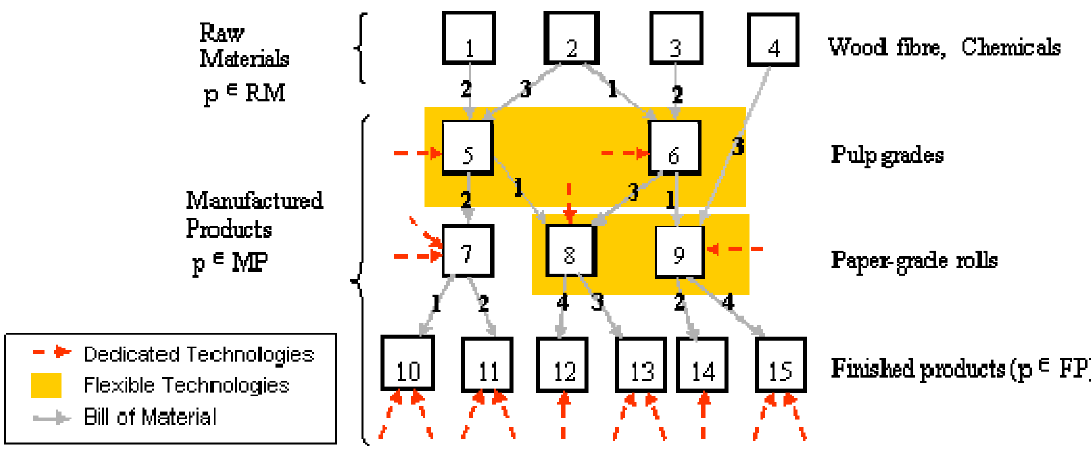

Figure 9: Aggregate Bill of Material and Potential Technologies

- Many capacity options are available to implement a given technology. An option j ∈ J can correspond to capacity already in place, to a reconfiguration of an installed equipment to increase its capacity, or to the addition of new resources. In this last case, different options can be associated with equipment of different size to reflect economies of scale. Moreover, the simultaneous inclusion of dedicated capacity options and flexible capacity options allow for the modeling of economies of scope. Each option j ∈ J is characterized by a capacity, b_j, stated in the units of its technology, by the floor space e_j required to install it, as well as by a fixed cost and a variable cost per product.
- The fixed costs associated with facilities reflect the *rent* paid (covering capital recovery and opportunity costs if it is owned by the company, or the actual rent paid if it is not) and

fixed operating expenditures. These costs are based on the engineering economy principles of capital recovery plus return over the planning horizon (Fabrychy and Torgersen, 1966). The fixed costs associated with potential capacity options cover change of state, capital recovery and opportunity costs, and operating expenditures.

- The products can be shipped to demand zones only from distribution centers. The warehouses can be supplied from any factory. The products manufactured in a mill can be shipped to other mills or to distribution centers.
- The prices P_{pd} of product p in demand zone $d \in D$ are fixed exogenously by the market, but the quantity sold in each market is a decision variable.
- The prices and costs associated with the nodes of the network are given in local currency. The costs associated with the arcs of the network are given in the source currency. Exchange rates are known and constant during the planning horizon considered.
- Each time products cross a border, export taxes may be charged on the flow of merchandise. These taxes may include antidumping duties or special taxes charged by the destination country. In other words, these taxes are calculated on the outflow from a given site to a foreign country. They depend on the nature of the product, they are calculated as a percent of the product price, and they are paid by the exporter.
- Transfer prices for products sent in the internal network are fixed by the accounting department of the company. They cover all the accumulated costs up to the shipping of the products from the origin to the destination and they include a predetermined margin.
- The income taxes paid in a country are calculated on the sum of the net revenues made by all facilities in this country. If a facility reports a loss, this loss is deducted from the total profit of the subsidiary before taxes.
- We consider a single period planning horizon (typically a year or two).
- The objective is to maximize the after tax profits of all the installations belonging to a multinational corporation.

To formulate the model, the following sets are required:

S = Potential network sites ($S = U \cup W$).
P = Product families ($p \in P$).
RM = Raw material families ($RM \subset P$).

MP = Manufactured product families, i.e. semi-finished and finished products ($MP \subset P$).

D_p = Demand zones of product family $p \in P$ ($d \in D = \cup_{p \in P} D_p$).

K_{pu} = Production technologies which can be used to manufacture product p in mill u ($K_{ps} \subset K$, $K_s = \cup_p K_{ps}$).

P_k = Products which can be manufactured with technology k ($P_k \subset MP$).

J = Set of potential capacity options.

J_u = Potential capacity options which can be installed in mill u ($J_u \subset J$).

J_{ku} = Potential technology k capacity options which can be installed in mill u ($J_{ku} \subset J$).

V_p = Vendors of raw material $p \in RM$.

O = Countries of the network sites ($o \in O$, o(s) = country of site s).

D_o = Demand zones in country o.

S_o = Potential sites in country o ($S_o = U_o \cup W_o$).

The following data is necessary to formulate the model:

$\underline{x}_{pd}$ = Lower bound on the flow of product p to demand zone d imposed by the market penetration objectives of the company.

$\overline{x}_{pd}$ = Upper bound on the flow of product p to demand zone d imposed by the largest market share the company can expect.

ρ_p = Number of periods of product p order cycle and safety stocks kept on average in distribution centers (inverse of the inventory turnover ratio).

β_p = Order cycle and safety stocks (maximum level)/(average level) ratio for product p.

h_{pw} = Unit inventory holding cost of product p in distribution center w.

$\underline{X}_{pu}$ = Lower bound on the quantity of family p products which can be manufactured in plant u when it is used.

$\overline{X}_{pu}$ = Upper bound on the quantity of family p products which can be manufactured in mill u.

b_w = Storage capacity of warehouse w in standard units.

b_j = Capacity provided by option j.

π_{pus} = Transfer price of product p shipped from mill u to site s (in the source country currency).

P_{pd} = Amount received for the sales of product p to demand zone d (in the demand zone country currency).

δ_{pus} = Export tax rate applied to the price of product p when transferred from the country of site u to the country of site s.

τ_o = Income tax rate of country o.

α_o = Minimal local content rate imposed by country o.

$e_{oo'}$ = Exchange rate, i.e. number of units of country o currency by unit of country o' currency (the index o = 0 is given to the base currency, whether it is part of O or not).

$f_{pnn'}$ = Unit flow cost of product p between node n and node n'. This cost includes the variable transportation cost, the inventory-in-transit holding cost, the raw material's price and the supply-order processing costs if $n \in V$, the order cycle stocks' holding cost (at the origin and the destination) associated with the corresponding load size if $n' \in S$, the shipping cost if $n \in S$ and the reception cost if $n' \in S$.

$g_{pp'}$ = Quantity of product p needed to make one product p'.

A_s = Fixed cost of using site s for the planning horizon.

a_j = Fixed cost of using capacity option j for the planning horizon.

b_{pv} = Upper bound on the quantity of raw materials which can be supplied by vendor v.

c_{pku} = Unit production cost of product p with technology k in plant u.

q_{pk} = Capacity consumption rate per unit of product p for technology k.

q_p = Number of units of warehousing capacity consumed by one unit of product p

e_j = Area required to install capacity option j.

E_u = Total area available in mill u.

The following decision variables are also required to define the model:

C_s = Total site s expenses.

R_s = Total site s revenues.

M_s = Operating income for site s.

M_o^+ = Operating profit made in country $o \in O$.

M_o^- = Operating loss made in country $o \in O$.

$F_{pnn'}$ = Quantity of product p shipped from node $n \in V \cup S$ to node $n' \in S \cup D$.

Y_s = Binary variable equal to 1 if site s is used, 0 otherwise.

Z_j = Binary variable equal to 1 if capacity option j is used, 0 otherwise.

X_{pku} = Quantity of product p produced in plant u with technology $k \in K_{pu}$.

To model the transfer prices and taxes correctly, it is necessary to derive a financial statement for each network facility. The revenues and expenses of the mills and distribution centers, in local currency, are outlined in *Table 1*. The expression for the transfer costs of material inflows is obtained by converting the transfer prices and transportation costs in local currency. A similar approach is used to calculate other revenues and expenses.

Using the numbered elements of the expenditures and revenues in Table 1, it is seen that:

$C_u = (1) + (2) + (3) + (4) + (6)$, $R_u = (8)$

$C_w = (1) + (4) + (5) + (7)$, $R_w = (9)$

The profit/loss for each site is thus given by:

$M_s = R_s - C_s,\ s \in S = U \cup W$.

		Mill (u)	Distribution Center (w)
Expenses	(1) Inflows transfer cost	$\sum_{p\in MP}\sum_{u'\neq u} e_{o(u),o(u')}\,\pi_{pu'u}\,F_{pu'u}$	$\sum_{p\in MP}\sum_{u\in U} e_{o(w),o(u)}\,\pi_{puw}\,F_{puw}$
	(2) Raw materials	$\sum_{p\in MP}\sum_{v\in V_p} e_{o(u),o(v)}\,f_{pvu}\,F_{pvu}$	
	(3) Production	$\sum_{p\in MP}\sum_{k\in K_{pu}} c_{pku}X_{pku}$	
	(4) Facilities and options fix costs	$A_uY_u + \sum_{j\in J_u} a_jZ_j$	A_wY_w
	(5) Inventory holding costs		$\sum_{p\in MP}\sum_{d\in D_p} h_{pw}\,\rho_p\,F_{pwd}$
	(6) Outflows to other sites	$\sum_{p\in MP}\sum_{s\neq u} f_{pus}F_{pus}$	
	(7) Outflows to demand zones		$\sum_{p\in MP}\sum_{d\in D_p} f_{pwd}F_{pwd}$
Revenues	(8) Outflows to other sites	$\sum_{p\in MP}\sum_{s\neq u} (1-\delta_{pus})\pi_{pus}\,F_{pus}$	
	(9) Outflows to demand zones		$\sum_{p\in MP}\sum_{d\in D_p} (1-\delta_{pwd})\,e_{o(w),o(d)}P_{pd}F_{pwd}$

Table 1: Site Expenses and Revenues in Local Currency

The corporate net revenues before taxes in the reference currency is given by the expression $\sum_{o\in O} e_{0o}M_o$, where $M_o = \sum_{s\in S_o} M_s$ is the operating income in country o. To calculate corporate after tax profits, one must first separate the divisions where the margin is positive from the divisions where it is negative because there is no income tax to pay on losses. To do this, M_o must be separated in its negative and positive parts $M_o = M_o^+ - M_o^-$, where the operating profit $M_o^+ > 0$ if $M_o > 0$ and the operating loss $M_o^- < 0$, otherwise.

The global after-tax profit maximisation model proposed to optimize the structure of the multinational production-distribution network is the following:

$$\operatorname{Max} \sum_{o \in O} e_{0o} \left[(1-\tau_o) M_o^+ - M_o^- \right]$$

subject to:

- Plant revenue definitions:

$$R_u = \sum_{p \in MP} \sum_{s \neq u} (1-\delta_{pus}) \pi_{pus} F_{pus}, \qquad u \in U$$

- Plant expense definitions:

$$\begin{aligned} C_u = & \sum_{p \in MP} \sum_{u' \neq u} e_{o(u),o(u')} \pi_{pu'u} F_{pu'u} && \text{(Inflows transfer cost)} \\ & + \sum_{p \in MP} \sum_{v \in V_p} e_{o(u),o(v)} f_{pvu} F_{pvu} && \text{(Raw materials)} \\ & + \sum_{p \in MP} \sum_{k \in K_{pu}} c_{pku} X_{pku} && \text{(Production costs)} \\ & + A_u Y_u + \sum_{j \in J_u} a_j Z_j && \text{(Facility and capacity options fix costs)} \\ & + \sum_{p \in MP} \sum_{s \neq u} f_{pus} F_{pus}, \qquad u \in U && \text{(Outflows to other sites)} \end{aligned}$$

- Warehouse revenue definitions:

$$R_w = \sum_{p \in MP} \sum_{d \in D_p} (1-\delta_{pwd}) e_{o(w),o(d)} P_{pd} F_{pwd}, \qquad w \in W$$

- Warehouse expense definitions:

$$\begin{aligned} C_w = & \sum_{p \in MP} \sum_{u \in U} e_{o(w),o(u)} \pi_{puw} F_{puw} && \text{(Inflows transfer costs)} \\ & + A_w Y_w && \text{(Facilities fix costs)} \\ & + \sum_{p \in MP} \sum_{d \in D_p} h_{pw} \rho_p F_{pwd} && \text{(Inventory holding costs)} \end{aligned}$$

$$+\sum_{p\in MP}\sum_{d\in D_p} f_{pwd}F_{pwd}\,,\qquad w\in W$$ (Outflows to demand zones)

- Definition of the operating income in each country:

$$\sum_{s\in S_o}(R_s-C_s)-M_o^{+}+M_o^{-}=0,\qquad o\in O$$

- Demand constraints:

$$\underline{x}_{pd}\le\sum_{w\in W}F_{pwd}\le\overline{x}_{pd}\,,\qquad p\in MP, d\in D_p$$

- Raw material supplier's capacity constraints:

$$\sum_{u\in U}F_{pvu}\le b_{pv}\,,\qquad p\in RM, v\in V_p$$

- Raw material requirements:

$$\sum_{p'\in MP}g_{pp'}\sum_{k\in K_{pu}}X_{p'ku}-\sum_{v\in V_p}F_{pvu}\le 0,\qquad p\in RM, u\in U$$

- Plant production capacity constraints:

$$\sum_{p\in P_k}q_{pk}X_{pku}-\sum_{j\in J_{ku}}b_jZ_j\le 0,\qquad u\in U; k\in K_u$$

- Min-max production constraints:

$$\underline{X}_{pu}Y_u\le\sum_{k\in K_{pu}}X_{pku}\le\overline{X}_{pu}Y_u\,,\qquad p\in MP, u\in U$$

- Warehouse capacity constraints:

$$\sum_{p\in MP}q_p(\beta_p\rho_p\sum_{u\in U}F_{puw})-b_wY_w\le 0,\qquad w\in W$$

- Plant flow equilibrium constraints:

$$\sum_{k\in K_{pu}}X_{pku}+\sum_{u'\neq u}F_{pu'u}-\sum_{u'\neq u}F_{puu'}-\sum_{p'>p}g_{pp'}\sum_{k\in K_{p'u}}X_{p'ku}-\sum_{w\in W}F_{puw}\le 0,\qquad p\in MP, u\in U$$

- Warehouse flow equilibrium constraints:

$$\sum_{u\in U}F_{puw}-\sum_{d\in D_p}F_{pwd}\ge 0,\qquad p\in MP, w\in W$$

- Site space constraints:

$$\sum_{j\in J_u}e_jZ_j-E_uY_u\le 0,\qquad u\in U$$

- Non-negativity constraints:

$Y_s \in \{0, 1\}, s \in S$; $Z_j \in \{0, 1\}, j \in J$; $X_{pku} \geq 0, \forall (p,k,u)$;

$F_{pn,n'} \geq 0, \forall (p,n,n')$; $R_s, C_s \geq 0, \forall s \in S$; $M_o^+, M_o^- \geq 0, \forall o \in O$

This model is a large-scale mixed-integer programming model that can be solved relatively easily, with modern solvers such as CPLEX 9.0, for moderate size supply chains. As it stands, it does not include any non-tarriff barriers. These are however generally not difficult to add. An import quotas is simply an upper-bound on country inflows. Local content rules are also easy to implement. Assume for example that, for a country $o \in O$, the value added to a product in the country must exceed a predetermined proportion of sales, and that this value includes operating, production and warehousing costs but not inventory holding costs. Then, the following constraint can be added to the model to take this into account:

$$\sum_{s \in S_o} A_s Y_s + \sum_{j \in J_u} a_j Z_j + \sum_{u \in U_o} \left(\sum_{p \in MP} \sum_{k \in K_{ps}} c_{pku} X_{pku} + \sum_{p \in MP} \sum_{s \neq u} f_{pus} F_{pus} \right)$$
$$+ \sum_{w \in W_o} \sum_{p \in MP} \sum_{d \in D_p} f_{pwd} F_{pwd} - \alpha_o \sum_{p \in P} \sum_{d \in D_o} P_{pd} \sum_{w \in W} F_{pwd} \geq 0$$

Note that other types of local content rules might be applied. For example, a percentage of the value of total purchases or a fraction of raw materials quantities used in production may be required to be of domestic origin. Such issues are discussed in Munson and Rosenblatt (1997) which studied the impact of local content rules on global sourcing decisions.

Mathematical programming models similar to the one presented in this section can be used to revise the location and the mission of a company facilities, to investigate possible mill reconfigurations or to evaluate mergers and acquisitions. Their main limitations, with respect to the needs of the pulp and paper industry are that they assume that future supplies, demands, exchange rates, costs and product prices are known with certainty, that transfer prices are fixed and that companies can obtain the capital necessary to finance any restructuration projects. These limitations are not unique to the pulp and paper industry. Given the strategic nature of network design problems, most sectors face the same issues to different degrees. This has long been recognized by the supply chain design community and it is why, in practice, the use of static deterministic models such as the one presented here is always accompanied by extensive sensitivity and scenario analysis.

One approach commonly used to investigate the impact of parameter randomness or uncertainty is to generate a set of possible future business environments and to solve the model for each of these environments. These environments are typically generated partly by using random values from the probability distribution of some parameters and partly by using subjective expert opinions to identify likely future events. Good discussions of how the optimal network design may change when some parameter values vary are found in Cohen and Lee (1989), Mohamed (1999) and Vidal and Goetschalckx (2000). The difficulty whith this approach is to determine which among the solution found is the best solution. A method to select a solution is presented in Lowe et al. (2002). They propose a screening procedure using a number of filtering criteria such as Pareto optimality, mean-variance efficiency and stochastic dominance. A good example of how scenario analysis may be used in practice is found in Körksalan and Süral (1999). When a design has been selected, it is also a good idea to use Monte Carlo analysis to assess financial risks, as suggested by Ridlehoover (2004).

The best approach to find a good design under risk is to attach probabilities to the scenarios generated and to use stochastic programming methods. The solution obtained when this is done is not necessarily the best for any scenario but it provides the best compromise design for the probabilities used. The first to suggest this approach was Pomper (1976). Eppen et al. (1989) present an application of the approach to the reconfiguration of the manufacturing network of General Motors. The two main difficulties of this approach are the estimation of the probabilities and the size of the problem. Santoso et al. (2005) recently proposed to use a sample approximation method base on Monte Carlo sampling techniques to partially remove these difficulties. These approches can be used to deal with uncertainties in supplies, demands, costs and prices in the pulp and paper industry context. The modeling of three factors is worth discussing in more details, however, namely transfer pricing, exchange rates and financing. The next section examines the modeling extensions necessary to take these factors into account properly.

4. Modeling Extensions

4.1 Transfer prices

We already discussed the impact that transfer pricing may have on multinational profits, despite the fact that companies have little margin due to increasing restrictions imposed by governments. Most papers on multinational supply-chain design assume that transfer prices are predetermined as we did in the previous section (Arntzen et al., 1995; Canel and Khumawala, 1996; Bhutta et al., 2003; Martel, 2005; Vila et al., 2005). However, in order to maximize after tax profits, they should rather be considered as decision variables which can take values in a feasible set defined by management, taking regulations and company policies into account. In other words, in our model, $\pi_{pus} \in \Pi_{pus}$ should be a decision variable, Π_{pus} being a continuous or discrete set of possible transfer prices. Clearly, when this is done, the constraints including π_{pus} become quadratic and the resulting model is much more difficult to solve.

Cohen et al. (1989) propose a hierarchical solution procedure for a nonlinear MIP model which maximizes after-tax profits for a global manufacturing system, and which includes the optimization of transfer prices. Vidal & Goetschalckx (2001) also present a global supply chain optimization model maximizing after tax profits which explicitly considers transfer prices as decision variables. To simplify the model, however, they assume that the facilities locations are predetermined. They propose a heuristic that applies successive linear programming to a relaxed version of the model. Gjerdrum et al. (2002) examine a transfer price policy in a two-enterprise network. They present a mixed integer non-linear programming model and use linearization techniques, coupled with a Nash-equilibrium based algorithm, to find optimal transfer prices and inventory levels which maximize the profits of each partner. These three contributions are interesting, but they lead to models which would be very difficult to solve without their simplifying assumptions.

Since the magnitude of the changes which can be made to transfer prices in practice is very small, a simpler approach which preserves the linearity of the model can be used. It involves performing a parametric analysis on the current transfer prices or on the transfer price determination method, by varying the markup percentage or modifying the allocated proportion of indirect costs. To reduce the problem size, this analysis can be done by applying the same percent changes to all the prices in a given country. To illustrate, let:

$\tilde{\pi}_{pus}$ = Current transfer price of product p shipped from plant u to site s (in the source country currency).

θ_{oi} = i^{th} element of the set of possible price multipliers for country o ($i \in I_o$)

λ_{oi} = Binary variable equal to 1 if multiplier $i \in I_o$ is selected for country o and to 0 otherwise.

F_{pusi} = Quantity of product p shipped from mill u to node s when transfer price multiplier i is used.

The optimal transfer prices can then be obtained by making the following variable substitutions in the previous model,

$$F_{pus} = \sum_{i \in I_{o(u)}} F_{pusi} \qquad \pi_{pus} F_{pus} = \sum_{i \in I_{o(u)}} \tilde{\pi}_{pus} \theta_{o(u)i} F_{pusi}$$

and by adding the following multiplier selection constraints:

$$\sum_{p \in MP} \sum_{u \in U_o} \sum_{s \neq u} F_{pusi} \leq M\lambda_{oi}, \qquad o \in O,\ i \in I_o$$

$$\lambda_{oi} \in \{0,1\}, \quad o \in O,\ i \in I_o; \qquad \sum_{i \in I_o} \lambda_{oi} = 1, \qquad o \in O$$

In these constraints, M denotes a very large number. This approach adds variables, but if the number of possible changes considered is limited, as it would be the case in the pulp and paper industry context, it may give very good results.

4.2. Exchange rates

In today's economy, exchange rates may vary considerably over time: as seen in *Figure 7*, the Canadian $ recently gained 16% in less than 7 months, which had a considerable impact on the performance of Canadian pulp and paper companies. Therefore, the use of variable rather than average exchange rates in network design models is desirable. This raises the necessity to incorporate an adequate exchange rate forecasting model in the design approach, and to take the distribution of forecast errors into account in the design model. Since historical data on cross-currency exchange rates are available from different sources, econometric models may be used to identify their time series trends. However, as discussed in Eiteman et al. (2004), forecasting exchange rates is a daunting task because random events, institutional frictions and market distortions may cause significant deviations. Mohamed (1999) and Bhutta et al. (2003) included a simple linear trend exchange rate function in their network design models. More appropriate models, such as the generalized linear auto-regression and neural networks model proposed by Yu et al. (2004), are available to forecast exchange rates. However, when a single period network design model such as the one presented in the previous section is used, trends in exchange rates cannot be captured and one can only take the probability distribution of the exchange rate during the period considered into account. This limitation can be overcome by transforming the model presented previously into a multi-season design model (see Martel, 2005). Stochastic programming can then be used to take the probability distribution of exchange rates into account. Hodder and Jucker (1985) also proposed to do this with a classic mean-variance portfolio selection approach.

The previous discussion, however, misses an important point: it does not consider the financial and operational instruments that a firm may use to effectively manage operating exposure to real exchange rate shocks. The operating exposure of a firm (also known as economic exposure, competitive exposure and strategic exposure) pertains to the effect on its present value resulting from changes in future operating cash flows caused by unexpected variations in real exchange rates (Eiteman et al. 2004). It is important to note that these effects are driven by real exchange rate changes rather than nominal ones, the former taking the inflation rates of the two countries involved into account. From a financial perspective, there exists several instruments for hedging against exchange-rate variability such as forward contracts, futures and options but these tools are useful only in the short run. Long-term financial instruments to mitigate operating exposure include risk-sharing agreements, parallel loans (see next section) and currency swaps. In addition to these financial instruments which are contracted essentially to reduce downside risks, operational policies can be used to create profit opportunities from exchange rate movements through diversifying operations and exploiting operational flexibility. In fact, as discussed in Dornier et al. (1998) and Eiteman et al. (2004), global sourcing and shifting production between countries, when spare capacity exists, are becoming key strategies for companies seeking competitive advantages.

The operational instruments used to manage operating exposure to real exchange rate variations involve both strategic and operational decisions. From an operational flexibility point of view, the strategic international capacity deployment decisions of the firm determine the amount of flexibility it has in the short term to shift production between countries. From a global sourcing point of view, signing long-term contracts on the basis of supplier's contribution to balancing currency flows, in addition to price and performance, gives opportunities in the short-term to either exploit favorable price/rate changes, or avoid unfavorable ones, through the timing and volumes of purchased quantities. Short term operating flexibility policies where studied by Kogut & Kulatilaka (1994) and Dasu & Li (1997). Relatively little work was done on the strategic decisions necessary, however. Huchzermeier & Cohen (1996) proposed a hierarchical planning framework to address the problem. It starts with the identification of a set of global possible network structures. Exchange rates scenarios are also obtained through a multinomial approximation model of correlated exchange rate processes. The value of a particular network structure is then determined by optimizing a supply chain network model for each exchange rate scenario. Finally, a multiperiod stochastic dynamic programming model uses these values as input to determine the firm's discounted expected global after-tax profit for each network structure available at the beginning of the planning horizon. Kouvelis (1999) proposed a modeling framework for evaluating global sourcing strategies in a multi-supplier portfolio and a two-supplier case application.

Operational flexibility and global sourcing strategic decisions are particularly important for Canadian pulp and paper industry companies. Referring back to the model presented in the previous section, the plant location and capacity options decisions determine the production-distribution capacity that will be available in each country, but as the model stands, there is no term in the objective function to anticipate the gains that could be made by investing in extra capacity to enable short term production switching or market entry/exit based on exchange rate fluctuations. Also, currently, the model assumes that raw material can be supplied from any vendors. This must be changed to examine possible supply contracts that provide mechanism to facilitate the balancing of currency flows. For example, these could incorporate different risk sharing schemes (Spinler et al., 2003), the possibility to pay in local or foreign currency and the possibility of anticipating or differing payments. In both cases, the difficulty comes from the fact that the strategic model must incorporate an anticipation of the benefits that the strategic decisions will generate through short term exchange rate risk management decisions. This is an open question that needs to be addressed.

4.3. Corporate financial planning decisions

We noted in our initial analysis that the pulp and paper industry has difficulty raising new capital because its ROCE is substantially lower than the cost of capital, and that it has limited financial flexibility because of its high debt/equity ratio. Any change that Canadian pulp and paper companies may want to make to their production-distribution network may thus be hampered by financial constraints. On the other end, since Canadian pulp and paper companies are deployed in several countries, they may have access to foreign borrowing sources which, as we saw in the previous section, additionally provide an instrument to mitigate operating exposure. The model presented in the previous section does not capture these important financial constraints and opportunities because all these elements are hidden in the fixed facilities and capacity option costs A_s and a_j. To remove this limitation, the financing needs of the company must be modeled explicitly. To illustrate how this can be done, the following notation is required:

A'_s = Capital recovery and fixed operating expenditures when using facility s (excluding financing costs)

a'_j = Capital recovery and fixed operating expenditures when using capacity option j (excluding financing costs)

A^B_s = Amount which must be borrowed (in local currency) to open facility s

a^B_j = Amount which must be borrowed (in local currency) to implement capacity option j

r_{so} = Interest rate for the planning period considered when borrowing in currency $o \in O$ to finance facility s

B_o = Maximum amount which can be borrowed on the capital market of country o

L_{so} = Amount borrowed in currency o for facility s (decision variable)

We assume in what follows that a certain amount must be borrowed to use a facility (A^B_s) or to implement a capacity option (a^B_j). This amount may be needed to cover a construction, renovation, acquisition or implementation cost, including a provision for working capital, or an outstanding debt. Although we assume all debt financing, equity financing is easily incorporated by considering equity as an additional country with an imputed cost r_{so}. In practice, the interest rate r_{so} is often the same for all facilities s. However, the use of the additional subscript s allows for the possibility that subsidized loans may be available for some sites. To take these financing opportunities into account in our model, the facilities and options fix costs expressions (4) in the mill and distribution center financial statements (Table 1) must be replaced, respectively, by the expressions

$$A'_u Y_u + \sum_{j \in J_u} a'_j Z_j + \sum_{o \in O} e_{o(u),o} r_{uo} L_{uo} \quad \text{and} \quad A'_w Y_u + \sum_{o \in O} e_{o(w),o} r_{wo} L_{wo} \ .$$

Furthermore, to ensure that the funds required by the facilities are available, the following constraints must be added:

$$\sum_{o \in O} e_{o(u),o} L_{uo} - A_u^B Y_u - \sum_{j \in J_u} a_j^B Z_j = 0, \quad u \in U$$

$$\sum_{o \in O} e_{o(w),o} L_{wo} - A_w^B Y_w = 0, \quad w \in W$$

Finally, to take into account the limited capacity of borrowing of the companies on the capital markets, the following constraints must be added:

$$\sum_{s \in S} L_{so} \leq B_o\,, \quad o \in O; \qquad L_{so} \geq 0, \quad o \in O,\ s \in S$$

A model based on a similar formulation was proposed by Hodder and Dincer (1986) for the simple plant location problem. In their formulation, they consider prices (P_{pd}) and fixed costs (A'_s) as random variables, and they use a mean-variance objective function in firm profit. Apart from this, little work has been done on the inclusion of financial planning decisions in supply chain design models. A good discussion of the problem is found in Shapiro (2001), but no model is provided. Also, the problem as formalized above implicitly takes a zero-based approach and it assumes that the company is in a capacity expansion context. In practice, at the beginning of the planning horizon, some facilities are already owned or leased, some long-term loans are already contracted, and they must be taken into account. In addition, another way of raising capital may be to sell some fixed assets, mainly if there is excess capacity in the industry as it is the case for pulp and paper. This means that the model used should take the current state of the company into account explicitly, and be expressed in terms of possible change of states over a planning horizon.

In fact, since the investment projects considered have an impact over several years, and since these projects may be divided into several stages that can be implemented gradually, the ideal approach would be to formulate the problem as a multi-period design model with real options. Such real options permit to wait (postpone), expand, contract, exit, switch or improve elements of the project when additional information becomes available during the planning horizon (Trigeorgis, 1996), thus providing a hedge for mitigating global supply chain risk. When a multi-period planning model is used, the objective becomes the maximization of the discounted sum of after-tax profits. Multi-stage stochastic programming with recourse (Birge and Louveaux, 1997) is a natural tool to formulate such problems, but the difficulty with such an approach is that the models obtained would be huge and extremely difficult, if not impossible, to solve.

5. Conclusion

In the first part of this paper, the international factors affecting the competitiveness of Canadian pulp and paper companies were examined. It was concluded that the traditional comparative advantages of Canada in this sector are eroding, and that to remain successful, Canadian companies must adapt the structure of their production-distribution networks to evolving supply and demand conditions. The impacts that exchange rates volatility, taxation systems, transfer pricing policies and the low attractiveness of the industry on capital markets have on company performances were also stressed. Based on the existing literature on global logistic network design models, in the second part of the paper we presented a simplified mixed-integer programming model to optimize pulp and paper supply chain structures. A variant of this simplified model was used by one of the authors to restructure the North-American distribution network of one of the largest Canadian pulp and paper companies. The benefits estimated for the recommended network design include a significant increase of next-day deliveries (from 35% to 80% of total deliveries for make-to-stock products), in addition to a 12% logistics costs reduction. This shows that even the partial reengineering of a global logistic network can be very beneficial.

To take the competitive context of Canadian pulp and paper companies into account adequately, we argued that the model presented should be extended to permit the optimisation of transfer prices, to take operational flexibility benefits into account and to incorporate corporate financial planning decisions. Suggestions were made on how the model could be modified to take these additional factors into account. Each of the extensions proposed lead to significant additional complexity, however, and the challenge is to arrive at a model which can be solved with the current state-of-the-art, but which captures the essence of the problem. Finally, since analysts and practitioners predict that the global pulp and paper industry consolidation will continue, and that the downward price trend is also likely to continue, cost efficiency and value creation will be more and more essential. The need for mathematical models and techniques that can handle the global factors discussed in this paper in an effective way then becomes clear.

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