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The Value Creation Network of Canadian Wood Fibre

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Abstract. In this paper, we describe the Canadian wood fibre value network by explaining what constitutes a value creation network, how to model this kind of network, and how it can be managed efficiently. Research for the forest industry conducted by national and international researchers as well as by Forac students are also provided. The paper finally reviews different technologies that could be useful to forest products companies in order to facilitate their decision-making process.

Keywords: Value chain modelling, forest industry, supply chain management.

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1 Introduction

The forest products industry constitutes one of Canada’s main manufacturing sectors. It supports more than 860,000 jobs, i.e. 5.3% of Canada’s total employment. Canada is the world's largest exporter of forest products and the world's leading producer and exporter of newsprint. Its products are exported to more than 100 different countries, for a total value of $41.9 billion (CAN$) (Statistics Canada). The industry is concentrated in Quebec, Ontario and British Columbia. While the western provinces primarily manufacture solid wood products, the eastern provinces primarily produce pulp and paper. Nevertheless, industry consolidation is increasing and a lot of mills are therefore closed temporarily or permanently all across Canada. There are different reasons to explain this situation. To begin with, globalization has led to increased competition among countries. For example, producers from Brazil or Russia have been very aggressive in expanding their presence in markets outside their homeland (Statistics Canada). Since the United States is Canada’s largest customer (80.8% of exports), a stronger Canadian dollar relative to the US currency has contributed to decreasing profit margins for Canadian producers. Rising energy costs have also had a significant impact on companies, especially in the pulp and paper industry, one of the heaviest energy consumers. In addition, global demand for paper has been declining, while poor conditions in the US housing market have significantly affected lumber sales.

To outperform the competition and maximize customer service level, the forest products industry needs to change its way of doing business. Rather than push traditional products to the market, the industry needs to focus on customer demand while optimizing forest resource utilization and coordinating all of its operational activities. Specifically, when trees are used to produce forest products, many stakeholders are involved. These stakeholders have to manage the forest, build forest roads, transport logs, convert them into finished forest products, and then ship the final products to customers. All these activities will be planned in order to ensure a profit margin and efficient use of available resources within operational and environmental constraints. This organizational arrangement that uses resources from more than one organization constitutes a network. Moreover, since all of the activities included in the network aim to create value for customers, this network becomes a value creation network.

To be efficient, the value creation network must be coordinated. More precisely, the overall process must be managed efficiently, not just its discrete pieces. The more stakeholders synchronize their operations, the better customer service will be.

In this paper, we will try to explain the concepts involved in a value creation network, and how adequate management of activities can become an efficient tool to compete with other countries. Our work will be presented as follows. We will first explain the notion of value creation network and describe the Canadian wood fibre network. Next, we will introduce different techniques to correctly represent the value creation network so as to better describe interactions between stakeholders. In addition, we will explain how to manage a network and the kinds of decisions the network stakeholders have to make to adequately plan their operations. Eight case studies conducted by students and professional researchers of the Forac Research Consortium over the past eight years will be described to demonstrate how these different concepts can be put into practice. A list of typical problems faced by the industry will also be detailed as well as the approach taken to solving the corresponding issues. To conclude, we will present a review of software applications available to support planning and control in the forest products industry's value creation network. A glossary will also be offered to help clarify some of the terminology and concepts used in the design and management of value creation networks.

2 The Value Creation Network

To convert raw materials into finished products, many operations have to be performed and consequently, several companies are involved. In past years, these activities have generally been managed separately, based on local objectives and limited constraints. But today, individual businesses recognize the links that exist between themselves and their strategic and non-strategic partners, as well as the need to coordinate related activities so as to add value to products and services. This complex set of entities that work together within relationships to create economic value is known as a value creation network. It encompasses all activities associated with the flow and conversion of goods, from the raw materials stage to the end-user, as well as the associated information flow (Figure 1) (Ballou, 2004).

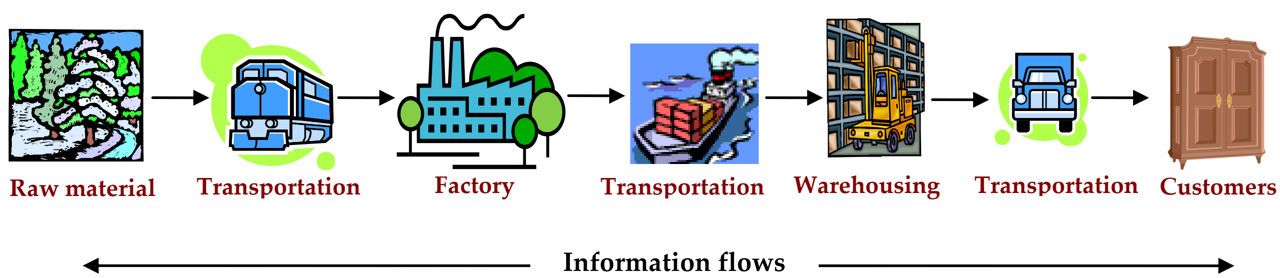


Figure 1: The value creation network for an individual organization

To be efficient, the value creation network needs to be managed as a whole. Specifically, the product flow across companies has to be coordinated in order to achieve profitability and competitive advantage for both individual stakeholders and the network. This can be achieved through information sharing.

2.1 The Canadian Wood Fibre Value Creation Network, a Description

The forest products industry's value creation network includes all the companies and business units involved in the procurement, production or conversion of a given product and its distribution to the market (Figure 2). This can include those companies responsible for forestry operations, sawmilling, value-added production, pulp and paper, etc. (Forac Research Consortium). Even though many activities are conducted to access the forest and optimize harvesting (e.g., silvicultural treatments, road construction, forest protection), these are not illustrated in the Figure 2. They are implicitly included in the *harvest areas* node.

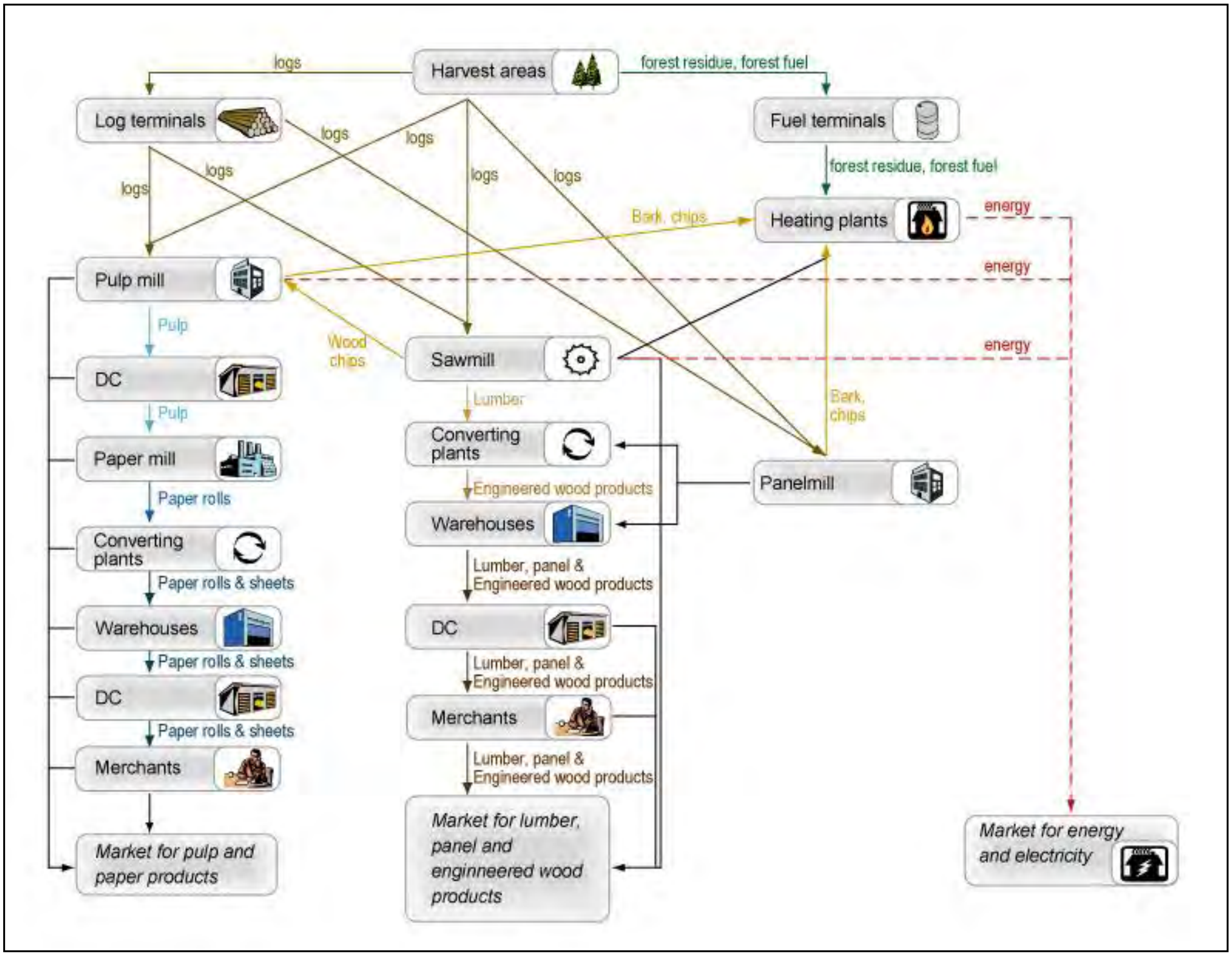


Figure 2: The value creation network in the forest products industry

The different companies typically own a set of business units that are involved in the conversion and distribution of forest products. When a company owns units covering the full range of activities, from harvesting activities to distribution, it is said to be integrated (i.e. vertical integration) (D'Amours *et al.*, 2008). In the pulp and paper industry for instance, a majority of companies are integrated, that is, they produce paper as well as the pulp needed for paper production. In addition to being integrated, a few large international companies are also active in all of the different markets shown in Figure 2. For example, Stora Enso, an international corporation with its head office in Finland, has many interrelated supply chains. In all cases, high operational costs, international competition and new technologies motivate them to efficiently manage their network. For our purpose, we will therefore refer to a "wood fibre value creation network" to describe the set of stakeholders involved in creating value from the forest to the end-user.

3 The Business Units

The Canadian wood fibre value creation network is divided into four main supply chains, i.e.: the forest; the pulp and paper operations; the units involved in the production of lumber, panels and engineered wood products; and the energy production, each supply chain starting with the use of wood as raw material.

Within all four supply chains, transportation is an important activity that can be managed by independent contractors, carriers, Third Party Logistics (3PL) or by the company itself if it owns a fleet of vehicles.

3.1 The Forest Supply Chain

Forests cover up to 45% of Canada's land area. Of this land, 71% belongs to provincial governments, 23% to the federal government and 6% is privately owned. Natural Resources Canada considers a major part of Canada's forests (56%) to be of commercial value, meaning that it is suitable for the generation of wood-based forest products. However, only 28% of these forests are available for harvesting. The annual harvest amounts to about 0.4% of the total commercial forest area (around 1 million hectares). Although the bulk of Canada's forests are under provincial ownership and control, the federal government has a marked influence on the management and exploitation of forests through industrial and regional development, trade, international relations, science and technology, environmental regulation and taxation.

All activities involved in the forest products value creation network are affected by the volume and quality of the wood fibre harvest. Efficient planning and management of the forest supply chain are therefore crucial, as they have a direct impact on the profitability of the other chains in the network. Moreover, if the raw material attributes and the operation modes are well known, network activity planning will be more efficient.

Several stakeholders and entities play a key role in the forest utilization process. They have to interact using information at different levels to deal simultaneously with environmental, social, operational and economic issues (Figure 3).

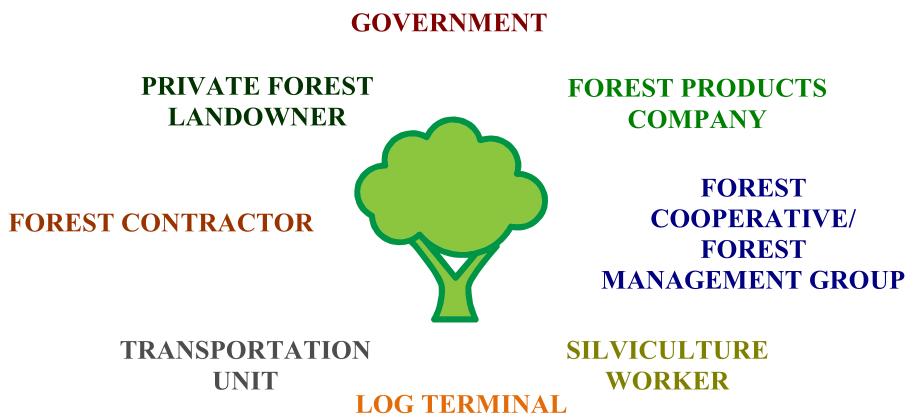


Figure 3: The business units of the forest

3.1.1 The Government

Given that forests are an essential natural resource for society, managing them is not limited to the production of forest products. It also involves the provision of recreational opportunities, the protection of biological elements, the conservation of soil and water, the control of pests and disease, the reduction of losses due to wildfire, and so on (Church, 2007). This is why, in many countries, the government is responsible for a portion of the forest (public forest) and regulates private forest areas, which are not under its direct control. The government may therefore be responsible for wood fibre allocations to the different companies, strategies to be applied to ensure forest sustainability, forest policies, areas to be harvested or protected, the forest road network, different tariffs and credits associated with forest use or protection, etc.

3.1.2 Private Forest Landowners

Individuals, families, organizations, First Nations groups or corporations (including those in the forest industry) can also be owners of private forest lands. The forest can be used in different ways such as recreation or timber production. The private forest landowners manage their lands in a manner that is beneficial to the sustainability of forest resources and that meets their objectives. Under all circumstances, they typically have to abide by rules defined by the government.

3.1.3 Forest Products Companies

The different companies use wood fibre for different activities. Typically, the fibre originates in private forests, public forests and importation. Depending on the conversion process, the company may be very small (e.g., a maple sugar bush), specialized (e.g., a sawmill) or fully integrated (multiple conversion stages controlled by the same organization). Planning decisions have to be made for the short, medium and long terms, and these decisions will be affected by a number of factors, including the role played by the government and the size of the company. Greater government control means less flexibility for the company, as well as more legal obligations, and a large organization needs to address a variety of decision-making problems.

3.1.4 Forest Contractors

As forest harvesting equipment can involve major capital investment and the area to be harvested may be limited, many companies choose to rely on forest contractors. These independent specialists use their own machinery to collect the timber. Depending on circumstances, contractors may be responsible for harvest operations, silvicultural treatments, road building and wood transportation. Therefore, they play a key role in the efficiency of the system. The agreement between the company and the forest contractor is usually formalized in a contract specifying the contractor's obligations.

3.1.5 Forest Cooperatives / Forest Management Groups

Like forest contractors, forest cooperatives and management groups are hired by companies to harvest timber, implement different silvicultural treatments, transport the wood, etc. They consist of several members specializing in forest management, and are generally based on a free membership open to everyone. These business groups generate value by pooling the needs of many forest owners. In addition, some cooperatives have their own wood transformation units.

3.1.6 Silvicultural Workers

Silviculture is a branch of forestry that deals with the establishment, development, reproduction, care and harvesting of forest vegetation. This makes silviculture one of the key factors providing biological and technical options to achieve management objectives. Without appropriate silviculture, sustainable forest management is impossible. This is why silvicultural workers have a significant role to play in forest development and sustainability.

Many silvicultural workers are employed by forest contractors and government agencies to perform a variety of duties related to reforestation and to the management, improvement and conservation of forest lands.

3.1.7 Transportation Units

Transportation is one of the main forest industry activities. Each year, approximately 190 million cubic metres are harvested in Canada (Natural Resources Canada). The timber is transported by trucks from the forest to the mills or transfer yards. Transportation costs account for up to 50% of fibre supply costs at Canadian mills, and 25% to 40% of the price of products delivered by the industry (Forest Products Association of Canada). Therefore, it has to be managed efficiently. Harvesting requires the development of an entire forest road network to access the timber. The length of the forest road network has more than tripled in 25 years. More than 3,000 km of roads are built annually. Provincial governments' support of the development of forest roads is quite variable depending on budgets, government and business needs. On Quebec public land, companies are responsible for the construction and maintenance of roads.

The means of transportation and those responsible for it can vary significantly among companies (Epstein *et al.*, 2007). A forest products company can have its own fleet of trucks and equipment to move timber (Figure 4). A large transport company can also organize transportation for several forest companies or organizations. In addition, transportation can be delegated to forest contractors, forest cooperatives, forest management groups or several small transporters. Typically, a contract is established between the forest products company and the transportation company (generally one year) and the parties' obligations are defined.

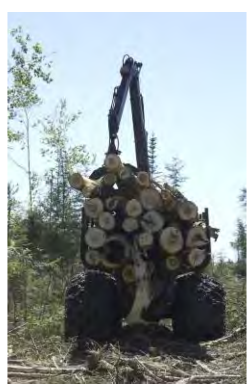


Figure 4: Forwarding in the cutblock (New Brunswick Government)

Changes in business logistics, including minimization of goods storage and the use of "just in time" distribution, have shaped the evolution of goods transportation in recent decades, mostly in favour of trucking. Indeed, this mode of transportation seems to better meet the criteria of reliability and speed associated with these strategies. In some circumstances, it may be preferable to use a warehouse for product distribution. Rail transit is then the favoured method to ship goods to warehouses, while trucking is preferred between warehouses and clients. A rule of thumb used by those responsible for distribution in the industry is as follows. Trucking is favoured for distances up to 800 km, intermodal systems are used for distances from 800 to 1600 km, and railroad cars are preferred for distances over 1600 km. In Quebec, wood products, pulp and paper and printing account for about 30% of all merchandise trucking (Denault and Julien, 2003).

3.1.8 Transfer Yards

A transfer yard is an in-transit location for the logs before they get to their final destination (Figure 5). Sometimes, a transfer yard can be referred to as a sorting yard, stockyard or merchandizing yard. There may be numerous motivations advocating the use of transfer yards. On the practical side, they can be used for the transfer of logs to other transportation modes. This may be required when the trucks used to move the timber out of the forest are oversize trucks that are not allowed on public roads. Other changes of transportation mode may be valuable to reduce transportation costs to the mill when a regular high volume of logs needs to be moved over a long distance. Railway or barge transportation may then be more appropriate than trucks.

Figure 5: A transfer yard (Halco Software Systems Ltd)

Transfer yards may also serve as a sorting yard where logs are classified according to optimum mill destination based on potential value. For example, some mills are more specialized in processing large diameter logs. Furthermore, some logs are more appropriate for paper mills and others for panel mills. In addition, gathering logs at a common place allows for proper sorting and stocking, more economic shipment sizes or increasing the value of the final product basket. Sometimes, pre-processing of the wood can even take place at a transfer yard, where more sophisticated or larger scale equipment can be used than would be the case in the forest, due to terrain conditions or the need for costly equipment relocation. Processing that can be done at a transfer yard includes debarking, bucking, chipping and sorting.

3.2 The Pulp and Paper Supply Chain

The pulp and paper supply chain involves many steps by different companies to offer a large number of products such as newsprint, copy papers, several types of tissues, bottle labels, and so on (Carlsson and Rönnqvist, 2007). While some companies control all of the activities from the forest to the final consumer (i.e. integrated pulp and paper operations), others work with subcontractors for specific operations (Lehoux *et al.*, 2009a).

3.2.1 Pulp Mills

A pulp mill is a facility that converts wood chips or other fibre sources (e.g., waste paper and paperboard) into a thick fibre board which can be shipped to a paper mill. Pulp can be manufactured using mechanical, semi-chemical or fully chemical methods, and the finished product may be either bleached or unbleached, depending on customer requirements. Mechanical pulp mills use large amounts of energy, mostly electricity, to power motors which turn the grinders. Pulp mills produce much of their energy requirements on site. In 2002, the U.S. Paper Industry generated 44% of its total electrical requirements. There are many types of fuels used by the industry, but the largest category is black liquor and hog fuel (bark/wood waste) which represent about 54% of the industry's energy input (Institute of Paper Science and Technology, 2006).

Bleached kraft and sulfite pulp are used to make high quality, white printing paper. One of the most visible uses for unbleached kraft pulp is brown paper for shopping bags and wrapping paper where strength is important.

Pulp made out of waste paper and paperboard is most often used to make paperboard, newsprint or sanitary paper. In mills using trees as the fibre source, the first step is to remove the bark, which is burned to generate steam to run the mill.

3.2.2 Paper Mills

A paper mill is a factory devoted to making paper from wood pulp. Many paper mills are integrated, the pulp and the paper mills being on the same site. Company-owned paper mills can also be fully integrated with sawmills and harvesting operations to ensure chip availability.

Modern paper machines can produce paper at a speed of 100 km/h on 10-metre wide rolls. These jumbo rolls are cut into various widths to make parent rolls (Figure 6).

Figure 6: Parent rolls manufactured at a paper mill (Paper Industry Web)

End products are characterized by sheet width and length, unit weight, colour, finish, brightness and packaging.

3.2.3 Paper Conversion Plants (Source: WiseGeek)

Paper conversion plants use paper as their primary raw material and process it to produce another, more specialized, product of the same type. For example, paper conversion can be used to create products such as envelopes, paper bags, boxes, containers and a full range of similar items.

Many businesses offer paper conversion. Often, these businesses offer the conversion of film and foil in addition to paper. Some focus on a specific type of paper, while others handle a wide variety of papers and materials. Most paper conversion companies work with both coated and uncoated papers.

Highly specialized machines are used in paper conversion. Some machines are used in cutting, folding, gluing and clipping tasks. Such tasks are part of the process involved in making carton, boxes and other products. Other machines are used to cut, fold, and apply glue to paper for the purpose of making paper bags and envelopes.

Products such as paper cups and food containers are made in paper converting machines that press paper into the appropriate forms and shapes. Paper tubes, paper towels and diapers are also produced with this type of machinery.

Some paper converting businesses do not actually sell paper, choosing instead to focus on the conversion process. The client is then responsible for supplying the paper or purchasing it from another company. However, other paper conversion businesses do supply paper, offering many different types from which to choose.

3.2.4 Paper Distribution Centres

In the distribution of fine papers or standard printing, it is common practice to book within 24 hours (next day delivery). Consequently, warehouses are heavily used and the deployment of products is optimized. In other cases, as in the distribution of newsprint or cardboard boxes, it is relatively common for deliveries to be made directly from the factory.

Case study 1: Synchronization of production and distribution planning

This study conducted by Rizk *et al.* (2008) explored the flow synchronization problem between a manufacturing location and multiple locations. The case study related to a North American pulp and paper company that had to deliver products to different locations via multiple transportation modes. Transportation costs between the mill and its customers' locations typically offer economies of scale that have an impact on inventory planning and replenishment strategies. The objective was therefore to develop a mathematical model that integrated production, inventory and distribution planning in order to capture potential cost savings.

Two transportation modes were considered with different costs and lead times: truck and rail. An integrated planning model (production and distribution operations planned together) as well as a sequential planning model (the production process is planned first; replenishment is then based on the production plan) was developed and compared in order to evaluate potential gains.

The results showed that using an integrated planning model can help **capture the potential savings accruing from multiple transportation modes**, while this was not possible with a synchronization planning model. With an integrated planning model, products could be produced earlier and stocked in order to take advantage of the cheaper transportation mode. As a result, **the transportation cost was considerably reduced**.

This shows that it can be very beneficial to solve the production and distribution planning problem with an integrated approach, instead of solving them independently.

3.3 Lumber, Panel and Engineered Wood Supply Chain

Again, the lumber, panel and engineered wood supply chain involves several operations and, consequently, different organizations. These organizations can be part of the internal supply chain, i.e. members of the same company, or part of the external supply chain, i.e. members of different companies (Gaudreault *et al.*, 2009).

3.3.1 Softwood Sawmills

Softwood is mainly used in the lumber market, and in engineering and construction products. At the sawmill, logs are processed into lumber of different dimensions and lengths, and co-products or by-products such as chips, bark and sawdust. A sawmill has a large yard where the logs are stored till processing. They can be stored based on size (length and diameter), species and end use (lumber, plywood, chips). It is important to keep track of the time a log has been stored in the yard, as the quality of the fibre will decrease with time. Although bucking may take place in the forest or at a transfer yard, bucking and debarking operations frequently need to be performed at the mill before the actual sawing of the logs occurs.

Though a typical sawmill can process logs of most sizes, some are optimized to process large-sized logs while others specialize in small-sized logs.

Sawing is the first of the three main activities that take place at the sawmill. Sawn lumber is usually dried and then planed at the same site. Not all products are required to go through all these steps, as there are markets for green lumber (not dried) and for rough lumber (not planed).

3.3.2 Wood Distribution Centres

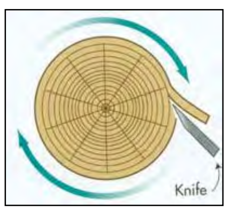
Some products are shipped directly from the factory to the merchant. But when aggressive deliveries are required, because of competition or when the delays to produce and ship to the customers exceed market expectations, distribution centres may be used to shorten delivery time.

3.3.3 Hardwood Sawmills

Hardwood is for the most part used in the production of products where appearance is important, as in furniture and flooring.

In a hardwood sawmill that produces boards, the machinery is similar to that used in the softwood sawmill, but capacities are typically smaller, and the product range is broader. The product flow through the plant is usually much slower and operations are more labour intensive.

Other hardwood mills specialize in veneer production and use very different machinery and methods. Veneer refers to thin slices of wood that are typically glued together into a plywood, or onto core panels such as particleboard or medium density fibreboard (MDF). Veneer is obtained either by "peeling" a log or by slicing large rectangular blocks of wood known as flitches. There are four main types of veneer-making processes: rotary cut, plain sliced, quarter sliced and rift cut (Figure 7). In veneer processes, knives are used instead of saws. More information on veneer applications is to be found in the Panel Mill section below.



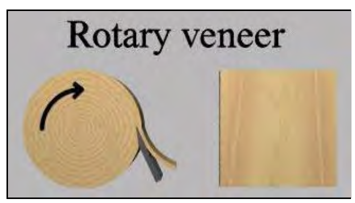


Figure 7: Veneer production (Horizon Plywood Inc)

3.3.4 Lumber Conversion Plants

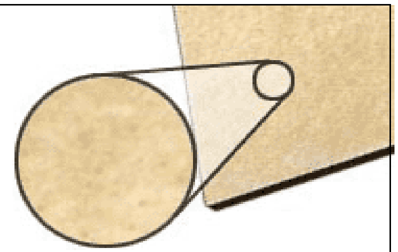
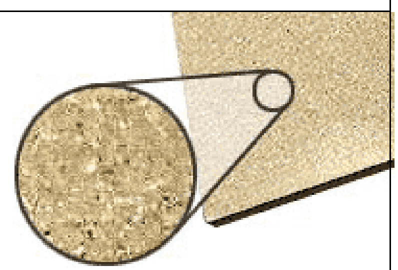
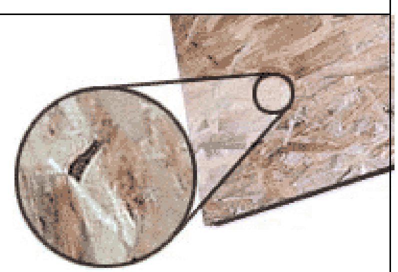
One kind of lumber conversion is related to wood preservation. It includes all measures that are taken to increase product durability and resistance. Preservative treatments generally involve a pressure impregnation process.

Engineered lumber is lumber created by a manufacturer and designed for a specific structural purpose. Examples of products that fall into this category are LVL (Laminated Veneer Lumber) that uses multiple layers of thin wood assembled with adhesives, and Glulam (Glued Laminated Structural Timber) composed of several layers of dimension lumber glued together.

3.3.5 Panel Mills

There are many kinds of panels made of wood fibre, wood flakes, veneer or sawmill residue. These are OSB panels (Oriented Strand Board), MDF (Medium-density Fibreboard) panels, plywood and particleboard. These different panels can be used in construction for roofing, subflooring or walls, or in manufactured, modular or prefabricated housing. They can also be used by the furniture industry or for shelving and cabinetry which will apply veneer to the panel to improve its appearance. Table 1 shows the differences between MDF, particleboard, OSB and plywood.

Table 1: Differences between MDF, particleboard, OSB and plywood

Medium Density Fibreboard (MDF) MDF is a waste-wood product that is made with fine wood fibre.	
Particleboard Particleboard is a waste-wood product that is made by mixing sawdust with adhesives. Although it will not bow or warp like plywood, it can swell and become unstable when exposed to water. Particleboard is a type of fibreboard but it is made up of larger pieces of wood than medium-density fibreboard and hardboard.	
Oriented Strand Board (OSB) OSB is an engineered wood product that is made from flakes or large chips of wood. The panels are formed from layers or plies glued together with their strands at ninety-degree angles to one another. The cross orientation of the layers adds strength to the panels and makes OSB well-suited for use as a structure board.	
Plywood Plywood is a type of engineered board made from thin sheets of wood called plies or veneers. The layers are glued together, each with its grain at right angles to adjacent layers for greater strength.	

Impact on timber resources (Source: Wikipedia)
Particleboard and other manufactured boards have had a very positive impact on timber resources, stemming almost entirely from the use of recycled materials. Seventy-five percent of particleboard manufactured in Canada and the US is constructed entirely from recycled materials. The remaining twenty-five percent of boards are constructed partially from recycled material and partially from virgin wood. These mixed panels have an average recycled content of sixty-six percent. This is still significantly more resource efficient than solid wood, even when considering that in many cases these panels will be covered with veneer.

3.3.6 Engineered Wood Mills

Engineered wood, also called composite wood or manufactured wood, includes a range of derivative wood products which are manufactured by binding the strands, particles, fibres, or veneers of wood, together with adhesives, to form composite materials (Figure 8). These products are engineered to precise design specifications which are tested to meet national or international standards. Typically, engineered wood products are made from the same hardwoods and softwoods used to manufacture lumber. Sawmill scraps and other wood waste can be used for engineered wood composed of wood particles or fibres, but whole logs are used for veneers, used in plywood (Wikipedia), and OSB. Other products in this category are the structural components made of wood such as floor trusses, roof trusses, I beam joists, wall framing products and glulam.

Figure 8: Examples of engineered woods (APA)

3.3.7 Secondary Wood Processing Plants

The forest products industry has a great variety of products and it would take a long time to describe them all. Every year, new wooden products are designed and appear on the market. We have briefly described the major uses of wood resources, at least in the primary processing industry. Products or by-products from that industry are then used as raw material in the production of other wooden products. Among the main products created in this secondary processing of wood are wooden doors and windows, wooden boxes and pallets, coffins and caskets, fences, shingles, siding, cabinet items, decking, flooring and moulding.

3.3.8 Modular Building Plants

Modular homes are houses that are divided into modules or sections which are manufactured in a remote facility and then delivered to the intended building site (Figure 9). The modules are assembled into a single residential building using either a crane or trucks. Modular components are typically constructed on assembly lines within a large indoor facility. Wood-framed modular homes contain about 10% to 20% more lumber compared to traditional stick built homes (Wikipedia). This is because the modules need to be transported to the job site and the additional lumber helps keep them stable. On the other hand, there is significantly less waste generated than for houses completely built on site.

Figure 9: A modular home (Wikipedia)

3.4 The Energy Supply Chain

Biomass energy, or bioenergy, is the energy stored in non-fossil organic materials such as wood, straw, vegetable oils and wastes from the forest, agricultural and industrial sectors. Municipal solid waste and sewage sludge can also be considered biomass.

It is generally assumed that the combustion of forest biomass is CO2-neutral as the emission of carbon dioxide during combustion is the same as the amount absorbed and sequestered while the tree was growing (Figure 10). This statement is not quite exact, but in the long term (100 years and more), the measure of carbon neutrality becomes closer to one (Schlamadinger *et al.*, 1995). Due to its green footprint (especially as a substitute for fossil fuel) and the increasing cost of other sources of energy, the use of forest biomass has rapidly been gaining in popularity for the production of different forms of energy

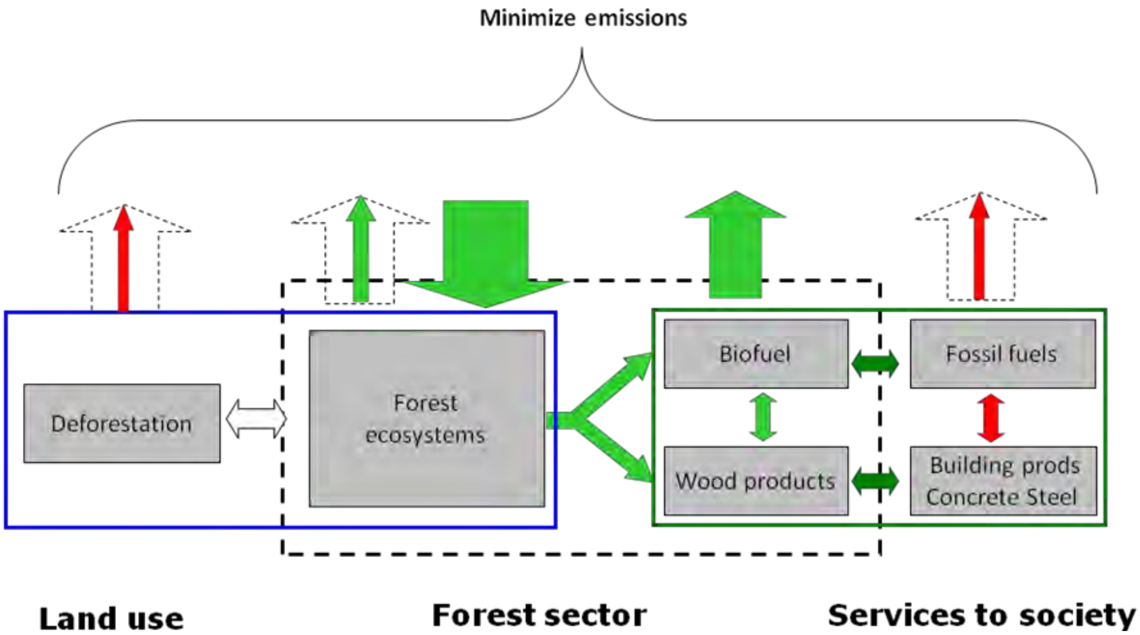


Figure 10: Carbon account of the forest sector

In view of their access to wood fuel and high energy demand, pulp and paper companies have been using wood-based by-products for some time to decrease energy costs. Forest industries have been increasing their use of wood wastes that otherwise would be incinerated, buried or land-filled. Major uses include firing boilers in pulp and paper mills to generate process heat and to provide energy for lumber drying. In some areas (e.g., British Colombia, Ontario, Quebec, Prince Edward Island, New Brunswick), forest companies supply wood waste (known as hog fuel), wood chips and pellets to nearby industrial and residential customers and non-utility electrical generators (Canadian Encyclopedia). According to the Canadian Encyclopedia Online, Canadian forest industries meet more than one-half of their own energy demand from self-generated biomass waste.

Biomass energy accounts for 6% of all energy usage (Canmet Energy), coming in second position behind hydropower in Canada's primary energy production. The use of biomass as a source of energy is largely dominated by companies and households that use wood or wood pellets for heating. Wood is the principal heating fuel for more than 100,000 Canadian homes. Some larger institutions, like hospitals and universities, have adopted integrated energy systems (cogeneration systems) which include biomass fuels into their energy generation process.

<u>Energy Payback Ratio</u>

The energy payback ratio (Figure 11) is the amount of energy generated during the lifespan of a system divided by the amount of energy required to build, maintain and supply that system with fuel. An energy payback ratio close to one requires almost as much energy as the amount of energy generated and is thus not attractive. Hydro Québec has published a chart showing the energy payback ratio of different electricity generation options. Regarding biomass, their finding is as follows: "Biomass performs well (ratio of 27) when power is produced from forestry wastes. But when trees are planted for the purpose of producing electricity, the ratio is much lower (about 3 to 5), because biomass plantations require high energy inputs. For all biomass options, the distance between the source of biomass and the power plant must be short, otherwise the energy payback ratio drops to very low values."

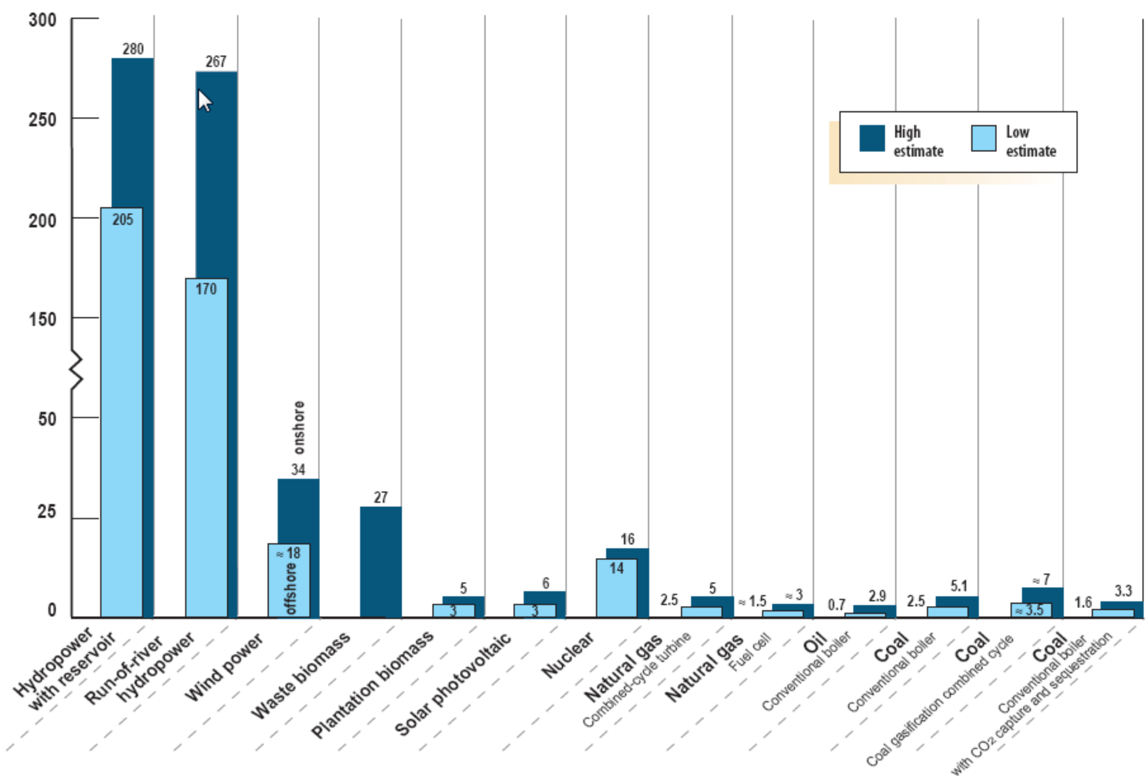


Figure 11: Energy payback ratio of different electricity generation modes (Hydro-Québec)

In regard to energy payback ratio, waste biomass comes in third place after hydropower and wind power facilities.

In order to increase the power of its network through sustainable development, Hydro Québec is opening a call for tenders for electric power from biomass purchases on the Quebec market, with deliveries expected to start no later than December 1st, 2012. The biomass used in the new cogeneration facilities must amount to a minimum of 75% of the fuel used for electricity production in these facilities (Hydro-Québec). From initiatives like this one, it is foreseen that the use of forest biomass will increase in the years to come.

4 Network Flows

A value creation network can also be described from the perspective of flows, specifically different inputs into a process, proceed through the various activities performed, and finally exit the process as outputs. The flow can be defined in terms of products, information, and cash or financial terms (Figure 12). The product flow represents the movement of raw materials, intermediate products and finished products from the forest to the final user. The information flow includes all information exchanged between the different business units, such as orders, forecasts and plans. The financial flow involves monetary transactions between units of the value creation network, such as payments, credits, transaction costs, transfer pricing, etc. These flows need to be correctly defined, as they will directly affect capacity and investment levels, as well as some key planning decisions.

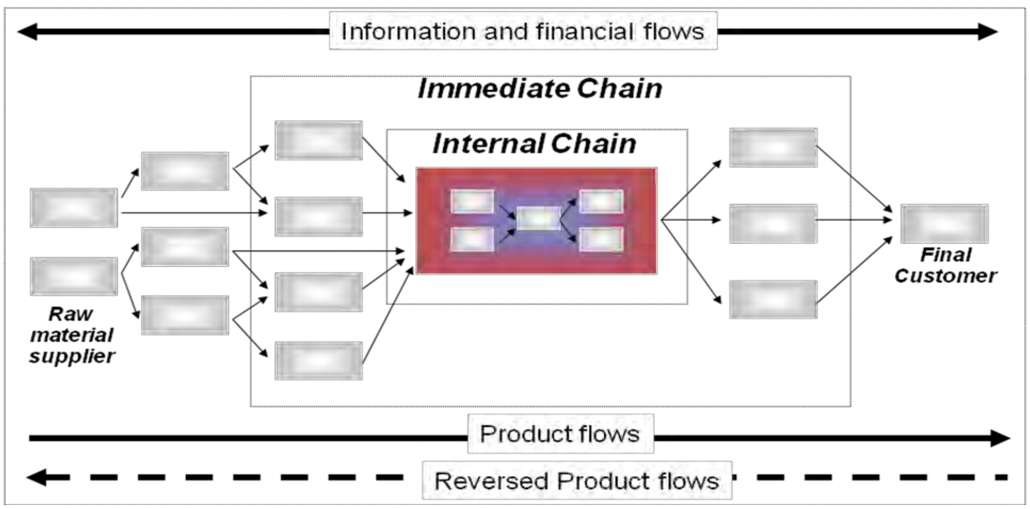


Figure 12: Illustration of the main flows within the value creation network

4.1 The Product Flow

Each business unit in the forest products value creation network contributes to the gradual conversion of raw wood fibre into finished products. The movement of goods is bottom-up (from the forest, to mills, to customers), except when the wrong product has been sent to a customer, when a product is broken or malfunctioning or when a product should be recovered and recycled (from customers, to distribution centres, to mills/warehouses). The products manufactured are typically designed around a desired set of outputs that are necessary to satisfy customer needs. However, one of the characteristics of the Canadian wood fibre value creation network lies in the many possible uses for intermediate wood products and co-products or by-product (Table 2). More precisely, a co-product is a valuable product that is created as a result of producing the main product, while a by-product is a product that gets produced anyway as a result of the processing but that is not desired by customers. Therefore, the impact is twofold. First, this makes the network deep or long as many conversion processes can be performed by different facilities before completion of the final product. Second, the output of a given process can go to several places because of the divergent nature of the processes, particularly at the sawmill: logs may be processed as lumber of various dimensions, chips, sawdust or shavings.

Table 2: Co-product and by-product definitions

Definitions
A *co-product* is a valuable product that is created as a result of producing the main product. For example, one may want to produce mainly 2x6 lumber, but the processing of logs is such that inadvertently, some 2x1 or 2x2 will also be produced.
A *by-product* is a product that does not have much value and that we would avoid producing if possible, but that gets produced anyway as a result of the processing. For example, planer shavings are a by-product of the lumber planing process.

To move products from the forest to the different business units, several transportation modes (e.g., trucks, rail and ships) and much equipment are needed, depending on the form of the wood product to be transported. In addition, the unit of measure to quantify the flow can vary from one product to another.

4.1.1 Fibre Flow from the Forest to the Mills

To begin with, the forest can be viewed as a business entity that keeps different kinds of products in stock, specifically different species, age classes, product dimensions, and so on. These primary products will be progressively converted into intermediate products (in the forest) and finished products (in the plants) so as to satisfy multiple needs.

There are two main harvesting systems: full-tree (tree-length) and shortwood (cut-to-length). The product flow varies accordingly. For a full-tree harvesting system, the trees are felled and skidded to the roadside. Next, they are delimbed and sorted at the roadside as per wood specifications, and piled for tree-length transportation. The limbs and tops are available at the roadside for biomass. The stems are bucked at the mill or yard. For the shortwood system (Figure 13), the trees are felled, delimbed and bucked at the stump. The limbs and tops can be left in the forest or forwarded to the roadside after the logs have been forwarded into various assortments.

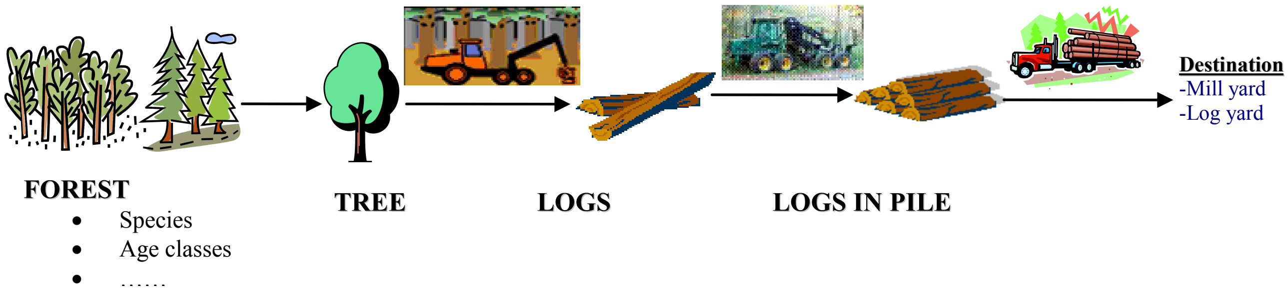


Figure 13: The product flow in the forest based on a shortwood system

Skidders are used in the full-tree system to drag the stems, while the shortwood system relies on forwarders to extract the logs (Akay *et al.*, 2006). Skidders are divided into two types, i.e.: rubber-tired skidders equipped with an articulated frame and crawler tractors that are equipped with steel tracks. Forwarders are rubber-tired machines that carry short logs to the roadside. Forwarders can also be used to load truck trailers at the roadside.

From the roadside, the logs are transported to an intermediate storage log yard or to a mill yard. For this secondary transportation step, one needs to determine how much volume to transport, the type of equipment/transportation mode to be used, best routing decisions, etc. The type of truck used to move full length timber will not be the same as that used to move chips or logs (produced in many log lengths). The transportation mode will also vary depending on the geographical location of the harvesting sites (Figure 14). Transportation can be done with a single transportation mode (e.g., truck) or a combination of different modes (e.g., truck and rail).

On the coast of British Columbia, for example, water based transportation is often used. There are three main methods to move logs in water: flat raft, bundle boom and log barge. A flat raft consists of free floating logs kept in place by a perimeter of logs, known as boomsticks, held together by chains. The travel time depends on the tow's susceptibility to weather conditions (Sarkar, 1984). A bundle boom is similar to a flat raft, except that the logs are held together in bundles secured by wire rope or steel strapping. This method is more common than the previous one because of higher speed and reduced log loss. Finally, logs can be loaded onto a barge that is towed to its destination by a tug.

In Quebec, as the average distance between the mills and the harvesting sites is more than 150 km (with large variations). The use of oversized vehicles may be economical for the portion of the trip that is on forest roads.

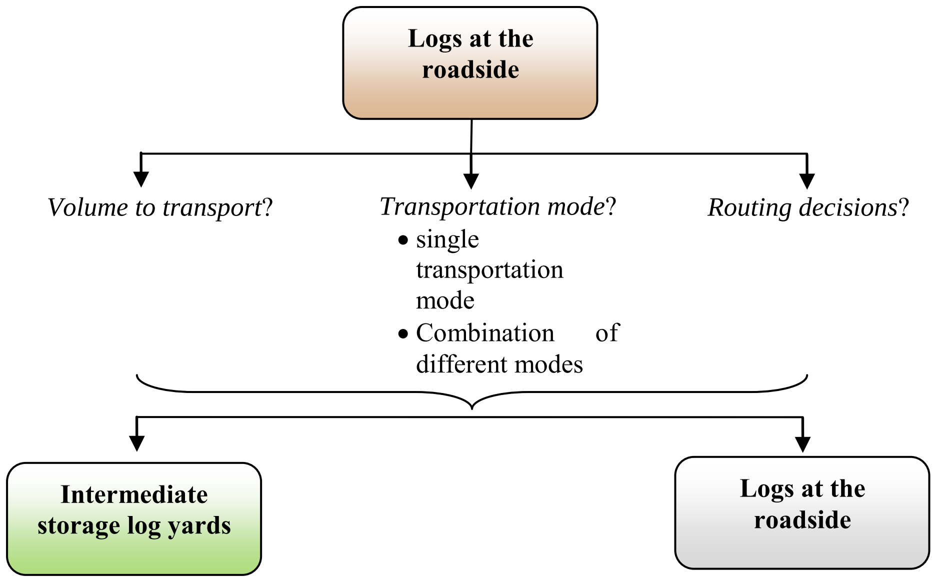


Figure 14: Decisions related to fibre transportation from the forest to mills/log yards

To optimize the transportation activity, operations are best planned in such a way as to ensure that a truck that has carried one load between two points carries another load on its return trip (Epstein *et al.*, 2007). This is called backhauling (Figure 15).

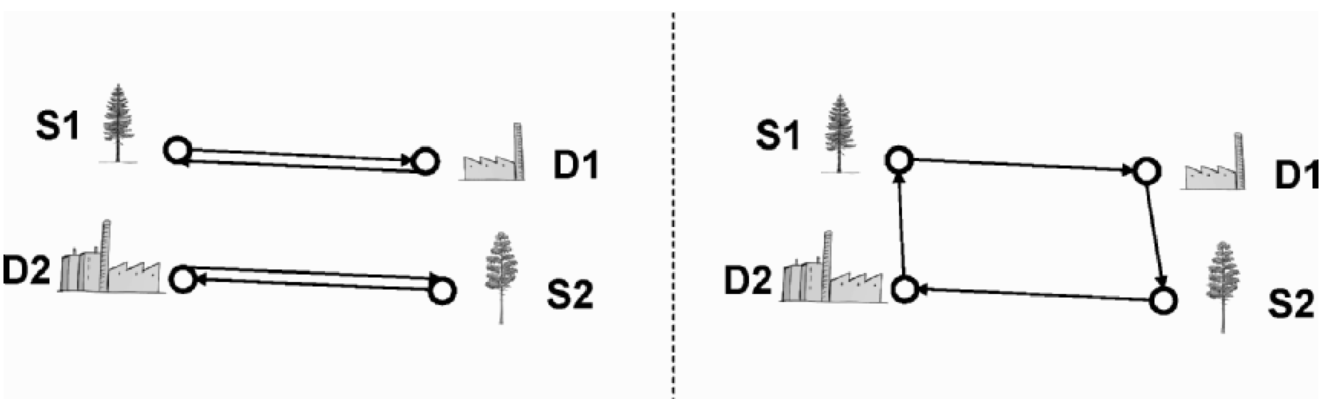


Figure 15: Illustration of two direct flows (left) and a backhaulage tour (right) (Epstein *et al.*, 2007)

The timber and logs to be transported are generally measured in cubic metre units. However, timber from private forests or from the U.S. is frequently measured on a foot board measure, i.e. "Mbf", basis. An "Mbf" is defined as the volume of a one foot length of a board one foot wide and one inch thick (1 ft × 1 ft × 1 in or 2360 cm^3).

4.1.2 Fibre Flow in the Pulp and Paper Supply Chain

As the name conveys, there are two main processes in the pulp and paper supply chain. The first is the production of pulp, which requires wood chips, water, chemical products and a lot of energy. Wood chips can be supplied from sawmills. A high volume chipper is often available at the pulp mill, in which case log procurement from the forest or transfer yards is another option to obtain wood chips. In making pulp, a specific mix of chip species must be obtained. The quality of the chips and thus the logs used to make them has an impact on the quality of the resulting pulp.

When the mill makes its own chips, the bark generated by debarking logs can be used by a heating plant on site or sold to other companies, also as an energy source. These heating plants, when burning organic matters, generate heat for buildings, whole communities or industrial processes. Moreover, they are highly efficient heating systems, achieving near complete combustion of the biomass fuel through control of the fuel and air supply, and often incorporating automatic fuel handling systems.

Depending on the end-use of the pulp, recycled paper may be incorporated into the pulp. In fact, the pulp used in the production of newsprint and that used for cardboard production contain a high proportion of recycled fibre.

The pulp produced has many possible destinations. Integrated companies often combine a pulp mill and a paper mill at the same location, therefore transportation is minimized. The pulp can also be sold on the market and, in that case, it is typically moved to a distribution centre before it reaches the customer. The pulp can also be transferred to another plant within the same company to produce paper. In the industry, pulp is most typically moved by rail and ship, although it may be trucked.

At the paper mill, the pulp is used to produce jumbo reels of paper of a specific grade, finish, base weight and colour. The jumbo reels are cut into rolls, which can be either sold directly on the market or sheeted for printing and writing paper products. From the mills, the paper is distributed either directly or through a network of wholesalers, distributors and merchants (Figure 16).

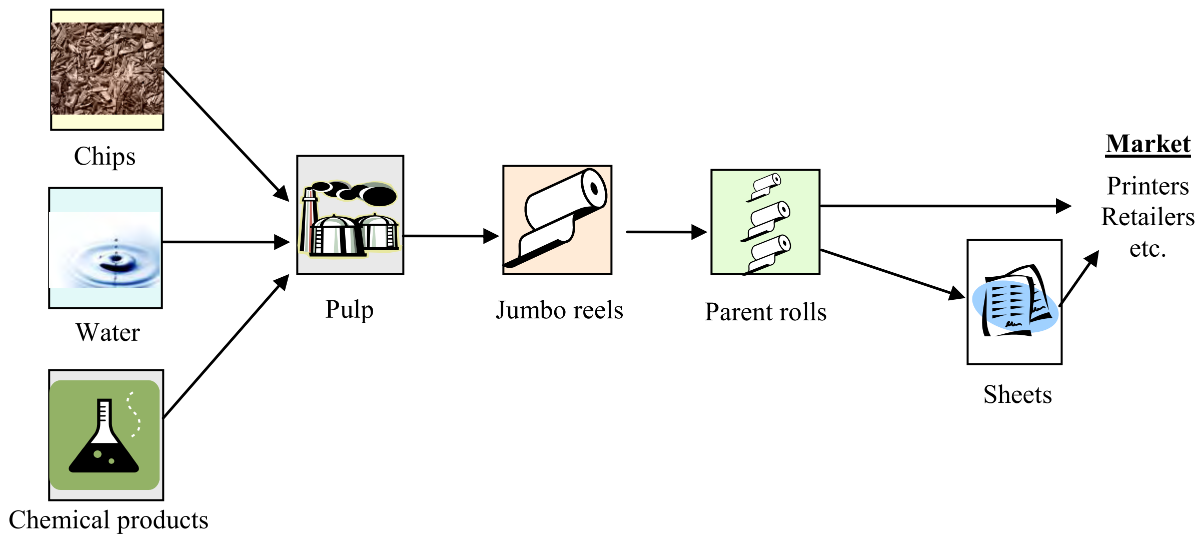


Figure 16: Product flow for newsprint

Pulp is also used to manufacture other products such as paperboard. Different customers typically buy different products; for example, printers may buy newsprint; retailers may buy fine paper; and food chains, packaging materials (D'Amours *et al.*, 2008). Finished paper is usually moved by rail or truck, while ships are required for overseas deliveries.

Chips and paper products are usually measured in metric ton units, 1 metric ton being equivalent to 1.1023113109 US tons. In addition, the volume of chips to transport may or may not include a percentage of water. Thus, a conversion factor that depends on, among other things, the freshness of the fibre has to be used to calculate this parameter.

4.1.3 Fibre Flow in the Lumber, Panel and Engineered Wood Supply Chain

The lumber and panel industries both use logs coming directly from the forest or from a transfer yard. At the sawmill, the logs are sawn into boards which are usually dried and planed to become the final lumber product. Sometimes, the lumber is sold before the drying process (rough green) or before the planing process (rough dry). Typically, drying takes place at the same location as sawing and planing, but when drying capacity in insufficient, the boards may be transferred to another mill for planing. Grading is a critical process in a sawmill, some remanufacturing plants commonly called "reman" are specialists in re-processing and re-grading primary sawmill lumber to upgrade its value. Finished products are generally delivered to the market by rail and truck (local and other North American deliveries) or by ship (overseas deliveries) (Figure 17).

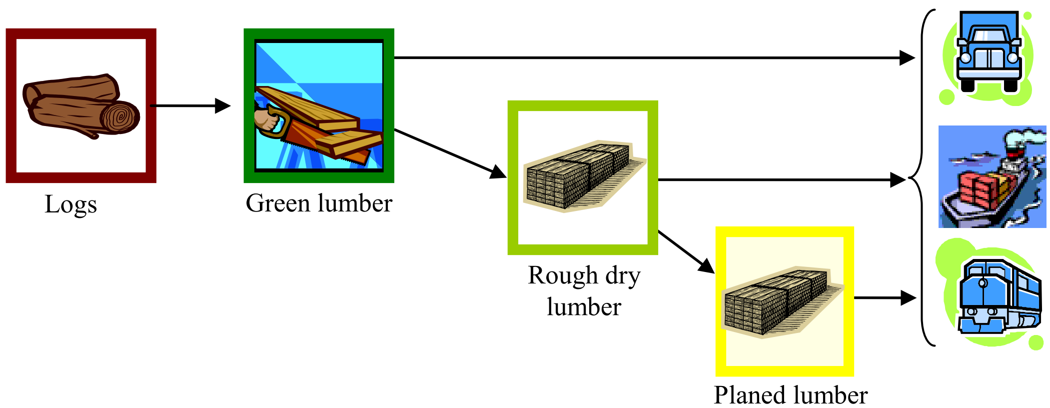


Figure 17: Illustration of the fibre flow in the sawmill supply chain

OSB panels are produced from wood flakes, which are dried, glued and pressed together. The wood flakes are cut from logs that have been softened by immersion in water in holding ponds. The flakes are then formed into a mattress (or "mat") which is then cut to length. The final board is produced by pressing the mat under heat. When the panels are used to make engineered wood products (e.g., prefabricated wood I-beams), they are again cut into smaller dimensions to meet specifications (D'Amours *et al.*, 2008). Other composite panels such as MDF and particleboard are made from by-products, so the raw material comes from sawmills rather than the forest or transfer yards. Again, all the different types of panels are usually transported by rail and truck (or by ship for overseas export).

Engineered wood products (EWP) are manufactured by assembling lumber and panels in various ways to produce structural components which can be used in building construction. Some pieces are unique and fabricated following specific design, and other engineered wood products are standard to the construction industry. Companies building and selling modular homes use large volumes of engineered wood products, often produced in-house. Special trucks are used to deliver these large products, but their use of public roads is strictly restricted. Modular homes for overseas delivery are designed to fit shipping containers.

In North America, panel shipments are commonly measured in square feet (sqf) for a given thickness of the product (3/8 or 7/16 inch panel basis, but all thicknesses can also be converted into 1/16 inch thicknesses). Countries outside North America typically use cubic metres. From a transportation perspective, weight units, i.e. lbs or tons, are generally used.

4.1.4 Fibre Flow in the Energy Supply Chain

The forest biomass includes trees that are of harvestable age (but not suitable for lumber), pulp, residual material from harvesting (like tree tops and branches) and trees killed by fire, disease or insects. The biomass may also consist of trees grown in plantations, specifically for energy purposes. In addition, the biomass includes the by-products of industrial processes: sawdust, bark, chips or "hog fuel" (pieces of wood of various sizes) and the lignin-rich "black liquors" generated by the pulping process (Figure 18).

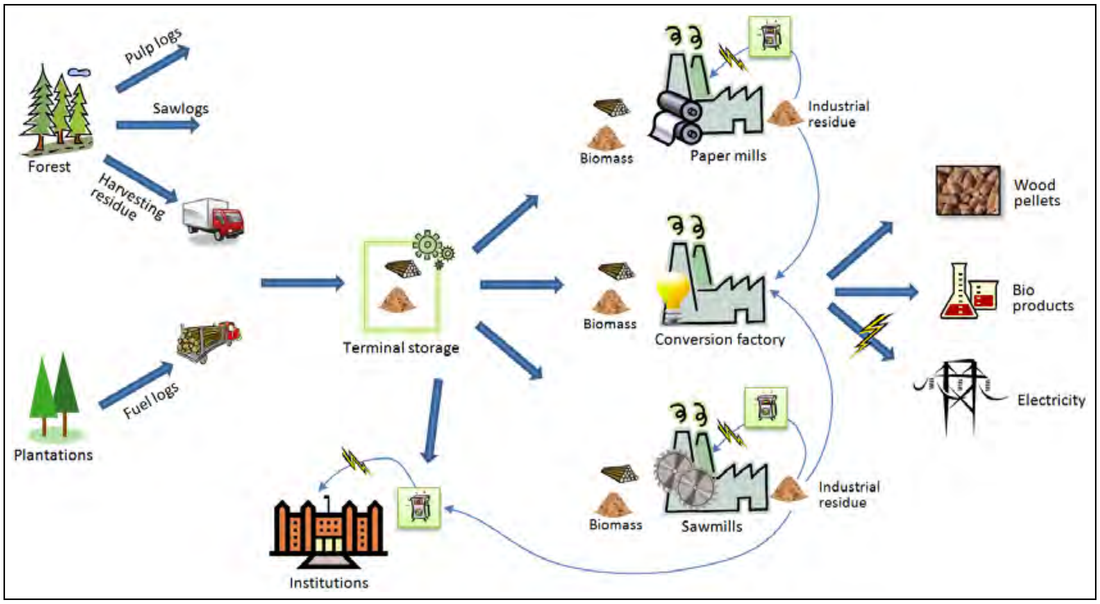


Figure 18: Illustration of the fibre flow for the energy supply chain

With the increased potential utilization of wood industry by-products, other sources of biomass have to be investigated, including stumps and other residues left on harvesting sites. The woody biomass provides important ecological functions such as soil organic matter, nutrient cycling, hydrological functioning and coarse debris for wildlife habitat. These ecological factors must be considered when deciding what biomass is surplus and can be removed, as well as the cost of using this biomass.

Trees grown in forests usually take 40 to 100 years to produce a crop, while those grown in plantations for energy biomass can usually be harvested on 3-15 year rotation basis. Plantation biomass can also be produced close to where the energy is needed.

Other major sources of biomass include agriculture, food-processing residues, industrial waste, municipal sewage and household garbage. Energy-from-waste projects include steam production for industrial or commercial use or electricity generation in several major metropolitan centres of Canada.

Biomass has mainly been used in the industry to produce heat, steam and electricity through combustion. Forest biomass can also be used in the production of many other bioproducts. Some of these products are still targeted at producing energy and heat such as pellets, ethanol, methanol, bio-diesel and bio oils. Other bioproducts are used in cosmetics, pharmacology, fabrics, adhesives and resins, solvents and lubricants, composite products and plastics.

4.1.5 Divergent Supply Chains

One of the particularities of the wood fibre value creation network relates to the divergent environment of supply chains. Specifically, products from one processing stage can be used as raw material for a variety of other operations. Haartveit, Kozak and Maness (2004) have proposed the figure below (Figure 19), which clearly shows how forest products flows are divergent and interrelated. In other industries, the environment is normally convergent, which means that several raw-materials and components are assembled into finished products.

A divergent flow involves many possibilities for production planning. Consequently, its management can become very complex. This is why good knowledge of prices, customer demand, market behaviour, point of sales data, etc., is crucial to the efficiency of the decision-making process.

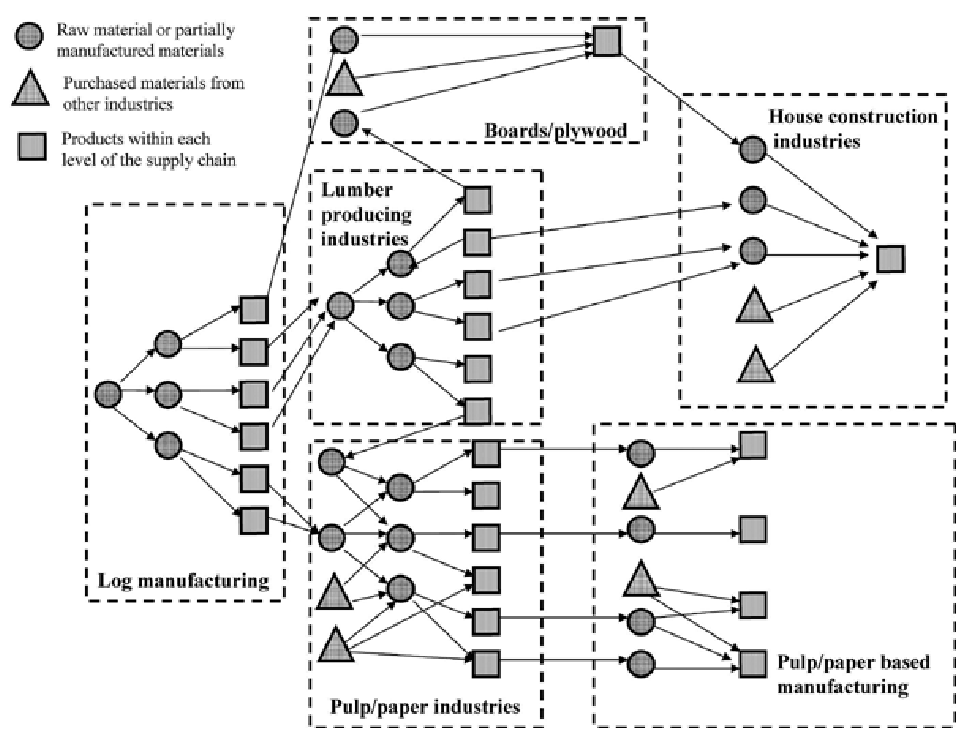
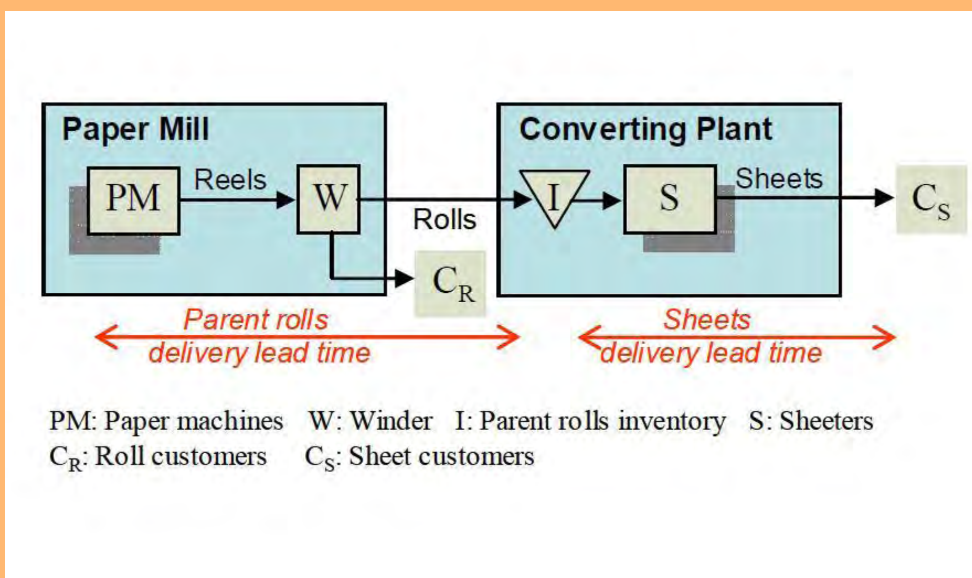


Figure 19: Illustration of the divergent environment for the forest products industry (Haartveit *et al.*, 2004).

Case study 2: Roll assortment optimization in a paper mill

This study conducted by Chauhan *et al.* (2008) in collaboration with a pulp and paper company aimed to identify the best assortment of paper roll sizes to be stocked as well as how these paper roll sizes should be allocated to finished products.

In the pulp and paper industry, the production planning is extremely difficult due to the huge variety of products offered to customers. Moreover, delivery lead times must be short to create a competitive advantage. Therefore, many reels of different paper grades are produced on a cyclical basis. These reels are next cut into rolls of smaller sizes which are then either sold as such, or sheeted into finished products in conversion plants. Typically, an assortment of rolls is kept in stock with the implication that the sheeting operations may generate trim loss. As a result, the selection of the assortment of roll sizes to stock and the allocation of these roll sizes to finished products have a significant impact on performance. Accordingly, the development of a decision-making tool aimed to improve yield and customer service levels at the lowest cost.



A model was first developed using mathematical programming. Two sets of experiments were then performed to test the performance of the tool, based on actual data from a North American pulp and paper company. One year's sales data were used for different finished products to find the optimal parent roll assortment for each paper grade produced by the mill.

The results showed that the use of the tool could help **reduce the number of rolls** in the mill's assortments from 75 to 53. In addition, this yielded a **29.34% reduction in inventory holding costs** and a **1.72% reduction in trim loss costs**.

4.2 The Information Flow

In order to correctly plan and execute all activities in the value creation network, a great deal of information has to be exchanged. This information flow can move either top–down along the chain towards the raw material suppliers or bottom–up towards the end customer. For example, orders, sales forecasts, point of sales data or customer surveys are sent top-down within the chain. In the opposite direction, information such as delivery plans, offers, catalogues, promotions and availability (e.g., capacity or inventory) are sent from the supplier to the customer. The information exchanged can be specific to a planning task or a more strategic decision-making process. At the operational level, basic information flows according to a specific standard without any processing. At the tactical or strategic planning level, the information flow is usually aggregated to support long term planning.

Typically, the flows link business units two by two within the network. However, new trends towards business networking and collaboration raise the need for flows which move through or within business units.

4.2.1 The Bullwhip Effect

A value creation network is characterized by asymmetric or private information. For example, when a merchant sells different types of paper to printers, he has access to specific demand information and he can choose to share this knowledge or not with the paper producer. However, if he chooses to keep this information to himself, the paper producer will have to plan production on the basis of merchant orders rather than actual demand from printers. As a result, this type of behaviour will negatively affect the performance of the value creation network. This phenomenon is described by the scientific community as the "bullwhip effect" (Lee *et al.*, 1997). The information transferred in the form of orders tends to be distorted and can misguide upstream network members in their planning decisions. The resulting distortion tends to increase as one moves upstream in the network (Figure 20). Consequently, the capacity of the system is not efficiently used, the occurrence of over- and under-stocking increases, the quality of service decreases, etc.

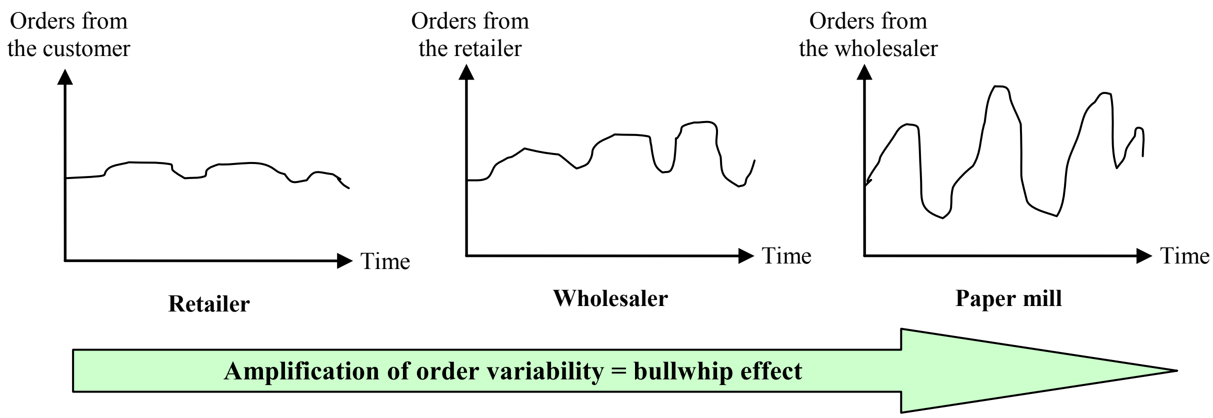


Figure 20: Illustration of the bullwhip effect (Adapted from Moyaux, 2004)

Four factors can trigger a bullwhip effect: demand signal processing, rationing game, order batching and price variations (Lee *et al.*, 1997). Demand signal processing refers to the fact that companies usually plan their operations using orders from downstream stakeholders rather than actual demand from final consumers. Thus, the quantity produced will reflect need plus additional stocks that will tend to increase from one network member to another. The rationing game describes stakeholder behaviour when demand exceeds available capacity. Under a shortage situation, the producer will try to ration the supply of products to satisfy retailer's orders, while the retailer will issue orders in excess of actual demand. Order batching is usually adopted by companies in order to decrease ordering costs, transportation costs, or obtain quantity discounts. Unfortunately, batch orders may not reflect the real needs of the final customer. Price variations mean that buyers will usually prefer to order a larger quantity of products when the price is lower, and then stop ordering for a period of time. In addition, a longer lead time will contribute to increasing the bullwhip effect.

To illustrate this supply chain phenomenon, in the sixties, the Massachusetts Institute of Technology created a game called the Beer game. The purpose of the game is to meet customer demand for cases of beer through a multi-stage supply chain with minimal expenditure on back orders and inventory. Players can see each other's inventory but only one player sees actual customer demand. Moreover, verbal communication between players is against the rules. A debrief session typically follows the game where results are compared and lessons learned are discussed.

The Forac Research Consortium has created a similar game adapted to the forest industry. The Wood Supply Game simulates operations in the forest products supply chain in order to demonstrate the dynamics at work in the value creation network, and show the importance of information sharing among stakeholders. Each game is played with a maximum of seven people, each responsible for the management of one business unit in the network. Each round in the game represents one week. Each game lasts 25 to 50 weeks. The supply chain is represented by different downstream business units: the forest, the sawmill, the paper mill, the distributors and the retailers. The divergent nature of the forest products industry supply chain is simulated by dividing the material produced at the sawmill into chips and lumber (an online version is available at: www.forac.ulaval.ca/en/transfer_activities/wood_supply_game/wood_supply_game_online/).

4.2.2 Data Collection and Information Sharing

In order to decrease the negative effects of asymmetric information such as the bullwhip effect, stakeholders have to share the information required to make planning decisions that will have a positive impact on the value creation network.

Some key information particularly needs to be exchanged:

- **Plan**: includes a set of information defining when, where and how the different activities will be conducted within a business unit or a set of business units. We can differentiate the following plans: sourcing, production, transportation, sales, promotion and return;
- **Order**: specifies a specific need from a specific business unit at a specific time. The orders can be procurement orders, production orders, transportation orders, sales order or return orders;
- **Delivery**: specifies delivery of a specific product or service to a specific business unit at a specific time. The deliveries can provide products/services to a business unit within the supply chain as well as to the end-user or end customer. A delivery can also be a return;
- **Demand plan**: a series of planned orders;
- **Supply plan**: a series of planned deliveries;
- **Capacity plan**: defines the planned availability of the resources and their productivity;
- **Forecast**: anticipation of an order, a delivery or any plan. Usually exchanged when a form of partnership is established;
- **Execution parameters**: a series of parameters defining how the different tasks should be executed;
- **Flow constraints**: a series of constraints defining when and how the flows can be exchanged;
- **Execution updates**: information on how execution really went.

Information can also be exchanged to inform on the status or characteristics of the main element of the value network, in such a case it may relate to the following:

- **Product/service**: defines the characteristics of the product/service;
- **Process**: defines the process in terms of input, resource consumption and outputs;
- **Processor**: defines the characteristics of the processor;

- **Inventory**: defines the number of products held in stock;
- **Facilities/customer**: defines a location.

Another key element that must be considered is the need for **high quality information**. More precisely, the information has to be available "on time", at the right moment, up-to-date and as frequent as necessary in addition to covering all the planning periods (past, present and future). The content of this information is also critical and it must be accurate, significant, complete and concise. Finally, the form of the information is important. It particularly needs to be easy to understand, detailed and correctly presented (via graphs, tables, in narrative form, and so on).

This information, once collected, can be shared among network members by means of established conversation protocols and messages. A conversation protocol links messages to form a conversation. As for messages, they have their own purposes and move from one sender to another or to many receivers. The platform required to support the flows of messages can vary greatly, going from a blackboard where messages are posted, to a direct B2B (Business to Business) exchange.

The aim of an information exchange can be to inform a business unit (or its supporting planning system) of a status or the completion of a task, to request information or the execution of a task, to reply to a request or to modify a previous message. The aim will define the message type.

Each information exchange (message) is also characterized by one sender, one or many receivers, a reference document, its message content and a message type. A message will normally trigger a task flow, which consists of a series of sequenced tasks to be completed in order to take into account the new information or to reply to a request. A task flow may trigger a new message or another task flow, either within a business unit or between units.

Figure 21 illustrates the mechanisms of information flows between business units (or softwares) linking the message, the conservation protocol and the task flow.

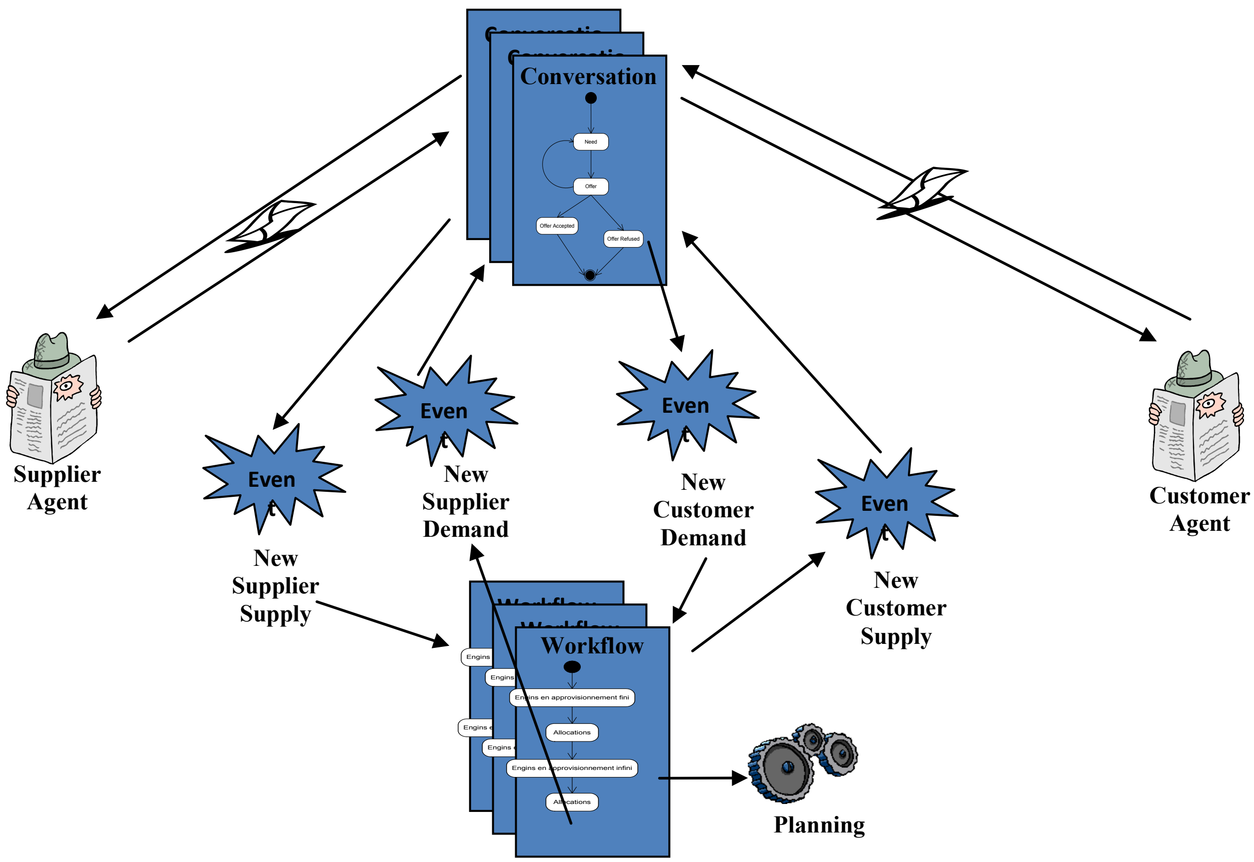


Figure 21: The exchange of information between business units in a value creation network (Frayret *et al.*, 2007)

4.2.3 Use of a Standard for Information Sharing

Since each business unit in the value creation network generally has its own management system with its proper product codes, sharing information between the network members can become very complex. Moreover, companies have their own missions, competences and objectives, and this will greatly influence their choices in terms of information they are willing to exchange.

This is why several standards have been developed in recent years to facilitate communication between companies. For the forest products industry, this initiative was named papiNet.

More precisely, papiNet provides an open standard supporting timely and effective interoperability within the value creation network. The aim is to eliminate the need for negotiating and agreeing on data definitions and formats with each trading business unit, each time a transaction occurs. A common messaging interface enables the business unit to exchange rapidly with many different business units by means of electronic data exchanges technology and to reduce errors in data treatment and exchange. Large corporations such as Stora Enso and International Paper have started using such standards to streamline their network with their main customers.

The *papiNet* standard is based on a set of *XML (*Extensible Markup Language*)* business documents that are needed for the forestry and paper industry. More precisely, *XML* is a general-purpose specification for creating custom markup languages. An XML document marks up every entry with a mnemonic name which is a "generic identifier". Rigorous markup implies that each entry is introduced and closed. Entries are structured in a hierarchical way. The XML standard permits any partner to define a general framework for sharing information (Figure 22).

```
<recipe name="bread" prep_time="5 mins" cook_time="3 hours">
<title>Basic bread</title>
<ingredient amount="8" unit="dL">Flour</ingredient>
<ingredient amount="10" unit="grams">Yeast</ingredient>
<ingredient amount="4" unit="dL" state="warm">Water</ingredient>
<ingredient amount="1" unit="teaspoon">Salt</ingredient>
<instructions>
<step>Mix all ingredients together.</step>
<step>Knead thoroughly.</step>
<step>Cover with a cloth, and leave for one hour in warm room.</step>
<step>Knead again.</step>
<step>Place in a bread baking tin.</step>
<step>Cover with a cloth, and leave for one hour in warm room.</step>
<step>Bake in the oven at 180(degrees)C for 30 minutes.</step>
</instructions>
</recipe>
```

Figure 22: Example of an XML script (Wikipedia)

Efficient use of XML usually requires a Document Type Definition. This document will define the legal building blocks of an XML document, stating its structure with a list of legal elements and attributes. It can be defined within an XML document or be an external reference (For more information on XML, please look up http://www.w3.org/TR/REC-xml/#sec-intro).

Since a series of information can be exchanged to support the advanced planning and scheduling of the wood fibre value creation network, the papiNet standard provides an exhaustive list of specifications and definitions (data definitions) for standardized data and information exchanges. For example, when defining the availability of a product (Figure 23), two pieces of information are mandatory. The first relates to the product itself, its identifier, characteristics and classification. The second relates to the time period over which the product is available. The other elements are optional. This information on the availability of a product is widely used in value chain planning, and provides a means for business units to plan their activities with accurate information on available products.

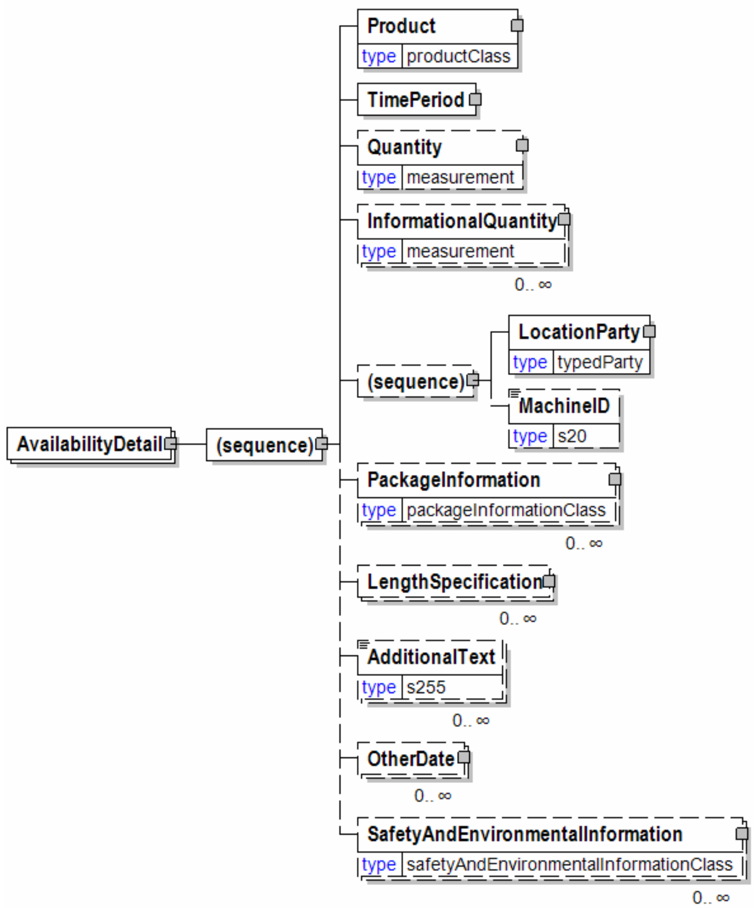


Figure 23: *papiNet* definition of product availability (papiNet.org)

Other examples of information used for value network planning are "Plan" (Figure 24) and "PlanLineItem" (Figure 25). The plan attributes are the planning process type and the language. A plan consists of a sequence of planning header and planning line item. The planning line items really specify what, when and how activities are planned to be executed.

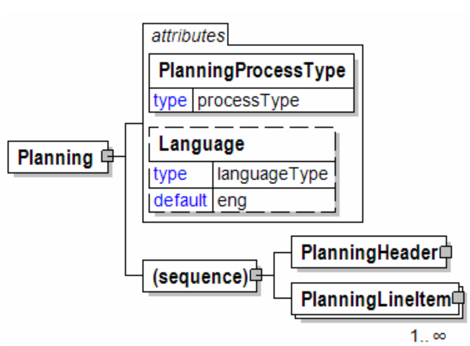


Figure 24: *papiNet* definition of planning

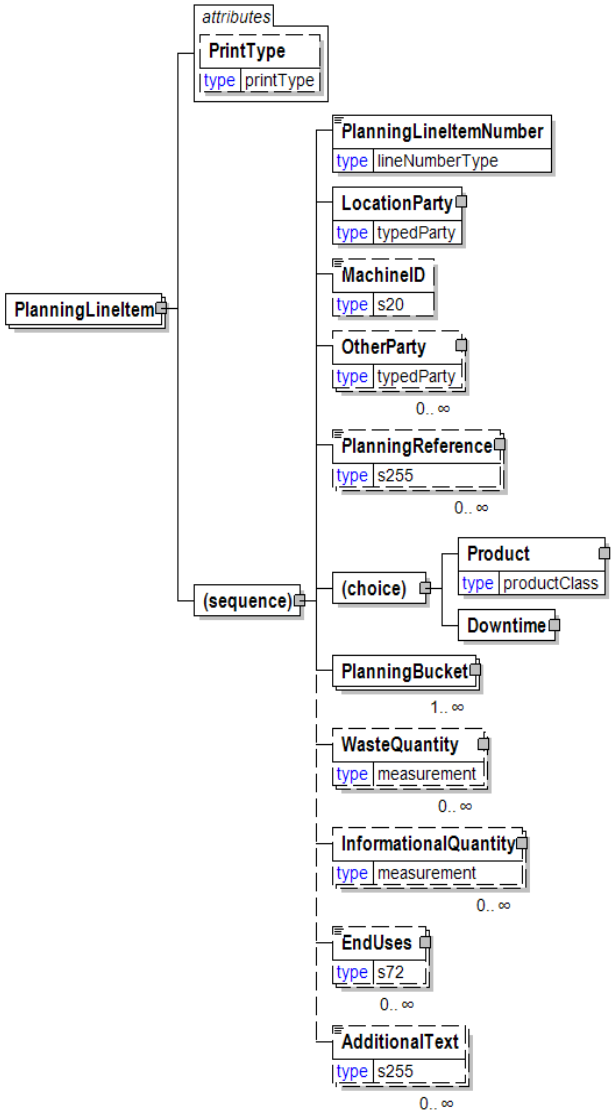


Figure 25: *papiNet* definition of planning line item

The use of a standard such as papiNet therefore contributes to exchanging the right information, at the right time and in a standard form, so that it can easily be processed by the different information systems. Communication among network members improves, as does the quality of planning decisions.

4.2.4 Geographic Information System (GIS)

In recent years, different technologies have been developed to capture the information needed. One of these is the Geographic Information Systems (GIS), also known as Geographical Information Systems, which can be used to capture, store, analyze, manage, and present data that are linked to location. GIS is frequently used in cartography, remote sensing, land surveying, utility management, geography, urban planning, emergency management, navigation, and localized search engines (from Wikipedia free encyclopedia).

Activities carried out on a GIS include:

- The measurement of natural and human-made phenomena and processes from a spatial perspective. These measurements emphasize three types of properties commonly associated with these systems: elements, attributes and relationships;
- The storage of measurements in digital form in a computer database. These measurements are often linked to features on a digital map. The features can be of three types: points, lines or areas (polygons);
- The analysis of collected measurements to produce more data, and to discover new relationships by numerically manipulating and modeling different pieces of data;
- The depiction of measured or analyzed data in some types of display - maps, graphs, lists or summary statistics.

A GIS typically consists of three subsystems, i.e.: an input system for data collection; a computer hardware and software system that store the data, allow for data management and analysis, and can be used to display data manipulations on a computer monitor; and an output system that generates hard copy maps, images, and other types of outputs (from www.physicalgeography.net).

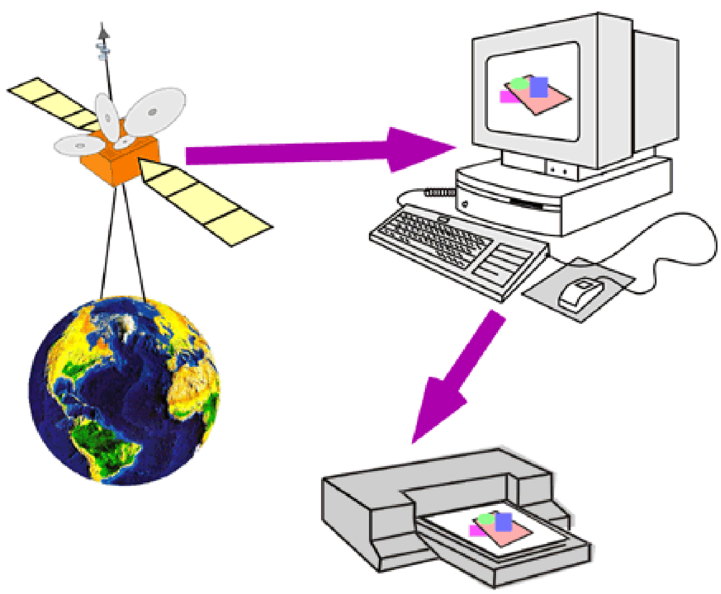


Figure 26: Illustration of GIS components (from www.physicalgeography.net)

In forestry, these systems are increasingly being used to support the decision-making process by capturing real world phenomena and features that have some kind of spatial dimension, e.g.: recording and updating resource inventories; harvest estimation and planning; ecosystem management; landscape and habitat location, etc. (Upadhyay, 2009).

4.3 The Financial Flow

The value creation network also includes a financial flow that represents the set of financial transactions associated with the procurement, production and distribution of goods and services. As for the information flow, the financial flow can move top–down along the chain towards the raw material suppliers or bottom–up towards the end customers. For example, payment will go from a customer to a supplier, whereas credits, returns or guarantees will go from the supplier to the customer. Such a flow is very important for two main reasons. First, it is the medium in which value is delivered from the end-user of products and services back up the value creation network to all stakeholders involved. Second, institutional arrangements, legislative and regulatory requirements and financial compliance frameworks are important exogenous factors that, while substantially affecting the structures, processes, and interactions along the value creation network, are less readily controlled by the network members than the relevant production, logistical and informational arrangements (Fellenz *et al.*, 2007).

It is therefore important to correctly identify what types of financial interactions are accessible over the network. It is also necessary to take into account the risk associated with financial arrangements (e.g., different trading terms, different partners, different transport arrangements, etc.). The higher the risk is, the higher the cost will be. Thus, information on stocks, material flows and historical data on the performance of particular firms will not only facilitate operations management, but also provide a basis for more accurate risk assessment. Reduced operational risk due to process and network optimization leads to lower financial risk, hence reduced financial costs for the firms involved (Fellenz *et al.*, 2007). Another critical aspect of the financial flow relates to the compatibility of transaction systems and integration of operations and technologies. The financial flow is characterized by a multitude of paper documents and verifications that are often duplicated. In addition, each business unit usually generates its own information, which needs to be synchronized and verified by the other network members. Therefore, as for product and information flows, the financial flow needs to be optimized through better integration of activities and the exchange of relevant data.

In the forest products industry, common financial operations vary with the time horizon being considered. From a long-term perspective, investments are made in order to maintain and enhance the competitive position of a company. Insurance programs are implemented as protection against risk and other factors. From a mid-term perspective, companies have to develop a budget to correctly detail variable and fixed costs (including interest), expected revenues and so on. From a short-term perspective, regular activities involve different financial transactions (invoices, payments, credits, etc.).

The financial performance of forest products companies may swing dramatically from one year to the next, and some key elements will reflect their financial health (DBRS).

Fibre cost
The impact of fibre cost depends on a number of factors, such as the type of fibre supply (e.g., harvesting rights, private timberland ownership and purchase contracts); the fibre mix (e.g., softwood versus hardwood, pulp logs versus saw logs and virgin fibre versus recycled fibre); the location of the fibre; etc.

Mill integration and efficiency
A company's cost competitiveness is directly linked to the age of its manufacturing equipment and the degree of energy self-sufficiency its facilities have achieved. Thus, each manufacturing location should be evaluated in terms of capital expenditure requirements, degree of mill upgrade and need for future upgrades, mill energy sources, etc.

Capital intensity
In order to measure a company's ability to decrease operating costs and expand its business, one should evaluate the company's capital expenditure history and its ability to maintain a conservative credit profile; its track record of successfully integrating acquisitions as well as achieving cash flows and synergies; its corporate history of expansions in existing or new geographic areas, etc.

Product development
Since value-added products are generally characterized by lower demand fluctuations and a higher profit margin, a company could be evaluated in terms of its historical success in converting commodity products into value-added products, the percentage of commodity products and specialized products offered, etc.

Currency exchange rate
A geographically dispersed company will be affected by exchange rate fluctuations. As forest products companies export a high percentage of their production, currency exchange rates between the country of manufacture and the country of sale may also have a significant effect on profit margins.

Forest products companies should therefore pay attention to these factors so that financial institutions will be able to offer them the financial tools required to change their way of doing business and tend towards value creation.

5 Modelling a Value Creation Network

To better understand interactions between network members, and analyze problems related to planning, scheduling and decision making, it is generally useful to model the value creation network, thus generating an abstract model that represents the actual system under study (Santa-Eulalia, 2009). The model is meant to provide a simplified representation of a real, complex system by including only the more relevant components. The first step is to identify what parts of the network need to be taken into account. Next, it is essential to determine the right approach or technique to use for modelling and analyzing the system. Then, performance has to be measured to evaluate the added value achievable through a particular scenario or strategy.

Before stepping into system modelling, it is very important to describe what information or knowledge is expected from the model. There are many ways to model various aspects of a value creation network. This effort always supports an objective linked in some way to greater knowledge of some parts of the actual system.

Once the information expected from the model is properly determined, two elements that flow from this determination need to be defined:

- What are the system's boundaries?
- What will the aggregation level and the planning horizon be? (see Table 3)

These elements are unavoidably linked to the main objective identified for the model. The system boundaries are what limit the parts of the real world that is to be modelled. The larger the limits are, the more complex the model is. A balance has to be found between model complexity and model development and implementation time.

The aggregation level and planning horizon also affect model development and implementation time. A great number of details over a long period of time might be useful to gain in-depth knowledge of a system, but the time and information required to run such a model may be impractical.

System modelling implies aggregating information related to products, processes and processors (such as product, time and location) at different levels. For example, a product may be aggregated at the species or family level; time may go from decades down to seconds in some applications; and location may be as general as a given province or a city, or it can be more specific, such as a plant level or even a specific location within a plant. The proper aggregation level depends greatly on the nature of the decisions for which the model is to be used. For example, strategic decisions are based on yearly data. It would be too complex to use low level detailed data to model a system on a multiyear horizon. In addition, such detailed information is either not available or insufficiently accurate. It would be like trying to forecast the exact weather for, say, 60 days: will it rain on such and such a day? If so, how many millimetres are expected? What will the minimum and maximum temperature be that day? Clearly, making an accurate detailed prediction on a long-term horizon is impossible.

Understanding the nature of the decision is important as it may have an impact on how the objects and the processes will be modelled. The table below shows typical aggregation levels for the different topics (product, time, location) depending on the nature of the decisions.

Table 3 : Illustration of aggregation levels for different topics

	Product	Time	Location
Strategic	Families Species	Decades Years	Country Province Region Landscape
Tactic	Families Classes	Year Semesters Weeks	City Facility Management unit
Operational	SKU (Stock-Keeping Unit) Unit	Week Days Hours Seconds	Facility Location within facility Stand

However, aggregating implies disaggregating. While aggregate planning is useful for providing approximate solutions for macro planning, the question is whether these aggregate plans provide any guidance for planning at the lower levels. A disaggregation scheme is a means of taking an aggregate plan and breaking it down to get more plans at lower levels.

Modelling a value creation network also involves modelling two very distinctive classes of elements: components and relationships. The components will be covered in the following section. The modelling of relationships is more complex, and it varies greatly depending on the modelling approach. The different modelling approaches will therefore be described immediately after the section on model components.

5.1 The Components of the Model

The abstract model used to represent a real, complex network usually involves many components. To model the conversion of a product, three components are required: a processor, a product and a production process. The processor is the machine, the human being, the equipment or the production line used to perform the production/conversion work. The product may take different forms as it is transformed along the production line or supply chain. The production process is what ties the processor to the product: it describes how the product will be transformed by the processor. In Figure 27, the gear represents the process which is the link between the product and the processor.

Figure 27 : Product, processor and process

It should be noted that the conversion of a product may involve not only a physical modification, but also a change in location or status. A truck may be a processor and the actual transportation can be seen as a process affecting the product to be moved. An inspection may shift the status of a product from “non-inspected” to “inspected”.

The processors are typically associated with capacity limitations (in terms of throughput, hours available, batch size or time availability) and operating costs, which can be a fixed cost, a cost per unit of time or a cost per batch. Processor parameters may change depending on the process and product they are treating. As for the product, it may influence some characteristics of the processes such as the quantity of resources required and the resulting products, co-products or by-products.

Aside from the product, processor and process trilogy, two other components are very important in modelling the network: supply and demand (Figure 28). Demand is what drives the whole supply chain; it is the main reason for its existence and it essentially dictates what should be produced. On the other hand, supply is often a limiting factor of what can be produced.

Figure 28 : Supply and demand

The following sub-sections describe in more detail the five main components used to model the value creation network. Other elements may have to be represented, such as decision rules and business relationships between the supply chain's partners and facilities. These will be discussed in section 7.

5.1.1 Product

The product modelling method can make the difference between a model that is hard to maintain and implement and one that is easy to use in practice. Because of the many attributes of the product, having a different SKU (Stock-Keeping Unit) for each item is not very convenient. Better modelling of the product involves maintaining each item with its characteristics or attributes. In the lumber industry, such attributes may include the species, grade, length and diameter. In the pulp and paper industry, attributes may be weight, dimension, grade and brightness.

Figure 29 shows how the Attribute Based Products were implemented in FORAC's agent-based simulation and prototyping environment. As shown in the figure, product types are first defined to specify which attributes relate to individual generic products. A specific product (AttributeBasedProduct) is fully defined by its product type and the value for each of the attributes related to it. Although this is not shown in the figure, the attribute's value can be numeric or not. Attributes can also be limited to a given domain value through an enumeration list.

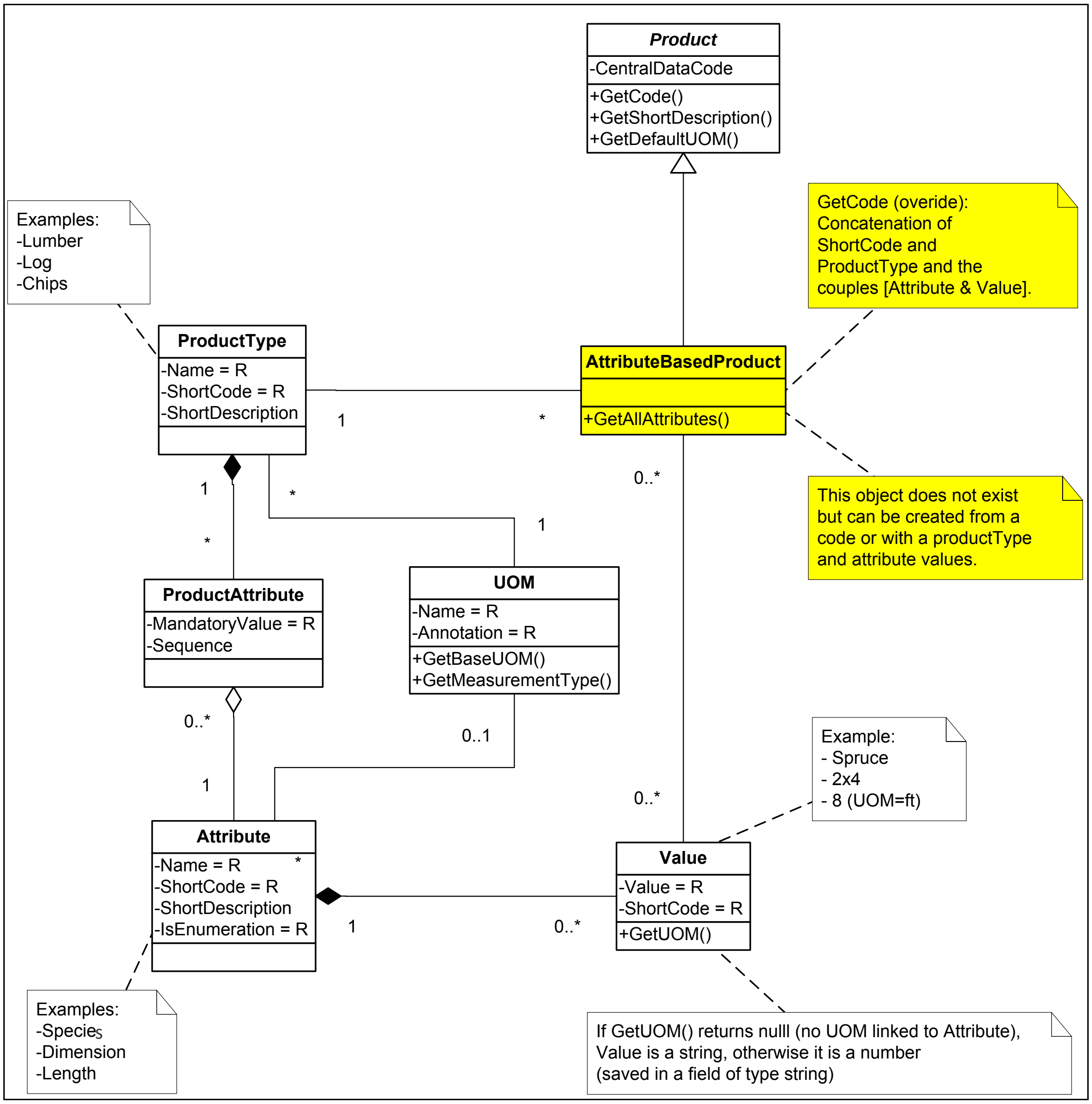


Figure 29 : Products in Forac's agent-based simulation and prototyping environment

5.1.2 Process

A process is an activity that may or may not apply to a product. Examples of processes which do not apply to a product are those taking place in a service oriented organization. We also find such processes in all indirect management activities required to support production and delivery activities. Indirect activities include financial tasks, facility maintenance, purchasing and invoicing, planning and scheduling, etc. In this section, the process will be assumed to apply to the product unless otherwise specified.

In regard to a product-related activity, a production process is an activity which may transform a product, change its status or modify its location within the supply chain. A process typically adds value to a product or is a necessary step in all the activities carried out in creating and supplying a product to the final customer.

Depending on the level of detail to be modelled, some processes may be either ignored or aggregated.

As the product flows through the supply chain, it is transformed and thus its characteristics change. The product entering a production process will be different from that exiting the process. For example, many products may be required in a process to produce a variety of items (Figure 30). A single input can also generate different outputs (Figure 31).

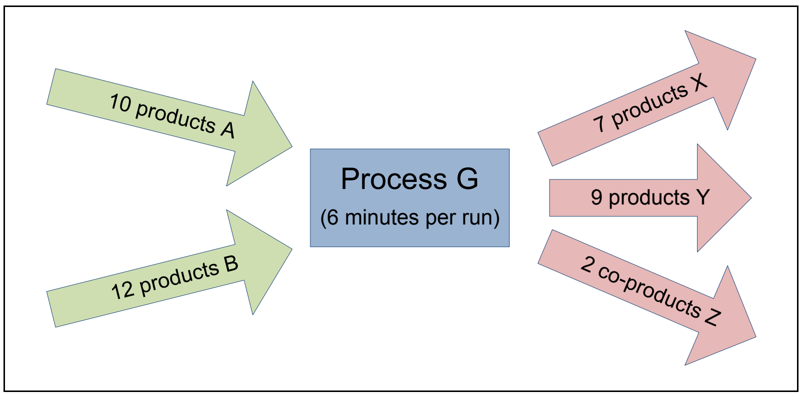


Figure 30: Modelling the production process

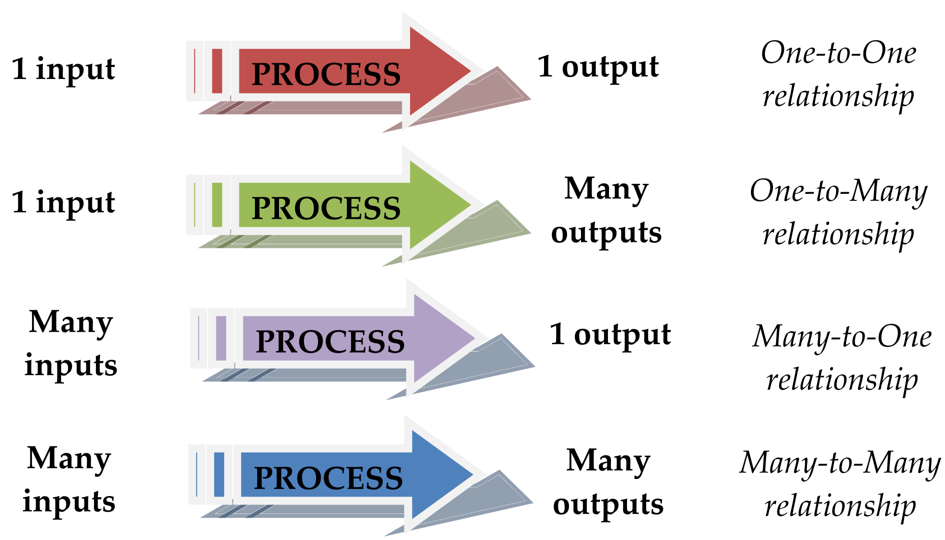


Figure 31: Different types of relationships to model a process

The most common approach to modelling a process involves specifying the quantities of input products as well as the quantities of output products.

The process is not only characterized by the relationship between the volume of the products entering the process and the volume of the products exiting the process. It is also characterized by a production rate which can be defined as the number of times the process can be executed by unit of time with a specific processor, or inversely the time required to execute the process once.

For a given type of operation, sawing for instance, many different processes may be involved. There will be a specific process defined for each different log source, as logs from different sources yield different products and co-products in different proportions.

5.1.3 Processor

The processor is the resource that performs the conversion of the product. Depending on aggregation level, the processor may be a machine, a piece of equipment or a facility. Processors typically have limiting capacity and an operational cost.

Machinery and equipment

Machines and equipment are generally characterized by their capacity, operation time and status. More precisely, a machine can convert one or more raw materials as well as produce one or several finished products. A machine can also keep the original nature of the product intact. For example, a sawmill machine produces several lumber lengths while a paper machine produces only one jumbo roll. In addition, a conveyor moves goods from one location to another without transforming the product. Depending on the product being manufactured, the operation time can be very short (e.g. sawmill machines) or very long (e.g. lumber kiln). The modelling of a machine can also take its status into consideration. Specifically, a machine can be in operation, idle, broken down or not used. The modelling of this parameter can be a good way to analyze the production process and identify which production stage constitutes a bottleneck.

Some machines or equipment may have to be set up. A new setup may be required at every change of product type, or it may be linked to a batch setup, as is the case with the preparation of lumber before it enters the kiln. In the most complex cases, the setup is sequence-dependant, in the sense that the setup time required varies with the sequence of product types entering or passing through a machine or equipment (as is the case with a paper machine).

Machine and equipment capacity

Different types of equipment infer different capacity and constraint modelling. However, at a high level of aggregation, the capacity of the different types of equipment may be modelled in a very similar way, as all equipment, independently of how it works, will transform a certain number of products in a certain amount of time.

For more detailed machine modelling, several different types of processes and characteristics will be considered. For instance, kilns may run for several days with a given batch of products. There is a physical limit to the volume of product that can fit into a kiln. Moreover, with this kind of equipment, not all product types can be mixed in the same batch. To be mixed and dried together, they have to require the same process time under the same conditions (e.g., temperature).

At the sawing stage of a sawmill, we can see another characteristic that is specific to a type of equipment. Depending on the type of logs being processed, setup time may be required to allow for attaining production/managerial objectives. The speed at which the process is run may have an influence on the quality of the product. Sawing may be available for only 80 hours per week if two work shifts are in use, as opposed to kilns, which can operate 24 hours a day once started. To give another example, a paper machine is modelled more like a continuous process and many factors influence the speed at which it will generate paper reels.

Machine and equipment cost

When the production process is modelled in more detail, the cost of the machines and equipment may be considered when it affects production level. The cost may be indicated per hour of use or per volume unit of product processed by the machine. The cost can be an aggregated value for the labour, maintenance, depreciation, and supplies required to run the machine. When a new setup is needed, an associated cost can also be considered.

Facilities

Facilities relate to the premises where the conversion processes take place. They may also be just consolidation or transhipment points. At a high level of aggregation, they can be viewed in a similar fashion to machinery or equipment with operating costs and capacity. In supply chain modelling, the facilities' physical location is of great importance as it impacts transportation costs. In some models, one of the objectives is to find the best location for a given facility. Other decisions which might be considered by a model are whether or not some facilities are to be opened or closed.

Facility capacities

Transfer yards, mills, warehouses and distribution centres are usually represented as having a fixed, limited capacity that can be defined based on the number of working hours, the number of products that can be stored, the space available, and so on. The purpose is to represent actual system parameters, but without being too rigid. Overtime, additional shifts or temporary storage space are some of the factors that can be used to expand capacity (Ballou, 2004).

Facility costs

Costs related to a facility such as a warehouse are usually represented in terms of fixed costs, storage costs and handling costs. Fixed costs refer to costs that do not change with the activity level of the facility, such as real estate taxes, rent and depreciation. Storage costs are those that vary with the amount of product kept in stock in the facility, such as capital tied up in inventory, or insurance on inventory value. Handling costs depend on facility throughput. Typically, they include labour costs, variable handling equipment cost and so on. Mills are also characterized by variable costs obtained from the accounting standard costs for production (Ballou, 2004).

In the modelling of a supply chain's design, other costs may have to be considered, such as the cost of opening a new facility or the cost of closing one down. Other tactical or strategic decisions related to a facility may have an associated cost. Examples of such costs are the cost of increasing the work force for an extra work shift, or the cost of updating the machinery to increase productivity or capacity.

5.1.4 Customer Demand

Customers are (conceptually) located at the end of the supply chain. Depending on the boundary of the system, the customer may be a warehouse, a retailer, a distribution centre or another plant. In modelling the value creation network, the demand does not always have to be at the SKU level, at a specific facility or at a retailer's location. In fact, getting an accurate forecast down at the SKU level for a specific location is very difficult. A more accurate demand forecast is obtainable on the basis of product families over a fairly long period of time (weeks, months, semesters or years) for a given region. The proper aggregation level must be used in regard to the purpose of the model.

The goal of the supply chain is usually to satisfy the customers at the lowest possible cost. Consequently, the objective is to maximize profit in relation to available resources within the supply chain. One of the elements linked to the concept of profit is revenue. In most models, it is assumed that revenues are generated only when a product reaches the final customer. The revenue generated may differ depending on the product, the customer and the time and location of delivery.

Customer location is another characteristic to be modelled, as it will impact delivery cost. Customers may also have restrictions on the hours and days at which deliveries can be made, though these restrictions will typically be considered only by operational planning models. But the most important characteristic is the demand pattern associated with the customer. The demand pattern provides information on the quantity or volume of each product that a customer will expect at each period in time, as well as the price that he is willing to pay for the product. The demand pattern used by the model may be deterministic or stochastic. The demand is said to be deterministic when the model knows in advance what the demand will be in time for each of the demand points. The demand is stochastic when it is randomly generated over time and changes at every model run.

Demand patterns can be quite different depending on the customer's buying behaviour. In the forest products industry, two types of demand patterns can usually be observed: spot market and contract-based demand. Spot market demand is correlated to availability and price while contract-based demand is more stable and correlated to customer consumption rate. In addition, contract-based demand is often constrained by a long-term contract defining annual and periodical demand volumes.

Some models will be strict on customer demand satisfaction. The objective of these models is to minimize the cost of satisfying customer needs (demand). Other models will try to optimize profit, given the maximum demand expected from the different customers.

On a final note, depending on the system's boundaries, the customer in the model may be a partner in the value creation network, or even a facility that is part of a vertically integrated company.

5.1.5 Supply

Supply is what we refer to as the source for the raw material or product that is entering the system being modelled. In more general terms, it is a resource that is available in limited quantity at a specific time, and that is used by some modelled processes. The supply is generally at the boundary of the system being modelled. In terms of the complete value creation network, the supply may be linked to the harvesting plan. When modelling a single pulp mill, the supply may be the amount of wood chips available in time from many different suppliers. When the raw material will come from, wherefrom and in what quantity may be part of a strategic decision made with the help of a supply chain model.

Case study 3: Integrated model for the design of a lumber mill and the selection of a production strategy

The goal of the project conducted by Marier *et al.* (2009) was to evaluate decisions in the design of a Canadian lumber mill and the selection of a production strategy.

A mathematical model was developed in order to select, among many non-exclusive investment possibilities, the combination that would maximize mill profit over a one-year planning horizon. The solution of the model showed the best capacity and log replenishment strategies to be implemented. Specifically, the model generated the aggregate production plan detailing the log volume to be replenished, volume of lumber to be kiln-dried with or without pre-drying, air-dry duration, volume to be subcontracted for drying and volume planed. The model worked on aggregated product families. The facilities, equipment, replenishment strategy and working shifts in use at the mill served as a reference in the assessment of various investments strategies. The possible investment strategies being considered were: 100,000 m3 increase of lumber replenishment potential ; addition of a working shift for sawing and planing; 50% increase of air-drying capacity; addition of a third kiln and replacement of the boiler with a more powerful one.

The results showed that all the investments under consideration should be implemented, except for air-drying and planing, for which no change was recommended. In addition, no subcontracted drying was required, nor was a new boiler. This new solution allowed for an increase of more than 30% in the differential between revenues and costs over the current scenario.

Replenishment	Sawing	Air-drying	Kiln-drying	Subcontracted drying	Planing
-Actual -+ 100 000 m^3	-Actual -3 shifts	-Actual - + 50%	-Actual -+ 1 kiln -+ 1 kiln & new boiler	-Unlimited	-Actual - 2 shifts

Another analysis was performed to verify if a slight increase in planing capacity could lead to further gains. Different planing productivities were added to the planing investment strategies, and the optimal solution suggested increasing planing productivity by 20%, which led to a further 2% financial gain over the previous best solution.

5.2 Specific Components of the Wood Fibre Value Creation Network

The previous section showed the five main components that are to be modelled in any value creation network. This section provides more details on some of the components that can be found in the wood fibre value creation network.

5.2.1 Transportation Activity

Transportation activity is an important component of the value creation network that needs to be adequately represented in terms of transportation modes, capacity and cost.

5.2.1.1 Transportation Mode

Transportation modes are complex resources to model as they may entail many constraints. Unless the system being looked at is limited to a single plant, transportation will have to be considered in most supply chain modelling.

In the forest products industry, three main transportation modes are generally used: truck, rail and ship/ barge. Each of these modes has its own types of constraints.

<u>Trucks</u>

Not every truck is suitable to move a given product. Wood chips need a closed trailer. Some trucks used to transport logs will be fitted with an on-board crane for loading and unloading. Some trucks are multi-purpose so they can be used to transport logs and lumber or chips with only a few quick changes that can be made on the road. Each truck has a specific capacity (volume and weight of products that can be loaded); some trucks are banned from the public road network because of their size. A truck can also be equipped with a Central Tire Inflation system (CTI) that allows an operator to vary tire pressure while the vehicle is moving. A CTI-equipped truck exerts less pressure on the road and better distributes heavy loads. In this way, it is possible to save forestry roads and public highways from damage caused by heavy truck loads while improving productivity (Ross, 2005). Fuel consumption is an important part of transportation costs. Fuel consumption varies with truck type, road condition and load. In some strategic or tactic modelling, an average truck capacity is used and no distinction is made between the different trucks (3 axles, 4 axles, B-train, etc.). At that aggregation level, it is the transport mode that matters, not individual truck characteristics.

Rail

Again, depending on the forest products to be moved, different types of railroad cars can be used and, consequently, different characteristics have to be taken into account in the model. For example, logs and lumber are generally transported in various kinds of flat cars, while pulp, paper and panelboard are transported in boxcars having different configurations. Depending on car design, unloading operations will not be the same (performed by top, end or bottom) (CN). If the mill is not directly connected to a rail line, more than one transportation mode, such as rail and truck, may be required. That is called intermodal. The rail transportation mode is basically chosen for its lower price and the large volume that can be transported over long distances.

Ship/Barge

To deliver Canadian forest products overseas, ships need to be used. The products are placed in twenty- or forty-foot marine containers and loaded onto ships at different ports in Canada and the United States. Lumber, panel, pulp and paper are examples of products that are shipped with this transportation mode. Depending on destination, transit time can vary significantly. Locally, barges are also used to transport forest products. They have an enormous carrying capacity while consuming less energy, since a large number of barges can be moved together in a single tow controlled by only one power unit (Boardman and Malstrom, 1999). However, water transportation service using barges is limited, since it is generally very slow and greatly influenced by the weather.

5.2.1.2 Transportation Capacity

In some models (as in FORAC's mathematical programming model Deliver, see the section on the "Virtual Lumber Case"), transportation capacity is modelled in the same manner for all transportation modes. In that model, lane groups are defined which are sets of lanes or origin/destination pairs (see Figure 32). For each lane group, a limit is set on the number of vehicles of a given transportation mode to flow through that lane group in a given period of time. For example, one could say that no more than 18 rail cars can move on lane group #1 from period 4 to period 6. This modelling is useful in the case of sites constrained by an infrastructure limit.

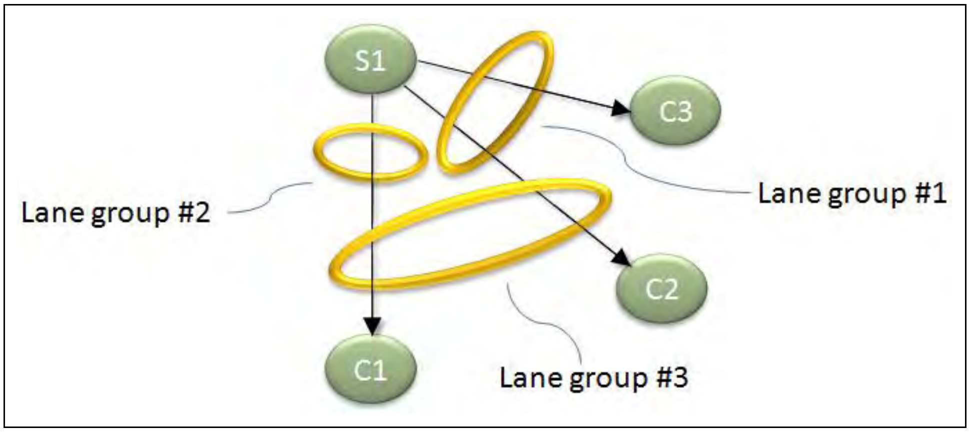


Figure 32: Concept of lane groups, as used in the Deliver model

Being able to model transportation capacity using the number of vehicles entails some conditions: for each mode of transportation (truck, rail, ship, etc.), it has to be possible to determine the quantity of each product that can be moved using each particular transportation mode. In the case of Deliver, a conversion factor is given for each combination (product, transportation mode).

Truck

Some companies may have their own fleet of vehicles, but most of the time, they hire independent truckers. Modelling transportation capacity is thus a challenge, as there is no control or centralized information on which types of trucks are available and when. One way of modelling truck capacity is by estimating the number of vehicles of each type that can be hired in different regions. This methodology was used in the Virtual Transportation Manager (VTM) developed by FPInnovation-Feric and FORAC (Figure 33).

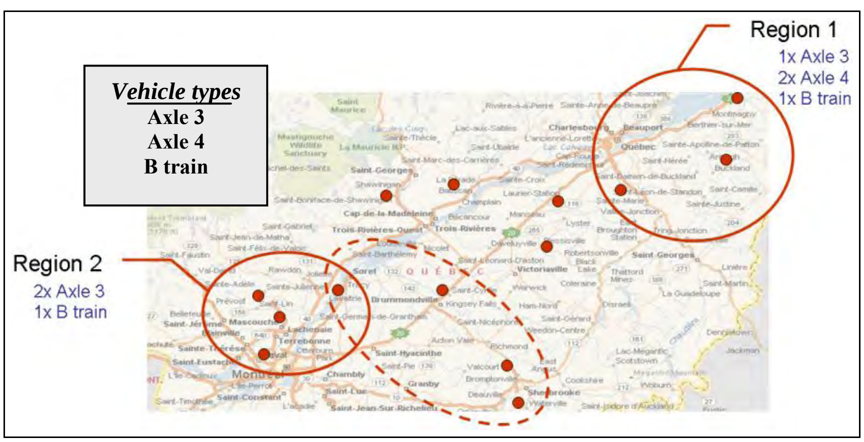


Figure 33: Regional capacity, as defined in VTM

5.2.1.3 Transportation Cost

As with facilities, transportation costs may include fixed and variable costs. Multiple approaches are possible to model truck transportation costs, which vary in complexity. The more detailed approach uses a fixed hourly rate per truck type and a fuel cost that varies according to the vehicle weight and distance travelled. Table 4 shows the fixed hourly costs suggested by FPInnovations-Feric in 2004 for different types of trucks.

Table 4: Fixed hourly rate (in $) for different types of trucks

			Without loading equipment		With loading equipment	
Item	**10 wheeler**	**3-axles**	**4-axles**	**B-train**	**4-axles**	**B-train**
Salary and benefits	22.74	22.74	22.74	22.74	22.74	22.74
Maintenance cost	7.57	10.40	10.90	11.35	13.20	13.65
Ownership cost	10.23	13.03	13.55	14.03	15.54	16.02
Total fixed cost	40.54	46.17	47.19	48.12	51.48	52.41

When the duration of a trip has to be estimated, the truck speed given in Table 5 can be used.

Table 5: Average truck speed (km/h) on different types of road

	Road type				
	Paved	**Primary**	**Secondary**	**Tertiary**	**Operation**
Empty truck	80	75	50	40	20
Loaded truck	75	65	45	35	20

The consumption rate and thus the fuel cost follow linear equations (A + Bx) that express the relationship between vehicle weight and fuel consumption for four classes of roads (Table 6). The equations shown in the table below can be used for both empty and loaded trucks. Origins and slopes for the linear consumption equations have been determined by FPInnovations through many simulations with Otto, their trucking performance prediction tool, on many different Canadian roads, with nine truck types typically used in Canadian forest operations. Based on these equations, an empty 20-ton truck will consume 15 + (1.06 x 20) = 36.2 L/100km on a paved road.

Table 6: Linear equations to compute fuel consumption (L/100km) based on vehicle weight (ton)

Fuel consumption (L/100km)				
	Road type			
	Paved	**Primary**	**Secondary**	**Tertiary**
Origin (A)	15	21	17	11
Slope (B)	1.06	1.10	1.55	2.03

Truck consumption while idling is estimated at 4L/h and 7.5L/h with the onboard loading equipment in operation.

The above approach is useful when the company has its own fleet of vehicles or when no predefined costs are available from carriers. When dealing with carriers, the approach below can be used. Carriers typically have a base transportation rate which is given between origin/destination pairs, and which varies with wood species. That base rate is a cost per ton, based on full truck loads. To account for fuel price, the base rate is then increased by a percentage which varies depending on distance range and transportation mode. That percentage can be updated on a weekly basis. Table 7 gives an example of the percentage increase for fuel over a given week.

Table 7: Percentage increase of fuel cost in the base transportation rate between origins/destinations

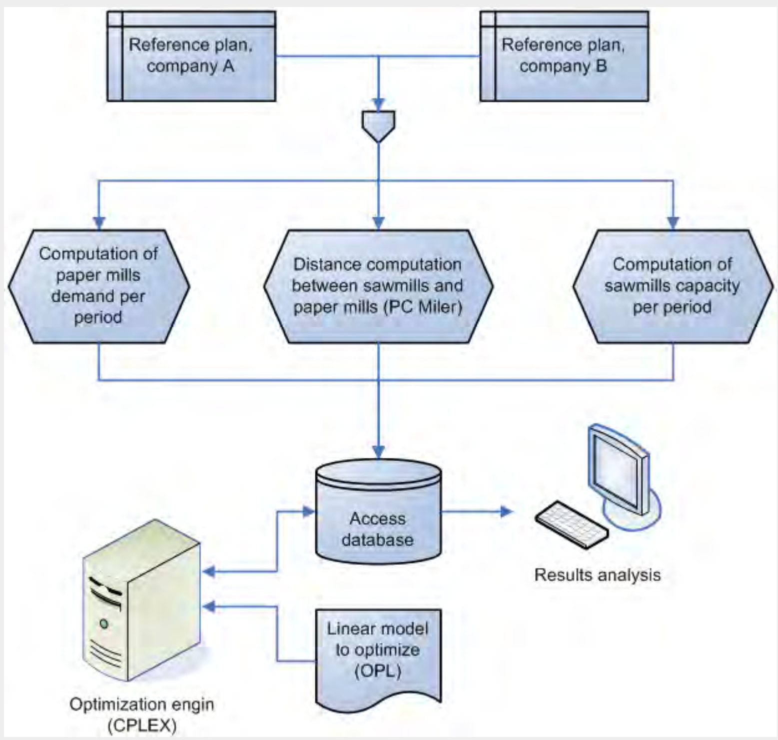
Distance (km)	Rail (%)	Truck (%)
0-150	0.14885	0.2977
150-350	0.19505	0.3901
350 and up	0.24640	0.4928

If, for example, a truck carrier has a base rate of $34.66/metric ton for the transportation of spruce timber between Chibougamau and Beaupré in the province of Quebec, a distance of 388 km, the increase on the base rate for fuel consideration will be 0.4928 x 34.66 = $17.08/metric ton. Hence, the cost per ton to be used will be 34.66 + 17.08 = $51.74/metric ton.

Case study 4: Chip supply in an integrated pulp and paper company

This study conducted by Marier *et al.* (2009) in collaboration with two Canadian pulp and paper companies aimed to explore the gain potential of collaboration through chip sharing.

The chip supply accounts for a large portion of the overall cost of pulp and paper production. The objective was therefore to verify if the transportation cost could be reduced by two companies sharing different species of chips. To achieve this, an integrated planning model minimizing total transportation cost was developed and compared with the individual planning models of the two companies.



The results showed that chip sharing may **reduce transportation cost by more than 5.25%**. In addition, from the total chip volume that could be shared, **12% was shared in the optimal solution, representing 3.3% of total replenishment** for one of the companies and **9.0% for the other**.

A second study was conducted to evaluate the benefits of implementing the optimization tool in actual practice (as opposed to Excel spreadsheets). Initial results are promising but the study is still ongoing.

5.2.2 Key Conversion Processes

Some key wood conversion processes also have to be modelled in more detail.

5.2.2.1 Harvesting Process

Harvesting includes the following main phases (D'Amours *et al.*, 2008). The trees are cut and branches are removed (delimbed). Then, the trees are bucked (or cross-cut) into logs of specific dimensions and quality, either in the forest or in a mill's log yard.

Over the last few decades, numerous harvesting systems have replaced more primitive methods in response to the driving forces prevalent at the time. Equipment is highly mechanized and often multi-functional (Industry Canada). While the full-tree (tree-length) harvesting system is in competition with the shortwood (cut-to-length) system in eastern and central Canada, harvesting operations in British Columbia and the Prairie Provinces are mainly full-tree. Full-tree harvesting involves the use of tracked feller-bunchers with sawheads, followed by grapple, clambunk or cable skidding, depending on site conditions (Industry Canada). Delimbing and sorting are usually conducted at the roadside. The shortwood method usually involves single-grip harvesters, at-the-stump processors and shortwood forwarders. This is predominantly used in mixed and hardwood forests.

The trees or logs are then transported to mills or to terminals for intermediate storage. Global planning usually combines harvesting and transportation.

5.2.2.2 Bucking Process

Bucking consists in cutting tree stems into shorter logs. Bucking optimization is the process of producing logs from tree stems attaining the highest value (Figure 34). The value of a log is in relation to the products that can be made from it. This is known to a certain degree by the log class, as each class can be associated with a set of final products. There are many ways of classifying logs, but it is typically related to length, diameter and quality.

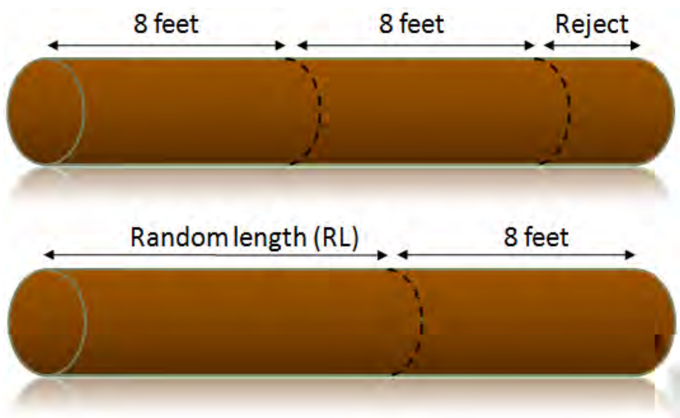


Figure 34: Illustration of two bucking patterns

This activity can be performed in different locations depending on harvesting equipment, and stand or ground characteristics (Beaudoin, 2008). When bucking takes place at the harvesting site, the transportation cost should be taken into consideration, as some sawmills have specialized equipment to process certain classes of logs with high efficiency. The high efficiency machines may produce higher value logs, but the transportation cost to the specialized sawmill may reduce the expected benefit. It is also important to mention that price and demand fluctuations will affect optimum bucking patterns over time.

One of the classical dilemmas in tree bucking optimization is that, in order to achieve the best possible result at the stand level, it is to some extent necessary to compromise on the principle of optimizing individual stems (Uusitalo, 2007).

5.2.2.3 Thinning Process

Thinning is a key activity necessary to improve tree growth rates, species composition, disease and insect resistance, quality of wildlife habitat and so on. This forest management tool also increases a forest's ability to survive wildfire. The removal of selected trees from a stand allows the residual trees to grow faster. As trees in a stand grow, they eventually occupy all the growing space, crowd out lower growing plants, and compete with each other. Unless some of the trees die or are removed, others cannot continue to grow. Thinning removes smaller trees before growth slows and keeps crop trees growing rapidly (Oregon Forest Resources Institute).

A thinning operation can be performed in a number of ways depending on circumstances (see the table below). For example, harvested trees can be removed from the site and used for commercial purposes. This is called commercial thinning. Trees can also be removed or retained on their individual merits. This technique is known as a selective thinning. In addition, thinning that does not yield trees of commercial value and that is usually designed to improve crop spacing is designated as precommercial thinning.

Table 8: Different thinning techniques (National Forestry Database)

Thinning form	Technique description
Chemical	Any thinning in which the unwanted trees are killed by treatment with herbicide
Commercial	Thinning in which harvested trees are removed from the site and used for commercial purposes
Crown	The removal of trees from the dominant and co-dominant crown classes to favour the best trees of those same crown classes
Free	The removal of trees to control stand spacing and favour desired trees using a combination of thinning criteria without regard to crown position
Low	The removal of trees from the lower crown classes to favour those in the upper crown classes
Mechanical	Thinning involving removal of trees in rows or strips, or by using fixed spacing intervals
Precommercial	Thinning that does not yield trees of commercial value, usually designed to improve crop spacing
Row	Thinning in which the trees are cut out in lines or narrow strips at fixed intervals throughout a stand, generally in plantations
Selection	The removal of trees in the dominant crown class in order to favour trees in the lower crown classes
Selective	Thinning in which trees are removed or retained on their individual merits
Spacing	Thinning in which trees at fixed intervals of distance are chosen for retention and all others are cut.

5.2.2.4 Reforestation

Reforestation is the restocking of existing forests and woodlands which have been depleted, with native tree stock. The term reforestation can also refer to afforestation, the process of restoring and recreating areas of woodlands or forest that once existed but were deforested or otherwise removed or destroyed at some point in the past. The resulting forest can provide both ecosystem and resource benefits and has the potential to become a major carbon sink.

There are two types of reforestation, natural and managed. Natural reforestation relies on the natural ability of a forest to rehabilitate itself and may occur without outside influence if the area is left undisturbed. Forest fires are one common natural disaster following which natural reforestation is often allowed to proceed. Managed reforestation is the human assisted replanting of a depleted forest through physical or mechanical planting of seeds, seedlings or juvenile trees.

5.2.2.5 Natural Forest Disturbance Management

Fires and pathogens, including insects and various kinds of diseases, are two disturbances that affect forest ecosystems over large areas. In Canada, millions of hectares of forests are damaged each year by forest pests, resulting in hundreds of millions of dollars of lost revenue to forest-dependent communities and industries. On the other hand, fires and insects are normal components of healthy forests, and are essential to biodiversity. Insects feed birds, and fires create openings, structural diversity and specific habitat elements, such as standing snags and large woody debris that are home to many species of animals, plants, fungi and other organisms (Natural Resources Canada). Therefore, long-term and short-term strategies must be implemented to protect the forest in a healthy manner. Examples of activities included in those strategies are cutting and burning individual infested trees, harvesting stands of susceptible trees before they become infested, creating a wildfire prevention program, etc.

5.2.2.6 Forest Road Design and Construction

Forest roads provide the most important means of accessing forests for timber harvesting, recreation and hiking. Because roads are long-term features, their location must be carefully chosen to avoid long-term maintenance problems, reduce potential for degrading water quality and minimize costs over the short and long term (Wiest, 1998). Planning and location are the most important aspects of road development. The key is to collect as much information as possible on the area to which access is needed, so as to design a road that takes land characteristics into account. Since forest roads cause more erosion than any other aspect of logging (Ochterski, 2004), they have to be built carefully. They are typically classified into three main groups: temporary roads, permanent seasonal roads and permanent all-season roads. Temporary roads are built for short-term use during a specific project such as timber harvesting. These roads are used only when the ground is frozen or firm. Permanent seasonal roads are maintained as part of the permanent road system but are again designed for use only when the ground is frozen or firm. Permanent all-season roads are designed for year-round use. However, there may be some restrictions on use at various times of the year.

Roads must be constructed during the time of year when the best results can be achieved with the least damage to the environment (Oregon.gov). In addition, they require regular inspection and maintenance to ensure safe access.

5.2.2.7 Equipment Movement Process

Equipment movement is another important activity. It is necessary to plan how the different machines will be moved so as to optimize travel time and/or the distance covered, in relation to the area to be harvested, the road network and the location where the equipment is parked. The volume of timber that can be harvested will vary with the type of machine used for harvesting, and equipment capacity must therefore be taken into account.

5.2.2.8 Sawing Process

No two logs yield the same set of products. As shown in Figure 35, for each class of logs there exist several cutting patterns. Depending on the production objective (demand requirement, product value), software is used to determine the best cutting pattern for each log entering the mill (Figure 36) in order to maximize revenue.

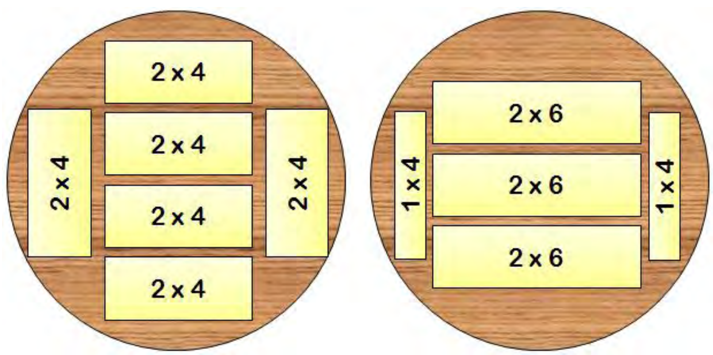


Figure 35: Two sawing patterns for a given log

Log breakdown decisions are critical, as they have a direct impact on mill revenue. Cutting a log solely on the basis of individual product value is not necessarily the best option as the item having the highest market value may not be the one that sells the most, or for which demand is highest.

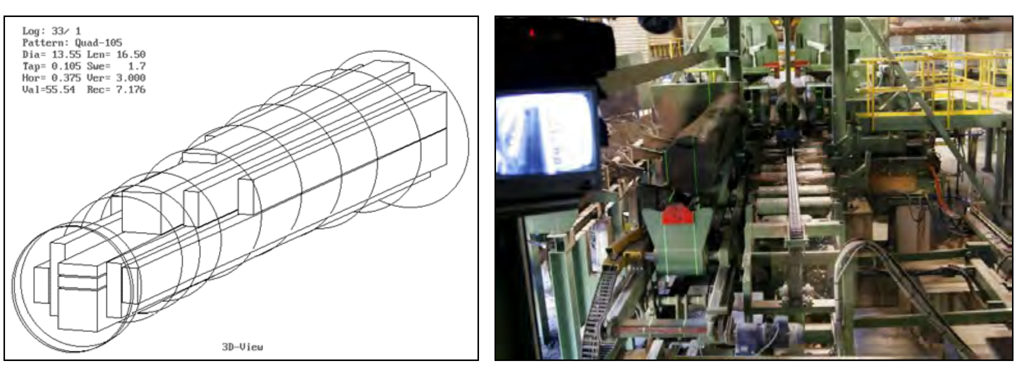


Figure 36: Use of software to determine optimum cutting patterns

Logs can be classified according to size, species and grade. It is possible to statistically determine the set of products which should be produced from a log of a given class. With this information, one can determine which class of logs is best suited to produce a given basket of products. Consequently, if the demand for the mill's products is known, it is possible to select the logs that will best match current demand. In order to feed the mill with the suitable class of logs, the logs must be classified. In Canada, log classification is seldom used and when it is implemented, it is with a low number of classes. By contrast, the Nordic countries have broadly adopted log classification at sawmills, with a number of classes that can be as high as 100.

In modern sawmills, most aspects of the work is computerized with an annual production going from 100 MMfbm and 700 MMfbm (Wikipedia). The sawdust and other mill waste can be sold to plants producing particleboard or related products, pelletized or used to heat wood-drying kilns. Co-generation facilities will produce power for the operation and may also feed surplus energy to the grid. While the bark may be ground for landscaping mulch, it may also be burned for heat. The larger pieces of wood that will not make lumber are chipped into wood chips and provide a source of supply for paper mills. Wood by-products of the mills will also make oriented strand board panels for building construction, a cheaper alternative to plywood.

5.2.2.9 Lumber Drying

Lumber drying is a conversion operation designed to reduce lumber moisture content to a level that meets customer requirements. These requirements are usually specified by industry standards, although some customers may require specific levels of moisture content. Lumber drying is a rather complex batch process that takes a number of hours; it is conducted in large kilns. Under certain circumstances, special sections of the wood yard may be reserved for air drying. Air drying, which precedes kiln drying, may take several weeks but allows for reduced kiln residence time and energy consumption.

In brief, lumber drying can be described as a two-stage conversion process which includes air drying and kiln drying. Each allowed combination of operations (i.e. each path in the graph of Figure 37) defines an alternative process that has a different usage rate of the resources (kilns, air-drying space and energy).

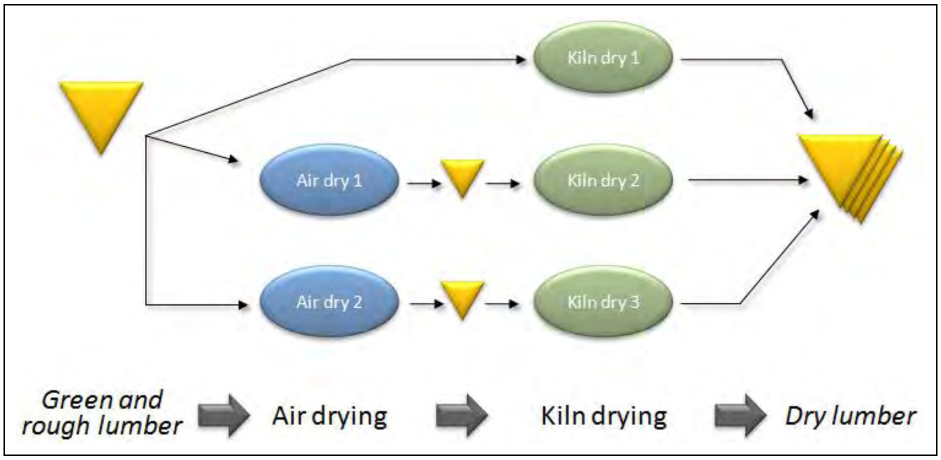


Figure 37: Alternative processes for a specific lot of lumber

For air drying, the different possible operations are mostly differentiated on the basis of duration. For kiln operations, they differ according to air temperature, humidity parameters and duration. These parameters define a "kiln program". Each kiln program may be considered a distinct operation. The air drying operation has an impact on the kiln program, as the lumber moisture content varies with the duration and condition of the preceding air drying operation. The main impact is a reduction in kiln drying time, hence lower energy consumption.

Each kiln program entails a different level of energy consumption, and a lumber mill may have different kilns characterized by their size and drying technology. Adding an air drying operation to the process makes it much more difficult to find the best drying alternative in view of the availability of green lumber and the dry lumber planing schedule. Despite the additional complexity involved in planning mixed drying operations, rising energy costs and the low efficiency of traditional kilns make it very attractive for the mills to consider a combination of air and kiln drying. Another trend is for the kilns to use wood residue, whereas many kilns still rely on electricity and natural gas as their energy source.

Modelling kiln drying capacity

For a given piece of green rough lumber, kiln drying will be done in one of the many, and possibly different, kilns available at a typical sawmill. From a strategic or tactical point of view, it is irrelevant which kiln will be used and at what time of day in a given week. What matters is that, overall, the company does not plan to kiln-dry more wood than physically possible at the facility. At that level of aggregation, the kiln drying capacity per period is simply the sum of individual kiln capacities. The capacity of each kiln is given by the volume of wood which can be dried in one batch (in Mfbm), multiplied by the number of hours the kiln is available in the period. The capacity of a given kiln may vary from period to period, depending on its capacity to be operated during cold weather.

5.2.2.10 Lumber Planing

Once the lumber is dried, it can go through a planing operation that gives it the desired thickness and surface finish. The width and length can also be adjusted at this stage and final grading decisions are made. The cycle time of this operation may be determined by the speed of the planer, which also has an impact on the quality of the planed lumber.

Planing can be performed on green as well as dry lumber, but the latter is more common. The operation generally takes place on the sawmill site, but it may have to be performed elsewhere if planer mill capacity is insufficient.

As illustrated in Figure 38, this process can produce several final products. Each rough piece of lumber is optimized based on its defects. It may be ripped into two pieces, or crosscut if trimming can remove a defect to increase its market value. Because a large quantity of lumber is produced every day, it is possible to model the output of the process as a percentage expressing expected output distribution in terms of lumber final characteristics.

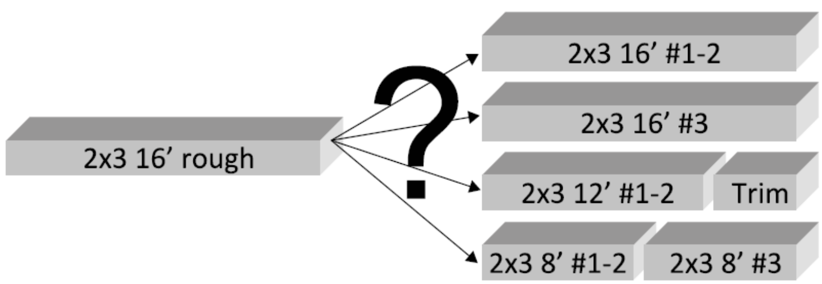


Figure 38: Example of possible outputs from a rough lumber piece

5.2.2.11 Panel Production

The raw materials required for OSB production are wood strands, resin and wax. OSB panels are typically produced in 4' x 8' sizes, and they are available in a range of thicknesses and grades. Logs are used as the raw material. The bark, log off-cuts and sawdust are used as fuel for energy. Trim-offs and sawdust from board cutting and trimming are also used as fuel for energy. In the OSB process, the hot press is the key processor that governs production capacity (Figure 39); it typically operates around the clock, throughout the year.

Figure 39: Illustration of hot presses

In a recent research paper, Yan Feng *et al.* (2008) described the OSB production process: “In the production line, the wood logs of different species are fed into the system according to specific proportions. These logs are debarked and stranded. The wood strands are separated into two streams of face and core materials that are dried to different moisture content specifications. The dried wood strands are mixed with wax and different resins, in liquid and powder forms, specially formulated for using in the face and core layers. The mixture of the wood strands is then formed into mattresses that are pressed under high temperature and pressure in the hot press to produce well bonded and consolidated structural panels. In each pressing cycle, a batch of full press load panels of the same product family must be produced. These panels are then cut into different sizes, packed and stored. Each product family has specific physical and mechanical properties as well as jumbo panel dimensions. As a result, each product family requires a unique quantity mix of raw materials and is produced based on a defined pressing sequence and cycle time. A change of product family from one to another requires a setup time which varies depending on the sequence by which the products are processed. From each product family, depending on the cutting pattern used, different cut-to-size panels (product items, Figure 40) can be produced that are packed and sold to customers in different regions.”.

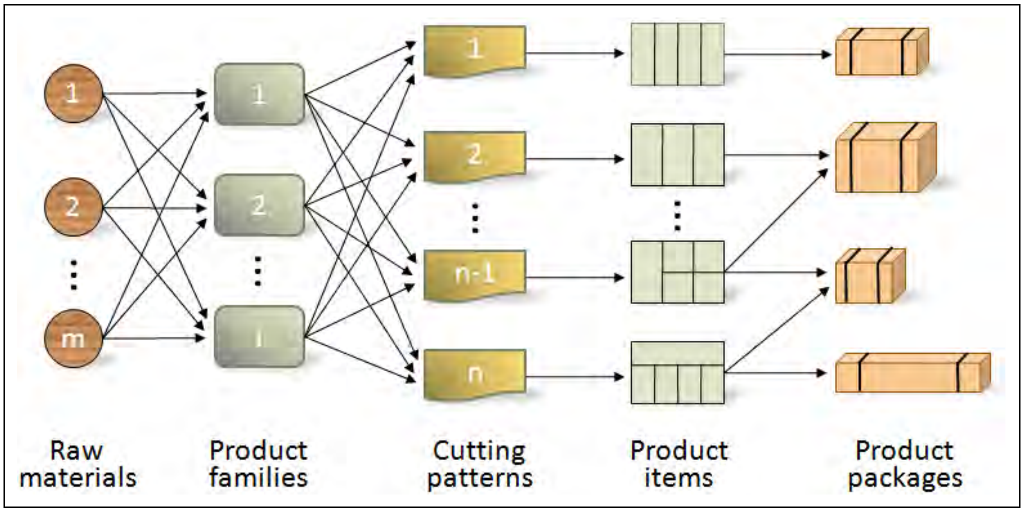


Figure 40: OSB product structure

MDF is a type of fibreboard made from wood or other lignocellulosic materials, refined into fibres and reconstituted with a resin binder (glue), the panel being consolidated under pressure at elevated temperatures. The raw wood material can include almost any wood species and almost any mixture such as low grade wood species, branches, small diameter trees, hardwood, softwood, mill waste and forestry waste chips.

Plywood production requires high-quality logs, called peeler logs, which are generally straighter and larger in diameter than those processed into dimension lumber. The log is peeled into sheets of veneer which are then cut to the desired dimensions, dried, patched, glued together and then consolidated in a press at 140°C (280°F) and 19 MPa (2800 psi) to form the plywood panel. The panel can then be patched, resized, sanded or otherwise refinished, depending on the market for which it is intended (Wikipedia).

5.2.2.12 Pulp Production

The residues of lumber production, together with logs harvested specifically for pulp production, are debarked and usually cut into thin chips before pulping. The chips are then screened to remove undersized and oversized fractions, and pulped to break the woody tissue down into individual fibres. This can be done either chemically or mechanically.

In a mechanical pulp mill, a grinder is used to refine the chips. If the wood is ground in a pressurized, sealed grinder, the pulp is considered pressure groundwood (PGW) pulp. If the chips are just ground with refiner plates (ridged metal discs), the pulp is called refiner mechanical pulp (RMP). If the chips are steamed while being refined, the pulp is called thermomechanical pulp (TMP). Steam treatment significantly reduces the total energy needed to make the pulp and decrease fibre damage (cutting).

Chemical pulping processes such as the kraft (or sulfate) process remove much of the hemicelluloses and lignin. They use a combination of high temperature and alkaline (kraft) or acidic (sulphite) chemicals to break down the lignin's chemical bonds and recover the cellulose.

Each pulp and paper product has a unique set of potential production recipes which define the set of product inputs (chips and other non-fibre supply), the amount of each input, and the production system used to produce a specific grade of pulp or paper. Each recipe is associated with a unique output product. In practice, a set of viable production recipes would be established for each pulp and paper grade based on the fibre properties of the inputs and the relationships between such properties and processing requirements. These recipes would also be constrained by the quality requirements of the output product. In the modelling of a pulp mill, the model would select those recipes that maximize value creation, given the demand for individual products and associated production costs, which may differ from recipe to recipe.

As pulp quality is determined by fibre properties, chip quality and processing conditions (Weigel, 2005), one can see that the nature of the demand does influence the type and grade of chips that should be procured. It is even possible to look further up the value chain at the harvesting, log sorting and chipping systems that would make the chip quality required to meet the demand for the different pulp grades.

5.2.2.13 Paper Sheet Production

Customers can place orders for sheets or rolls of paper with specific characteristics. The paper characteristics are unit weight, finish, colour and brightness. All paper products made from the same jumbo roll will have the same paper characteristics (Figure 41). Given that starting the production of a new jumbo roll with specific characteristics is both time-consuming and costly, production is planned on the basis of sales forecast for the paper grades.

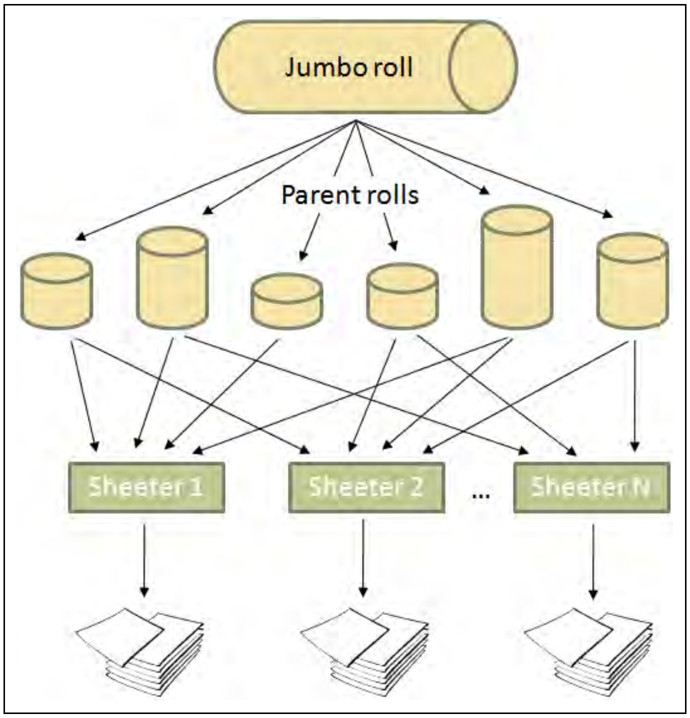


Figure 41: Paper conversion from jumbo roll to sheet (Adapted from Bélanger, 2005)

At the end of the jumbo roll production process, the roll is cut into smaller rolls called parent rolls (see Figure 41). The parent rolls are either shipped to customers or kept in inventory till their use to make sheet. The decision regarding the width of the parent rolls may reflect demand for specific roll widths, sheeter constraints and paper sheet demand forecasts. When a parent roll is cut, a trim is made on each side of the roll to ensure that the edge of the sheets will be straight (Figure 42). Depending on sheet size, the trim may be more or less wide, but as it is waste, parent roll width should be chosen in such a way as to minimize waste. As there is a wide variety of paper sheet sizes and demand is not known very far in advance of delivery time, parent roll sizes to be kept in stock need to be chosen wisely. Inventory costs should also be considered in the decision.

Sheeter production is subject to a double constraint. On the one hand, a given sheeter can only process parent rolls whose width falls within a given range and with a specific core size. On the other hand, a sheeter can only produce sheets of specific sizes. The combination of these two constraints makes the planning of parent roll production a difficult problem.

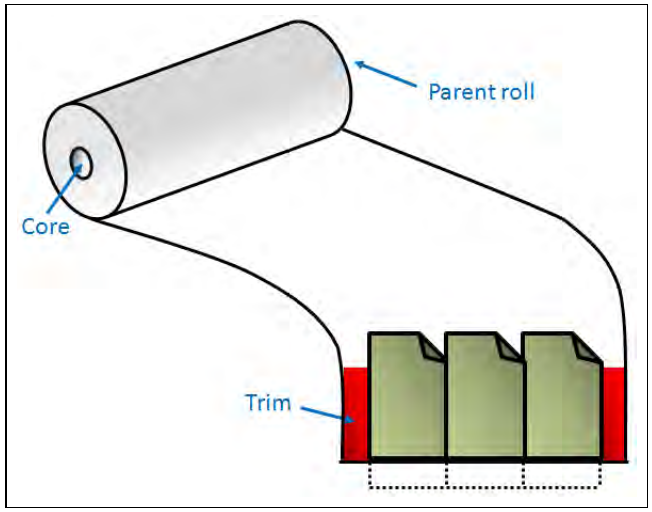


Figure 42: Sheeting of a parent roll (Zoundi, 2006)

5.2.2.14 Paperboard Production (Source: IGGESUND)

Pulp can also be used to produce paperboard (Figure 43). The pulp is first bleached and this can take many forms depending on a number of factors, specifically the degree of colour change required, the choice of chemicals, the method of treatment and whether coloured compounds are removed (delignification) or merely changed in colour. The pulp is next treated in various ways to prepare it for use on the paperboard machine. Afterwards, the fibre suspension in water is "formed" in several even layers on a moving wire or plastic mesh. The combined sheet is then pressed and dried. Depending on the strength required, a starch solution can be applied to the paperboard surface. The sheet can also be passed through a series of nips between steel rollers to improve its smoothness and adjust its thickness. Moreover, a coating process is necessary to achieve the required appearance, colour, smoothness and printing properties. Some paperboard machines incorporate equipment for further surface enhancement by brushing and glazing. The final process on the paperboard machine is to reel up the paperboard in the full machine width to specified reel diameters.

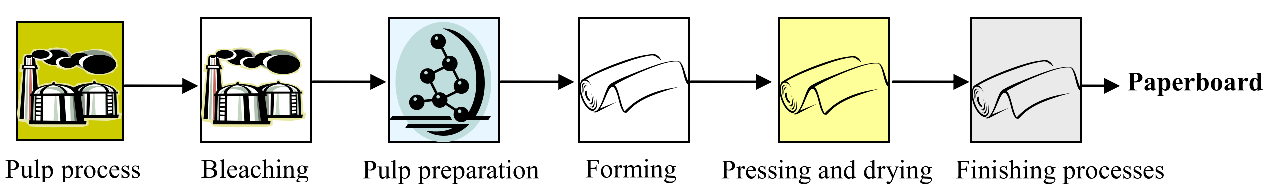


Figure 43: Paperboard production process

5.2.2.15 I-Joist Production

An I-joist is an engineered wood product providing a high level of strength in relation to its size and weight. It is designed to carry heavy loads over long spans while using less lumber than a solid timber joist designed for the same task.

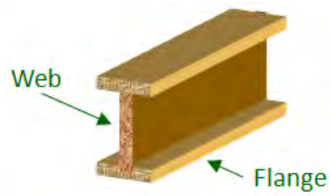


Figure 44: I-Joist components

An I-joist comprises two main parts, the web and the flange (Figure 44). The web is sandwiched between a top and a bottom flange, creating the "I" shape. The flange can be made from laminated veneer lumber (LVL), solid lumber or lumber that has been finger-jointed for improved strength. It is then grooved on one side to receive the web which is typically made of plywood or oriented strand board.

Once cut to the specified widths and lengths, the web and the top and bottom flanges are assembled under pressure with a waterproof adhesive (Figure 45). After initial assembly, the I-joist is end-trimmed and allowed to cure in an oven at room temperature to approximately equilibrium moisture content.

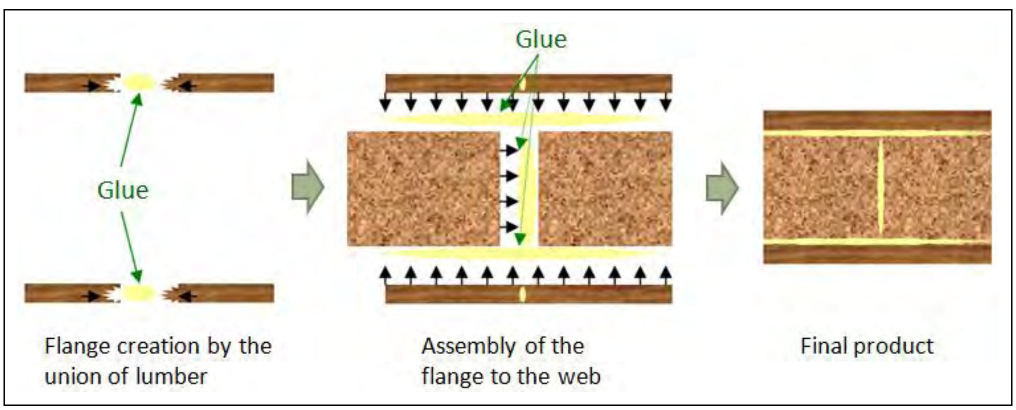


Figure 45: I-Joist production (Louazel, 2006)

I_joists are manufactured in different sizes in relation to intended loads and spans. Their depths can range from 9¼ inches to 24 inches and lengths can go up to 80 feet. I-joists are meant for use as floor joists and roof rafters in both residential and commercial construction.

5.2.2.16 Biomass Energy Production

Biomass energy may be in solid, liquid or gaseous form, permitting a wide range of applications. At present, the majority of Canada's biomass energy is supplied in solid form (e.g., hog chips, sawdust, pellets, charcoal, garbage), and in liquid form (e.g., pulping liquors and ethanol). Other liquid forms of biomass energy include methanol (wood alcohol) and vegetable oils.

Biomass can be burned directly to produce heat and/or electricity, or it can be converted biochemically, catalytically or thermally to produce liquid fuels (such as ethanol and renewable diesel fuel). It can be digested or gasified to produce gaseous fuel; or pyrolized to produce pyrolysis oils and high value chemicals.

Different conversion technologies exist to convert different sources of biomass into different forms of biomass energy (Table 9). CanmetEnergy (a Canadian leader in clean energy research and technology development) mainly studies thermal and thermochemical as well as biological and biochemical technologies. The table below shows the different uses of these technologies.

Table 9: Use of biomass energy conversion technologies (Canmet Energy)

Thermal and Thermochemical Technologies	*Combustion* — convert forestry, agricultural and municipal residues into heat and power under environmentally sound conditions *Gasification* — convert forestry, agricultural and municipal residues into syngas *Pyrolysis* — convert forestry and agricultural residues into bio-oils and value-added products *Thermal and Catalytic Processing* — convert a variety of new and used vegetable oils; tall oils; waste greases and animal fats into renewable diesel fuels and diesel blending stocks
Biological and Biochemical Technologies	*Fermentation* — convert the starch and cellulose components of biomass to bio-ethanol *Anaerobic Digestion* — convert manures, food processing and municipal wastes into methane rich biogas

The most widely used technology is combustion, which converts biomass into heat and power.

Case study 5: Maximizing profit through sawmill specialization and supply chain design

In this case study conducted by Marier *et al.* (2009), a large forest products company wanted to explore whether it would be more profitable to specialize the planing equipment of some of its sawmills in order to process specific lumber products more efficiently.

The company owned many mills in the Lac Saint-Jean area in the Province of Quebec. Some of these mills only had the equipment required to saw logs. Others only had the equipment required to dry lumber, and yet others were equipped to saw, dry and plane lumber. The study included 11 mills, all with different processes and capacities. Of these mills, nine were owned by the company, one was a supplying partner that only performed the sawing operation, and one was a service provider for the drying and planing operations. An optimization tool was thus developed in order to optimally allocate the rough green lumber to facilities that could dry it, and the dry lumber to facilities that could plane it. Since it was also possible to modify the planing equipment to improve productivity, another objective was to identify planing specialization to implement at each planing facility.

The optimization model yielded solutions that were compared to existing conditions. In the base case, the network was unable to fully utilize the different mill's capacities; despite an average capacity utilization of 71% for the drying operations and 69% for the planing operations, 9% of the potential product volume could not be processed and sold. By contrast, the optimal solution **successfully processed the full lumber volume potential,** and the **difference between revenues and costs increased by more than 14%**. In addition, the mill's capacity utilization increased by 11% on average, as more lumber was dried and planed. Therefore, no ending inventory or work in process remained in the network at the end of the planning horizon.

5.3 Other Elements to Consider When Modelling a Value Creation Network

The uncertainty factor is another critical element that needs to be taken into account when modelling a value creation network. Given that a value creation network generally includes different types of products (e.g., different demand and price patterns), multiple mills, warehouses and stocking points located all around the world (geographical company dispersion) and several exchanges between business units (e.g., products, information and financial exchanges), many unknown or unpredictable events can considerably disturb the system. This is why it is necessary to correctly identify these problems as well as measure their impact in order to reduce the vulnerability of the value creation network.

5.3.1 Risk and Uncertainty

Risk is one of the main factors to consider when analyzing a value creation network. It can be described as the potential variation of outcomes that can influence the decrease in added value at any activity cell in a chain, where the outcome is described by the volume and quality of goods in any location and time in a supply chain flow (Bogataj and Bogataj, 2007). The sources of risk are multiple and can be classified into five major categories: demand risk, supply risk, process risk, control risk and environmental risk (Figure 46).

Figure 46: Illustration of different sources of risk (DecisionCraft Inc.)

Demand risk relates to potential or actual disturbances to flow of product, information, and financial transactions, emanating from within the network, between the company and the market. Demand risk can be a failure on either the high or low side to accurately accommodate the level of demand (products that are not in demand, shortage, etc.). Supply risk is the upstream equivalent of demand risk. It relates to potential or actual disturbances to the flow of product or information arising from within the network, upstream from the focal company. Therefore, it is risk associated with a company's suppliers, or supplier's suppliers being unable to deliver the materials the company needs to effectively meet its production requirements/demand forecasts (e.g., flow of goods that is not on time). Process risk is associated with production and distribution systems, specifically the possibility that products will not be manufactured on time, in the desired quality and quantity (yield). Control risk is the level of risk that a misstatement will occur and not be detected by the business unit's internal controls as well as ineffective control of the replenishment process. Environmental risk is the risk associated with external and, from the company's perspective, uncontrollable events. It includes weather-related as well as human-related risks. Examples would include port and depot blockades, closure of an entire industrial area due to fire, and events such as earthquake, cyclone, volcanic or terrorist activity.

While companies hold all the cards for day-to-day operations (process and control activities), they cannot dictate the rules of the game for demand, supply and environmental risks. Under all circumstances, however, some strategies can be implemented to mitigate risk. For example, efficient management of inventories can protect from the risk of shortage or deterioration of goods in process, and from final demand exceeding planned final supply. Flexible capacity can contribute to developing the flexibility required to satisfy stochastic demand. The use of different procurement sources can also be a good strategy to decrease dependency on a main supplier, and ensure continuous supply of the material. In addition, it is important to consider different distribution and logistics alternatives so as to react more rapidly when an unpredictable event occurs. Finally, back-up arrangements are another good approach to protect the network against potential risks.

The process involved in modelling and analyzing the value creation network provides a good opportunity to identify:

- What kind of risks can affect the system;
- Which risks are more critical;
- What is the probability of such risks occurring;
- What should be done to decrease risk;
- What are the consequences of these unpredictable events;
- How their impact can be reduced.

Unknown events can occasionally be simulated and different strategies tested to verify whether the value creation network is sufficiently robust to withstand them. This analysis can then be used to recommend actions to implement a modification of the existing design or the establishment of new management strategies.

5.3.2 International Factors

Since forest products companies generally manufacture, stock and sell products from different units located all over the world, they need to take into account several international factors that will influence the structure of their network. For example, duties are based on the flow of goods so they must be considered when products cross international borders. Quantitative restrictions (quotas) on the importation or exportation of particular products have to be taken into account since they contribute to restraining the volume of products exchanged between countries. In addition, other barriers such as local content rules, administrative barriers and ecological constraints can have the same effect. The exchange rate is another key element that considerably affects the activities of companies and this can vary significantly over time (Figure 47). The Canadian forest products industry is very sensitive to this factor, as it exports a large part of its production, particularly to the United States. To mitigate the effects of exchange rate fluctuations, companies seek to redeploy their production-distribution networks globally, thus making themselves less vulnerable to sudden changes in the value of the Canadian dollar (Martel *et al.*, 2006).

Figure 47: Illustration of daily exchange rate fluctuations: U.S. dollar / Canadian dollar for 2007 and 2008 (Martel, 2009)

Because of the geographical dispersion of companies, transfer pricing is another international factor that has to be taken into account (see section 5.5.1 for a more detailed description of this parameter). Finally, taxes and subsidies usually vary from one country to another, so they will have an influence on location decisions.

5.4 Modelling Approaches

A value creation network is an extremely complex system. With several different companies being linked together, it is not always easy to correctly analyze this system. Moreover, the behaviour of individual network members is not necessary predictable and an unknown or stochastic event occurring at one node of the network can have an impact on all other nodes. In addition, the different organizations usually have different objectives and decision-making processes. Capturing the full complexity of the systems demands an efficient approach to correctly model and analyze the network.

All modelling approaches will make use of the previously described components (product, process, processor, etc.), and then, either find the best way of organizing these components in time and space to attain certain objectives, or apply rules that dictate how these components should interact, and see how the system is behaving.

A number of techniques can be used to represent a complex system, and they can be grouped into three main categories: simulation models, optimization models and artificial intelligence (Figure 48) (Santa-Eulalia, 2009).

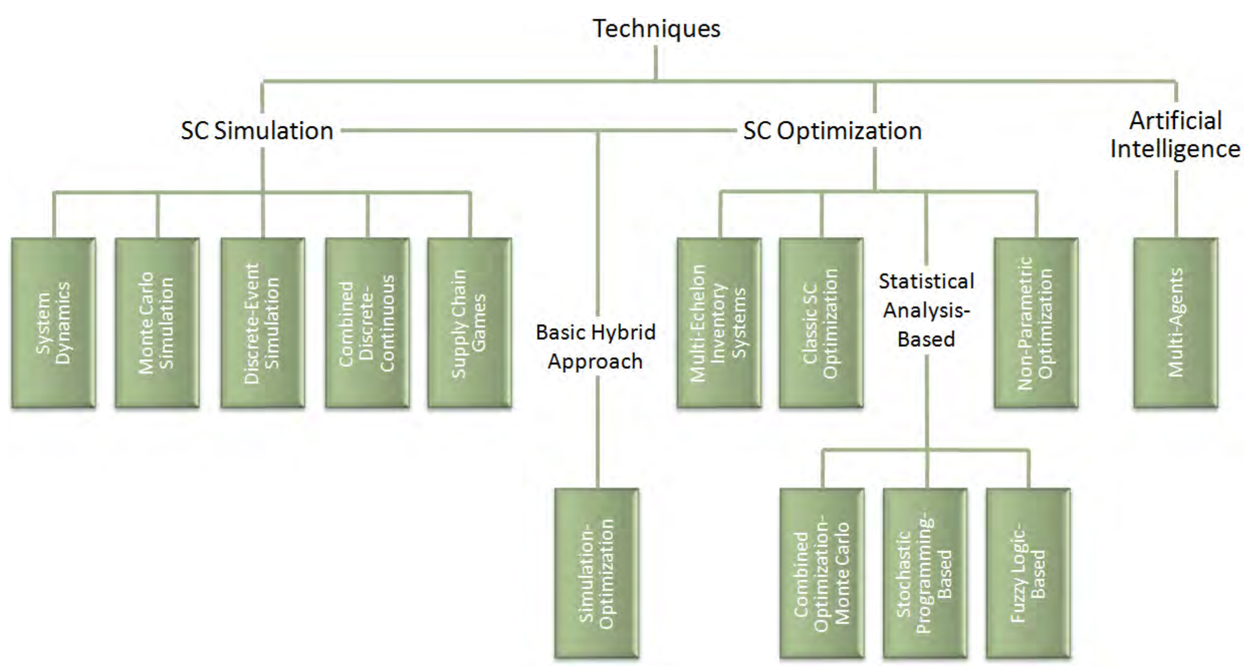


Figure 48: Classification of modelling techniques

5.4.1 Simulation Models

A simulation model can be defined as a mathematical representation of the essential characteristics of a real-world system or situation, which can be used to predict future behaviour under a variety of different conditions (Bnet). The process of developing a simulation model involves defining the situation or system to be analyzed, identifying the associated variables, and describing the relationships between them as accurately as possible.

A simulation model can be deterministic or stochastic. Deterministic simulators are essentially cost calculators, where the values of structural variables such as product flows in a network are given to the model and it in turn calculates the costs, services statistics and other relevant information. On the other hand, stochastic simulators attempt to mimic actual events using probability distributions to represent the uncertainty of events in time, and the level of event variables (Ballou, 2004). Thus, deterministic simulations can be used to evaluate an organization’s actual network design and establish a base case to which future optimized network designs will be compared, while stochastic simulators can be used to show the performance of planning methods, transportation mode selection, customer service policies, etc. A stochastic simulation should be chosen rather than a deterministic simulation when the problem is characterized by stochastic elements (demand, price, etc.).

Simulations models can be used **to address different problems such as**: Where should I build my new warehouse? How many products should I keep in stock to ensure an adequate service level? Which transportation mode should be used to decrease lead times? and so on. Simulations make it possible to capture system dynamics: from probability distribution, the user can model unexpected events in certain areas, and assess the impact of such events on the supply chain. Depending on the problem, a simulator or simulation languages can be used to perform multiple experiments on the model of the system.

5.4.2 Optimization Models

Optimization models are based on specific mathematical formulations and procedures for evaluating alternatives. Their aim is to **guarantee that the optimum or the best alternative has been found to the problem** as proposed mathematically (Ballou, 2004). Thus, with this technique, it is possible to prove mathematically that the resulting solution is the best. However, as problem complexity increases, an optimum solution cannot always be obtained within a reasonable computational time. As a consequence, the level of detail applied to describing the problem must be balanced against the time needed to develop a solution.

Optimization models can be categorized into three groups: multi-echelon inventory systems, classic supply chain optimization and statistical analysis-based methods (Santa-Eulalia, 2009).

Multi-echelon inventory system

A multi echelon inventory system generally deals with the cost and service optimization of warehousing policies at different levels of a supply chain (Santa-Eulalia, 2009). These approaches are derived from the inventory control theory, where specific analytical models are used to derive ideal inventory policies.

Classic supply chain optimization

The classic supply chain optimization is typically used for mill design, production and drying scheduling, logistics of distribution and inventory management. This technique includes mathematical programming (linear, nonlinear, dynamic, integer programming), enumeration, sequencing models, calculus-dominated models, equipment replacement models and heuristics.

Statistical analysis-based method

The statistical analysis-based method can use at least one unknown variable, modelled as a particular probability distribution function (Santa-Eulalia, 2009), or be based on game theory, a mathematical technique commonly used in economic science. It can be useful to analyze the impact of enterprise behaviours as well as the importance of information sharing. Some other methods can also be included in this category, such as stochastic programming-based approaches and fuzzy logic-based methods.

5.4.3 Mathematical Programming Example

A simple example will give a better idea of what constitutes an objective function, a constraint and a decision variable. Let us assume that we have a network of warehouses which supplies vendors (Figure 49) and we want to determine what quantity of a given item should be supplied from which warehouse to which vendor in order to minimize supply costs. Warehouses have limited supply capacity but can supply any of the vendors.

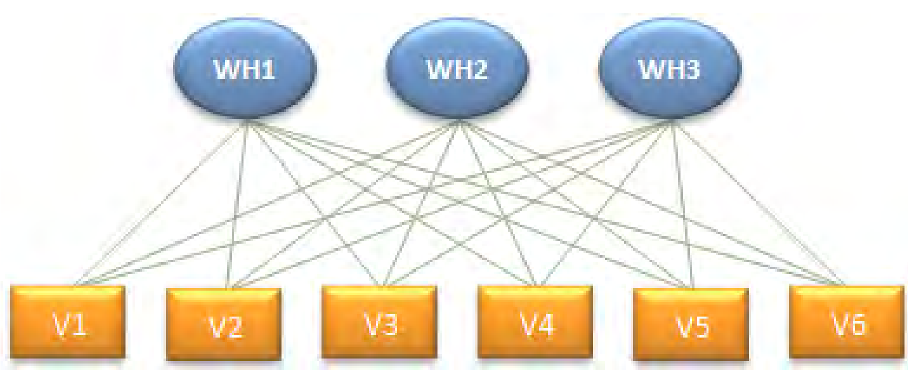


Figure 49: Network of warehouses supplying vendors

To describe our problem mathematically, we need to define some parameters and variables. We will start with what is known. Let S_w be the supply capacity of items at warehouse w and let D_v be the item demand from vendor v. Also, let T_{wv} be the transportation (supply) cost of one item from warehouse w to vendor v.

The decision variables are what we do not know, what we are looking for. In our problem, we want to determine, for each vendor v, how many items will be supplied from each warehouse w. We will call this value x_{wv}.

This is all the information we need to write the objective function and the constraints. As stated before, we want to minimize the supply cost of items to the vendors. The supply cost can be expressed as the sum (Σ), for all warehouse/vendor combinations, of the number of items supplied, multiplied by the unit transportation cost from that warehouse to that vendor. Mathematically, this objective function can be expressed as follows:

$$Minimize \sum_{w \in W, v \in V} (T_{wv} x_{wv})$$

Two sets of constraints emerge from the model. The first one expresses the fact that no warehouse can supply more items than its capacity. Said differently, the sum of all the shipments from a given warehouse w should be equal to or less than the quantity available at that warehouse (S_w). So, for each warehouse w in the set of all warehouses W, there will be one constraint of the form:

$$\sum_{v \in V} x_{wv} \leq S_w \quad \forall w \in W$$

Note: "$\forall\ w \in W$" reads for each warehouse w in the set of all warehouses W.

The second set of constraints guarantees that each vendor will get its required amount of items, wherever they come from. So for each vendor v in the set of all vendors V, there will be one constraint of the form:

$$\sum_{w \in W} x_{wv} = D_v \quad \forall v \in V$$

The mathematical model can also allow for minimum or maximum values in the decision variables. In our example, the number of items that are shipped from one warehouse to a vendor cannot be negative. Hence:

$$x_{wv} \geq 0 \ \ \forall w \in W, \forall v \in V$$

In summary, we get the following mathematical formulation:

$$\text{Minimize} \sum_{w \in W, v \in V} (T_{wv} x_{wv})$$

$$\text{subject to}$$

$$\sum_{v \in V} x_{wv} \leq S_w \quad \forall w \in W$$

$$\sum_{w \in W} x_{wv} = D_v \quad \forall v \in V$$

$$x_{wv} \geq 0 \;\; \forall w \in W, \forall v \in V$$

5.4.4 Artificial Intelligence

Artificial intelligence is an advanced technique used to solve problems that are difficult, or simply impractical, for a monolithic model to solve (Santa-Eulalia, 2009). It refers to the branch of computer science concerned with making computers behave like humans. The term was coined in 1956 by John McCarthy at the Massachusetts Institute of Technology (Webopedia). Artificial intelligence includes, among other things, robotics, neural networks and agent-based systems. With these advanced approaches, it is possible to **solve problems at an expert level by utilizing the knowledge and problem solving logic of human experts**.

From artificial intelligence, multi-agent-based systems use learning aspects, social capabilities and others. Normally, agents encapsulate one or more techniques from supply chain optimization and supply chain simulation to perform their activities, but they usually go beyond by including additional issues, such as negotiation protocols and learning algorithms.

Agent and multi-agent systems

An agent is an abstraction to represent complex entities and it is the main building block to form a multi-agent-based system. The concept may be very popular today, but defining it is not simple since it encompasses concepts from many domains, such as distributed artificial intelligence, distributed computing, social network theory, cognitive science, operational research, etc. One of the most broadly accepted definitions found in the literature may be that offered by Jennings and Wooldridge (1998): "an agent is a computer system situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives". Wooldridge (1998) complements this definition by detailing some properties of agents:

- **Autonomy**: autonomy refers to the capacity to act without the intervention of humans or other systems: they have control over both their own internal state and their behaviour;
- **Reactivity**: agents are situated in an environment. An environment can be the physical world, a user (via a graphical user interface), a collection of other agents, the Internet and, sometimes, many of these elements combined. In addition, agents are able to perceive this environment in order to respond in a timely fashion to changes occurring in the environment;
- **Pro-activeness**: agents do not just act in reaction to their environment; they are able to show goal-directed behaviour in which they can take initiatives;
- **Social ability**: agents interact with other agents, and normally have the ability to engage in social activities (e.g., cooperative problem solving or negotiation) in order to achieve their goals.

The environment of an agent is normally composed of other agents with whom it interacts. These agents together form an agent society or a multi-agent system. This set of agents works together in order to accomplish certain tasks. All of them use their competences and knowledge to strengthen the capacity of solving problems.

Agents use sophisticated interaction schemas that include cooperation capability, coordination capability and negotiation capability. In order to perform their interactions, they have to communicate. Communication makes use of certain mechanisms, mainly:

- **Communication model**: the way in which agents can communicate with each other, identifying information exchange synchronism and the interrelation scheme among agents.
- **Message communication language**: for the definition of a set of performatives and their meaning to support the communication process.
- **Knowledge representation language**: for message content. This type of language establishes conditions to the creation of knowledge databases and allows knowledge manipulation by inference machines. Diverse knowledge has to be represented, such as domain knowledge, knowledge about the environment, self-knowledge, etc.
- **Ontology**: gives semantics to a conversation, i.e., a formal explicit specification of a shared conceptualization.

In the context of supply chains, Operations Research (OR) and agent technology can be combined to capture the complexity of supply chain modelling. OR proposes a mathematical modelling paradigm that can capture the complex relationships between decision variables. In other words, OR recognizes the input/output relationships of a supply chain system, linking these relationships with performance metrics and decision options.

Agents can also be used to model the system's input/output behaviour. When the system becomes too complex, various reactive agents can be used to model several of its parts; together they model the behaviour of the entire system. They can, for instance, model real life entities, including human decision-makers and artificial entities, such as organizational units or functional software modules, in order to capture more complex supply chain behaviours.

As OR proposes a large body of literature to model various supply chain problems, both approaches (agents and OR) can be used together to propose accurate and detailed models of supply chains. The intuitive way to do so is to encapsulate OR models and tools into software agents that represent either planning functions or organizational units. These models and tools are then used to model part of the decision-making ability of agents. However, the functional ability to use these tools, according to the situation, still needs to be modelled in the agent (Forget *et al.*, 2008).

Over the last few years, FORAC has developed such an agent-based planning and simulation environment. This platform aims to address the ability to plan and coordinate operations throughout the supply chain, and the ability to analyze the dynamics and simulate different supply chain scenarios through simulation. It allows the user to evaluate and compare different planning models, coordination mechanisms or supply chain configurations, according to user specified performance measures (Frayret *et al.*, 2007).

5.4.5 Decision Support Systems (DSS)

All the techniques described above may appear somewhat complicated and difficult to put into practice. Yet they are routinely incorporated into information systems to analyze and organize data as well as assist users with important decisions (Ballou, 2004).

Such systems are called Decision Support Systems and they can be defined as computer-based systems designed to provide assistance in determining and evaluating alternative courses of action. A DSS acquires data from the mass of transactions and operations of an organization, analyzes it with advanced statistical techniques to extract meaningful information, and narrows down the range of choices by applying different rules. Its objective is to facilitate "what if" analyses rather than replacing managerial judgment (adapted from www.businessdictionary.com). Data analysis procedures can also take the form of optimizing procedures. In a well-designed decision support system, the user can first use the tool to obtain an initial answer, and then interact with the system to provide his inputs in order to generate a more practical solution to the problem than that suggested by the optimizing procedure alone. Systems of this type are developed to support decisions relating to inventory management, harvest scheduling, production planning, routing and dispatching, and so on.

5.5 Performance Measurement

After modelling and testing different scenarios for a specific system, one needs to evaluate their performance. The impact of using various planning techniques, changing transportation modes, offering a complex set of products, etc., needs to be measured to verify whether or not the changes actually create value for the system.

5.5.1 The Concept of Value

"Value-added" refers to a process or operation that increases the worth of a good or service as perceived by the internal or external customer, as opposed to an operation that may simply incur costs due to the performance of an activity. In determining the value of a product, customers take into account all of the benefits derived from the product and compare these to all of the costs of that product. If, in their opinion, the benefits exceed the costs, then they perceive value in the product. Therefore, one of the goals in the development of an operation strategy should be to maximize the value added to the goods and services that are provided by companies (Figure 50).

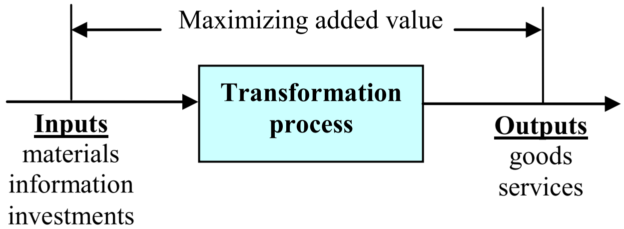


Figure 50: Maximizing added value in operations

Adding value can take various forms depending on the type of product or service proposed. For example, it can consist of reducing the sales price (by improving the production and distribution system), increasing the availability of the product (based on an efficient replenishment method), decreasing delivery time (by changing the planning strategy or transportation mode), improving after-sale service (by proposing product return policies, controlling the inventory management process, etc.), customizing products (adapted to customers' needs), etc. (Davis *et al.*, 2007). The economic measure of value added therefore needs to consider the different costs involved in the conversion process as well as the revenue obtained from sales, including the price customers are willing to pay for the product or service (see equation below).

ECONOMIC VALUE ADDED (EVA) = **(1-tax) x (revenues – costs) – (capital cost x capital used)**

In this mathematical formulation, different costs need to be taken into account. First, some costs are associated to the use of space. For example, the cost of stocking products can vary with the inventory level maintained by the company. There is also a cost when the stock and the products manufactured are not sufficient to satisfy demand. Although lost sales and late deliveries are sometimes difficult to evaluate, they have to be estimated, as they have a considerable effect on the system. The movement of products between business units also entails significant costs.

Depending on the transportation mode chosen, different fixed and variable costs will be generated. The movement of goods within a business unit involves an expense. And the procurement and production of goods further entail costs. For example, processing an order involves an ordering cost (order form preparation, order tracking, etc.), while production initiation leads to a setup cost. A cost is also associated to the procurement of raw materials or products (buying cost), and it can include different quantity discounts and rebates. In addition, the production of an item generates a significant cost that will increase with the volume manufactured. Table 10 summarizes these different costs.

Table 10: Logistic costs to be considered in the analysis of added value

Cost category	Cost type
Related to the use of space	Handling cost Lost sales/Late deliveries cost Transportation cost Inventory cost
Related to the procurement and production of items	Ordering cost Setup cost Production cost Buying cost

The revenues include all sales to customers, as well as transfer pricing. Transfer pricing refers to the price at which an item is traded across different business units within a company. They are particularly critical when the products are crossing international borders between subsidiaries of a multinational company (Figure 51). Even when the mills are owned by the same company, if they are exchanging products, transfer prices have to be set. These can be very useful for shifting profits from one subsidiary in a higher-tax country to another located in a lower-tax country, thus minimizing global tax liabilities and maximizing global after-tax profits (Martel *et al.*, 2006).

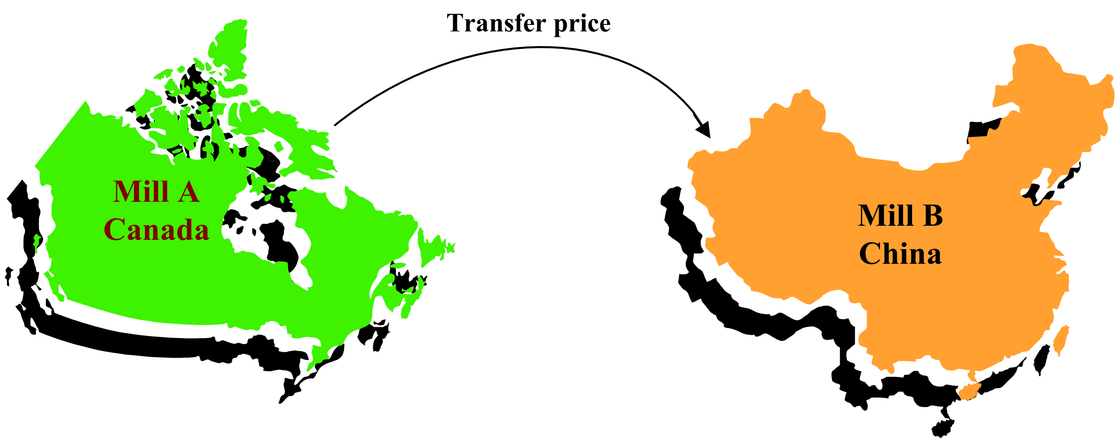


Figure 51: Illustration of transfer pricing

The capital cost is a return that providers of capital expect to earn on their investment. For an investment to be worthwhile, the expected return on capital must be greater than the cost of capital. Specifically, the risk-adjusted return on capital (that is, incorporating not just the projected returns, but the probabilities of those projections) must be higher than the cost of capital (Wikipedia).

5.5.2 Key Performance Indicators

The performance of models can also be measured using key performance indicators. It is a way to determine if the established goals or standards are being met. Indicators can be qualitative (e.g., customer service) or quantitative (e.g., lead time), as well as local (e.g., an individual company) or global (e.g., the value creation network). Indicators are generally grouped into four main categories: volume, time, quality and value. Volume indicators refer to measured quantities, such as inventory size, demand volume, etc. Time indicators are based on moments in time or time periods, specifically when something happens and how long it lasts, such as supplier lead time, throughput time, etc. Quality indicators include the perceived characteristics of product and service features, such as defective products, CO_2 emissions of a given product during its manufacturing process, etc. Value indicators encompass all the financial measures, such as costs, profit and prices.

Among the numerous performance measures available, some of them are more critical:

<u>Profit</u>
The best known measure of the success of a business, it is the surplus remaining after total costs are deducted from total revenue.

$$\text{Profit} = \Sigma\ \text{Revenue} - \Sigma\ \text{Costs}$$

<u>Material yield</u>
This measure associated to the conversion process is commonly used by forest products companies. It can be described as the ratio of the amount of primary product output to the amount of raw material input (typically expressed as a percentage).

$$\text{Material yield} = \frac{\text{Amount of primary product output}}{\text{Amount of raw material input}}$$

$$\text{e.g.: } \frac{\text{Sawn timber output volume}}{\text{Log input volume}}$$

Inventory turnover

The inventory turnover is a measure of how often the company sells and replaces its inventory.

$$\text{Inventory turnover: } \frac{\text{Cost of goods sold}}{\text{Average value of inventory on hand}}$$

Speed/variability of delivery

Refers to the amount of time from when the product is ordered to when it is received by the customer (production + distribution lead times) as well as the variability or uncertainty in delivery time.

Flexibility

Flexibility reflects the ability of a business to provide customized products in a timely manner. This can be measured by evaluating how quickly a process will shift from producing one product to another, or analyzing the plant's ability to react to changes in volume.

Process velocity

Refers to the ratio of the actual time it takes for a product to go through the process, divided by the value-added time required to complete the product.

$$\text{Process velocity} = \frac{\text{Total throughput time}}{\text{Value-added time}}$$

Other commonly-used performance indicators include productivity and capacity utilization. However, these measures do not necessarily reflect the value added to products and services.

In view of the variety of performance measures available, the first step must be to identify what exactly one wants to measure. The next step is to select the right units to express the quantity or quality of what is being studied. Then, the sources of data have to be chosen (Santa-Eulalia, 2009). In this way, it will be possible to determine relevant measures for analyzing the model. Figure 52 illustrates an example of metric clustering developed by the Nike company.

Figure 52: Illustration of metric clustering developed by Nike (Lohman *et al.*, 2004)

6 Management of the Value Creation Network

Efficient management of all operations in a value creation network goes beyond locally optimizing the way each business unit is doing business. It is essential to coordinate activities involving producers, wholesalers, warehouses and retailers, so that merchandise is produced and distributed in the right quantities, to the right locations and at the right time, thus minimizing system-wide costs while satisfying service level requirements. To this end, one needs to adopt a broader perspective and look at the processes involved in managing the production, conversion and transportation processes, as well as the collaboration existing between partners of the value creation network. That is referred to as the business process.

6.1 Business Processes

A business process can be defined as a complex set of activities performed by resources that convert inputs into outputs (Figure 53).

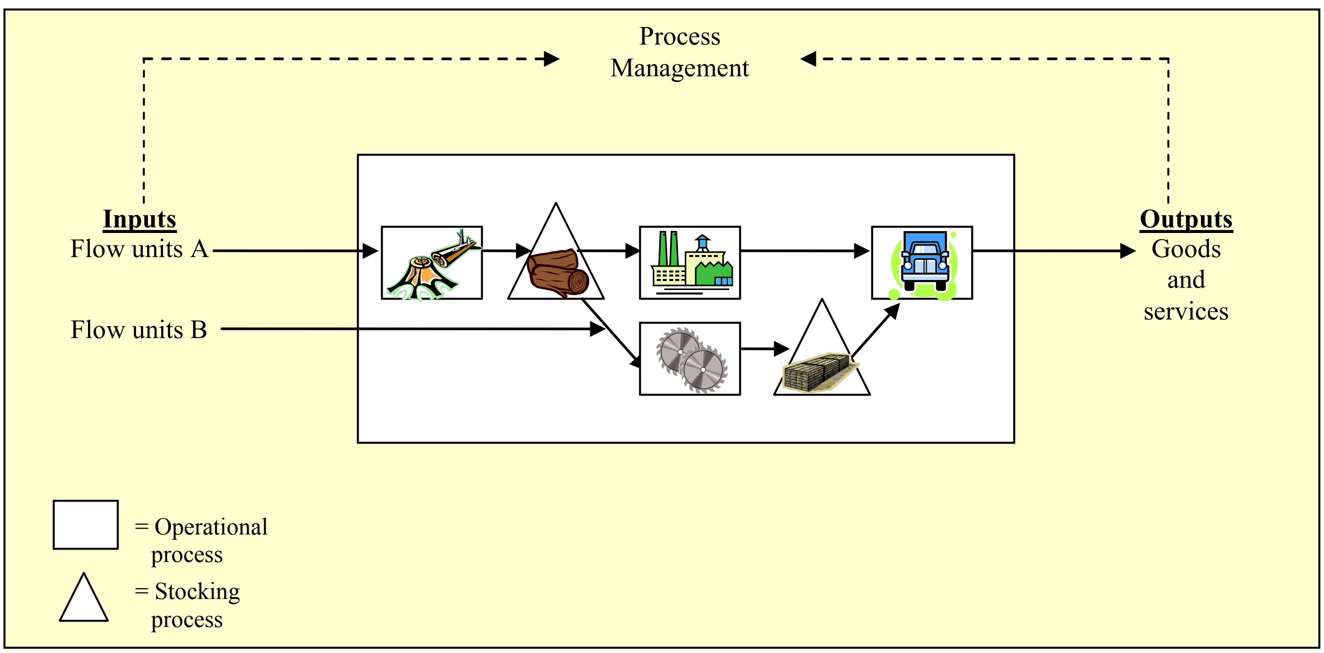


Figure 53: Illustration of a business process (Anupindi *et al.*, 1999)

In the past few years, different people and organizations have suggested grouping all the network business processes into an integrated framework. Two such frameworks have particularly attracted the attention of practitioners: SCOR (Supply Chain Operations Reference-model) and GSCF (Global Supply Chain Forum). Beyond these acknowledged models, researchers Azevedo, D'Amours and Rönnqvist have reviewed the literature in supply chain management journals between 1996 and 2007, and identified 142 different process nomenclatures. Based on their review, they propose a framework made up of seven interrelated supply chain management core processes (Figure 54):

- Strategic planning process;
- Sales & Operations Planning process;
- Customer negotiation process;
- Order fulfilment process;
- Inventory replenishment process;
- Product return process;
- Value proposition process.

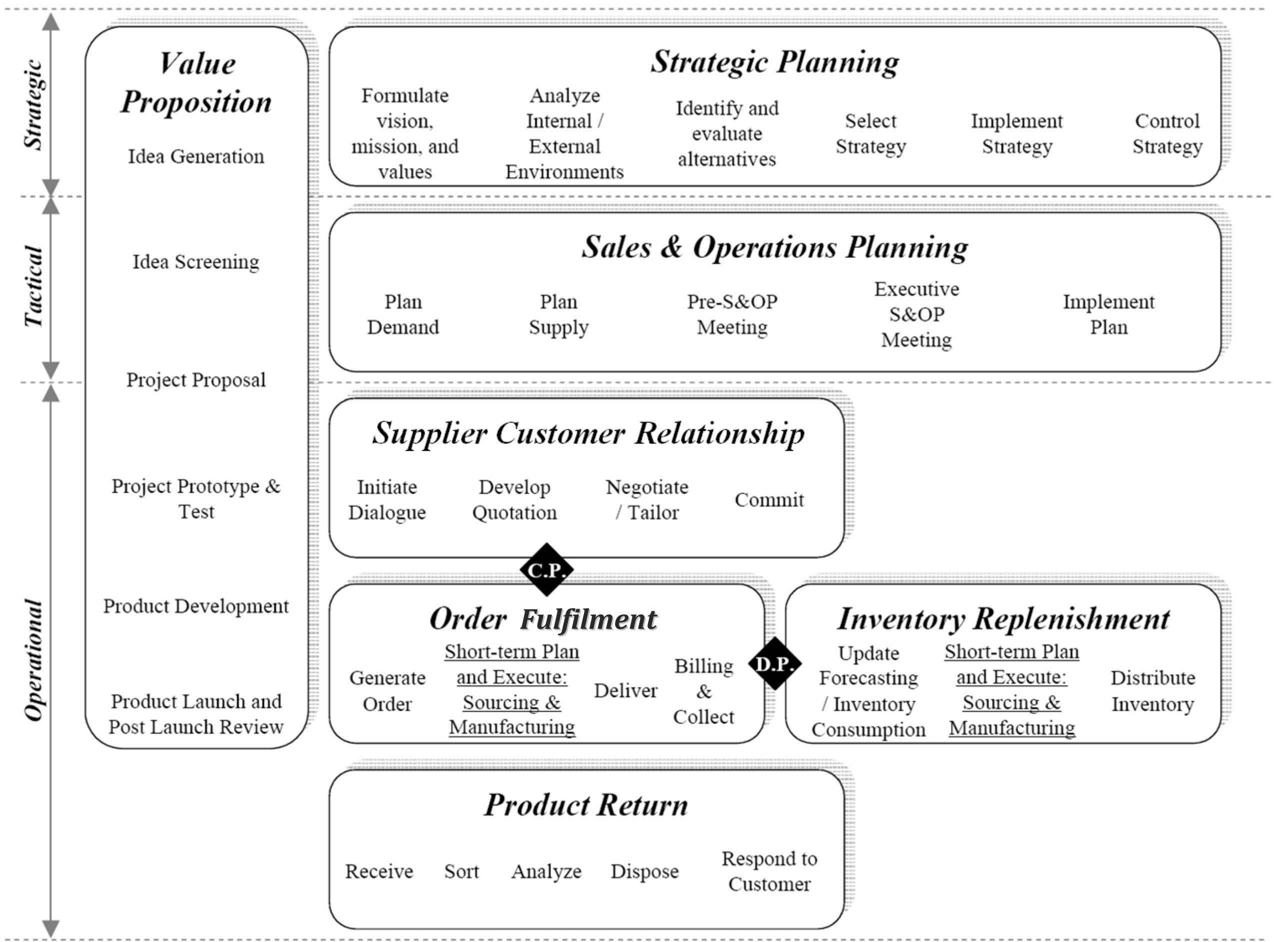


Figure 54: Supply Chain Management Core Processes Framework proposed by Azevedo *et al.* (2008)

6.1.1 Strategic Planning Process

Strategic planning is a decision-making process relating to the long-term mission and objectives of an organization, the resources used in achieving these objectives, and the policies and guidelines that govern the acquisition, use and disposition of such resources. This process can be divided into three main components:

- Formulation, including setting objectives, assessing the external and internal environments and evaluating and selecting strategic alternatives;
- Implementation; and
- Control.

The formulation of a vision, a mission and values is needed to clarify the purpose of the organization for the planning period. The evaluation of the external and internal environment also allows for identification of the threats and opportunities that the organization has to face, as well as its strengths and weaknesses. The next step is to define and analyze different strategic alternatives that the company could pursue over the planning period. Depending on the results obtained from the analysis, a particular strategy can be chosen and implemented, i.e. translated into a feasible set of actions. Finally, the strategy needs to be controlled through continuous monitoring and a review if necessary (Azevedo *et al.*, 2008).

6.1.2 Sales & Operations Planning Process (S&OP)

Sales & Operations Planning is the set of business processes and technologies that enable a business to respond effectively to demand and supply variability with insight into the optimal market deployment and most profitable supply chain mix. S&OP strategies help companies make “right-timed” planning decisions for the best combination of products, customers and markets (Muzumdar and Fontanella, 2006). A typical planning period ranges from three months to three years and the process takes place in monthly cycles with a rigid agenda. The method can be divided into five main activities:

- Plan demand;
- Plan supply;
- Pre S&OP meeting;
- Executive S&OP meeting; and
- Plan implementation.

A successful demand plan requires the collection of different data to create forecasts that will consider updates by the sales team and product requirements, among other parameters. To plan supply, one must generate an operations plan that will take into consideration forecast changes as well as inventory shifts or capacity problems. The company then has to ensure that the demand plan and the supply plan are compatible before it schedules an executive meeting to evaluate new opportunities, risk parameters, etc., and relate the monetary version of the S&OP to the business plan, including any necessary changes. The plan can then be implemented into all the function areas of the organization. Thus, the production department will establish its new production targets, the sales department will define sales quotas and action plan, the finance department will share the up-to-date targets with stakeholders, and so on.

6.1.3 Supplier and Customer Negotiation Processes

The supplier and customer negotiation process includes all discussions between the company and its business partner from the initial enquiry to the time when it is converted into a delivery (supplier) or an order (customer). These imply four main activities:

- Initiate dialogue;
- Develop quotation;
- Negotiate/Tailor; and
- Commit.

A discussion has to be initiated with the business partner via the Internet, personal sales, telesales, etc. Next, the feasibility of responding to the request and the product price have to be analyzed. A negotiation is then started to define aspects such as product characteristics, payment conditions and operational and product related services in order to adjust the price paid to the supplier or offered to the customer. Finally, a commitment is made.

For the customer negotiation process, the customer quote document is converted into a customer order that triggers the order fulfilment process (symbolized in the framework by the linking element C.P. or Commitment Point).

Depending on the operational environment, different configurations of the supplier/customer negotiation process are possible. For example, an environment based on a Make-to-Stock method, namely a manufacturing system in which finished goods are produced and stocked prior to receipt of an order (Figure 55), involves a simple negotiation scheme. On the other hand, a Make-to-Order mode, specifically a manufacturing process established to satisfy the demand only after an order has been placed (Figure 55), involves a more complex negotiation process.

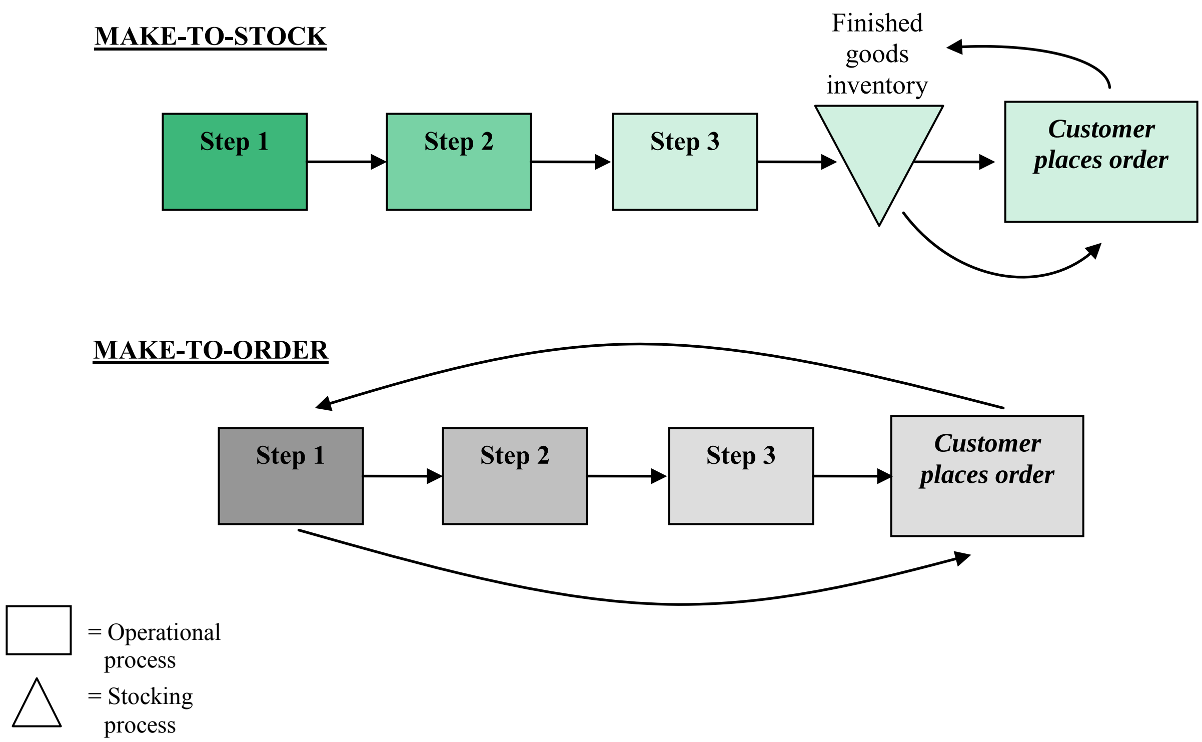


Figure 55: Make-to-Order and Make-to-Stock processes (Davis *et al.*, 2007)

Table 11: Push versus pull system

Definitions
There are two typical philosophies for moving products through the network, **push and pull**. A ***push system*** is one in which planning is done in advance, based on forecasts or schedules. Once the operation is completed, units are pushed to the next level. Therefore, a push process is *forecast driven*. A ***pull system*** is one in which units are moved from one level to the next only when requested. In pull systems, demand acts as the trigger for action. Consequently, a pull system is *demand driven*.

6.1.4 Order Fulfilment Process

Order fulfilment is a key process in managing the value creation network. Rather than just filling orders, this procedure includes all activities from the time the order is received to the time the customer receives the products and the seller collects the agreed compensation.

Again, different configurations are possible depending on the type of operational environment.

The process/link in the chain up to the customer's order penetration point (referred to as the decoupling point (D. P.)), sets the scope of the order fulfillment process as well as its complementary inventory replenishment process. Before the decoupling point, intermediate and finished products are manufactured on the basis of forecasts; but ,after this point, the operations required to finish the product are based on customer demand. For example, a Make-to-Stock method will not involve planning and execution activities related to sourcing and manufacturing, as demand will be satisfied directly from products held in stock. Activities are performed under the inventory replenishment process. However, for a Make-to-Order system, more activities are involved. This concept is well illustrated with the paper process. The pulp and paper producer can decide to 1) satisfy customers' orders using stocks; 2) keep in stock different types of parent rolls and cut paper when needed; or 3) process all the operations when the product is required (Figure 56). Thus the configuration will vary with the selected strategy.

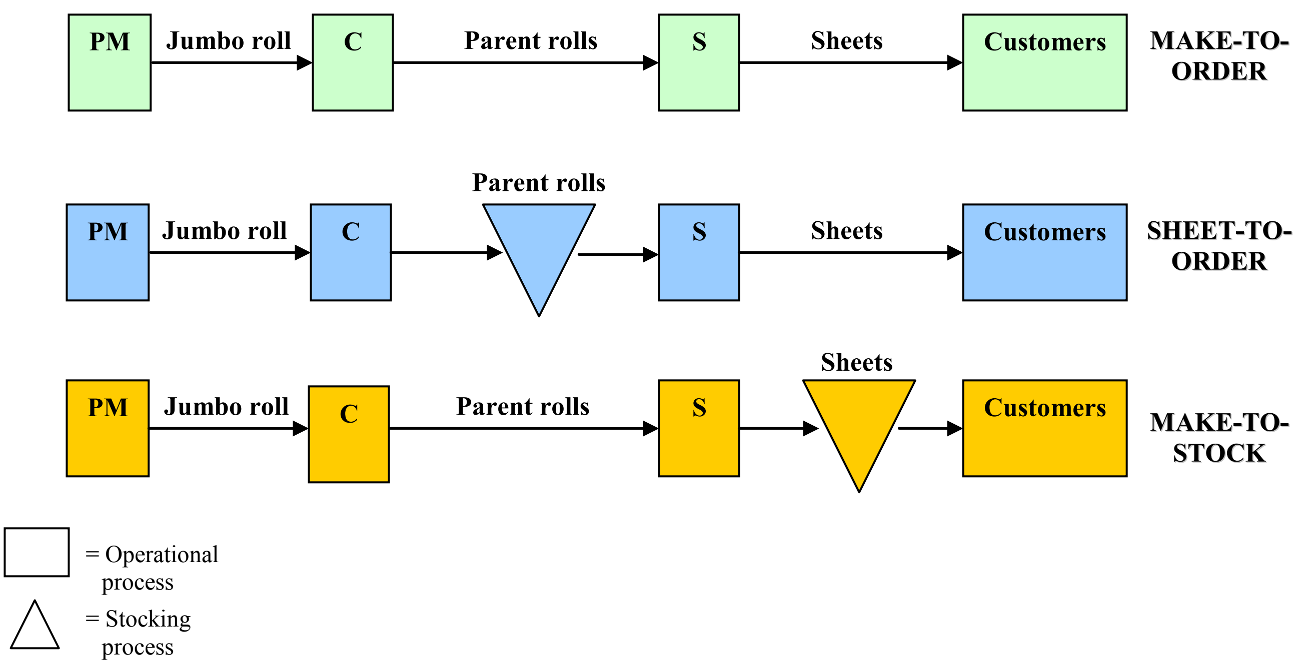


Figure 56: Decoupling point for the paper process (Adapted from Chauhan *et al.*, 2008)

Four major activities can characterize the process:

- Generate order;
- Plan and execute sourcing and manufacturing;
- Deliver;
- Bill and collect.

When an order is generated, one needs to process it, check the customer's credit and transmit the order to upstream members. Activities such as production scheduling and material and capacity requirements must then be planned, executed and controlled. To ensure proper delivery of the product to the customer, a delivery plan has to be defined as well as the transportation mode to be used. The invoice will finally be sent to the customer and payment collected.

6.1.5 Inventory Replenishment Process

Considering that inventories such as stockpiles of raw materials and finished goods can cost between 20 and 40% of their value per year, inventory replenishment needs to be carefully managed. Three major activities must be performed:

- Update forecasting/inventory consumption;
- Short-term plan and execute sourcing and manufacturing; and
- Distribute inventory.

The sales plan derived from the S&OP process must be implemented, and the quantity of products to keep in stock must be defined. Also, forecasts have to be updated on the basis of recent demand records and sales quotas. The forecast can then be translated into inventory requirements. In addition, activities such as production schedule, material and capacity requirements must again be planned, executed and controlled. Finally, all the activities necessary to place the product in its final inventory location, such as transportation preparation, orders consolidation and so on will be executed.

Depending on the pattern of demand for the various goods, different inventory replenishment strategies can be implemented. For example, if demand is practically the same for all periods (e.g., demand known and constant) and the lead time "L" is constant, one can use a fixed-order-quantity technique or (R,Q) method, which involves defining the fixed quantity "Q" to be ordered as well as the specific point "R" at which an order will be placed (Figure 57).

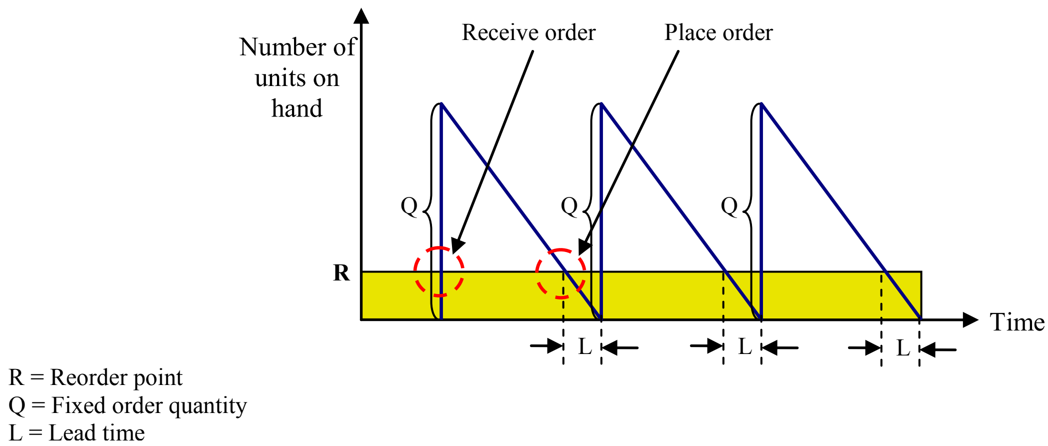


Figure 57: Basic fixed-order-quantity technique to manage inventory (Adapted from Davis *et al.*, 2007)

However, when the demand and/or the lead time are uncertain, it may be necessary to add some safety stock (SS) to account for this uncertainty. The reorder point "s" will therefore become higher than in the absence of uncertainty, as it has to include the safety stock (Figure 58). This is referred to as the (s,Q) method.

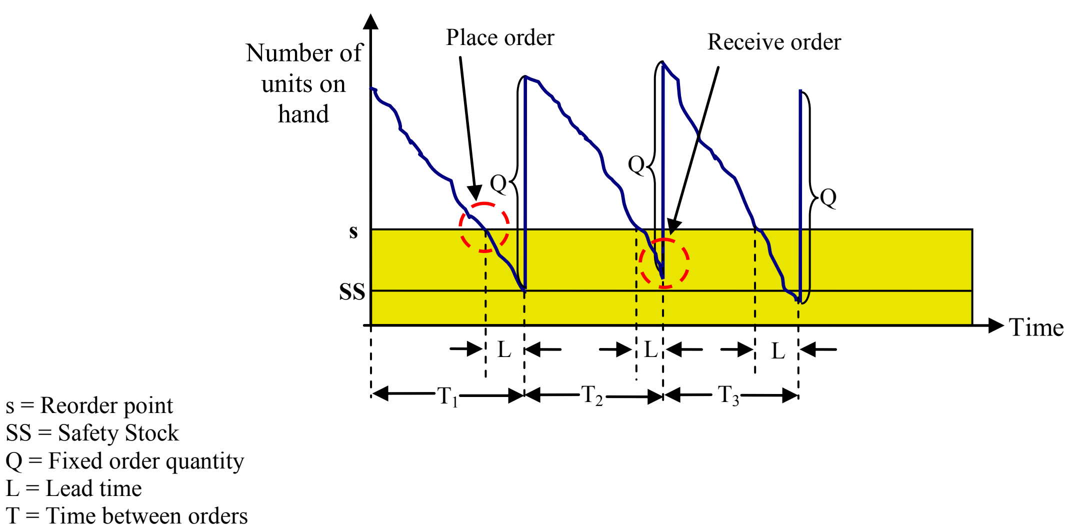


Figure 58: (s,Q) method to manage inventory when demand and/or lead time are uncertain

6.1.6 Product Return Process

The product return process includes all operations from the return to the disposal of the product. Five main activities must be specifically considered:

- Receive;
- Sort;

- Analyze;
- Reuse, repair, recycle or dispose; and
- Respond to customer.

After discussion with the customer, the product can be returned to the seller's facilities. Once the product is received by the seller, it is sorted according to such characteristics as the type, the technology, etc. The quality of the product is then analyzed to determine if it can be reused, repaired, returned to the market or recycled. The process will be completed with a response to the customer's inquiry such as the shipment of a new product or a refund.

6.1.7 Value Proposition Process

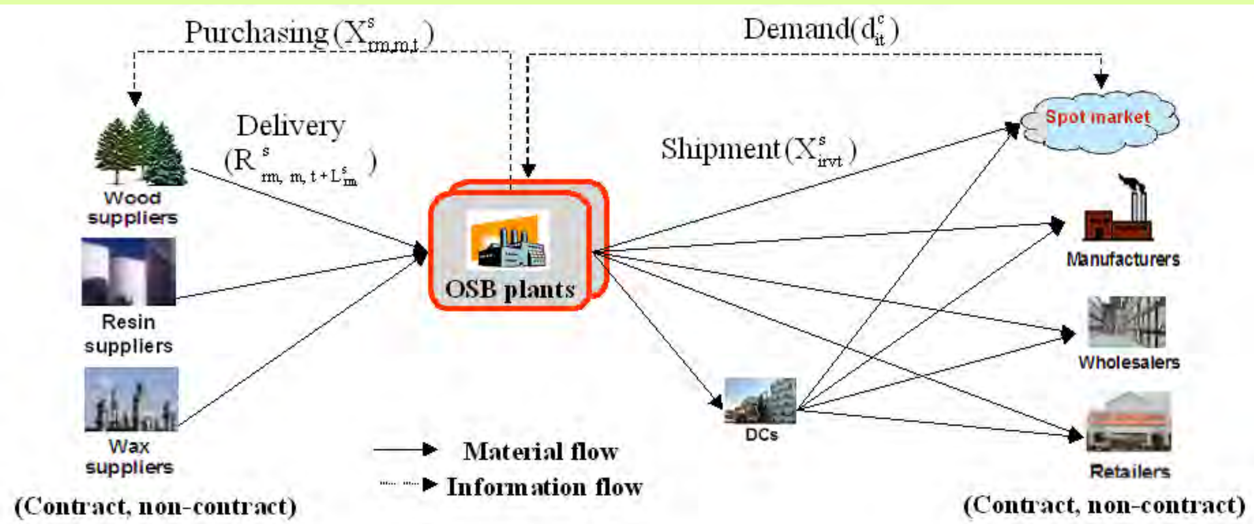
The value proposition process is a utility that companies create for customers. It includes all activities from the generation of an idea or opportunity to the launching of a product and service that adds value for customers, the company and the network. The process can be divided into six main activities:

- Idea generation;
- Idea screening;
- Projects proposal;
- Prototype development and testing;
- Product development;
- Product launch and post launch review.

The first step is to make up a list of opportunities for value creation. Next, ideas must be analyzed to identify which are more relevant. They are then turned into a planned project which includes the establishment of operation requirements, financial expectations and the business plan. In addition, a prototype is developed and tested, so if experiments are conclusive, the product is developed. The product is finally introduced to the market, with some monitoring and adjustments as necessary.

Case study 6: The value of sales and operations planning in the oriented strand board industry with the Make-to-Order manufacturing system

The objective of this study conducted by Feng *et al.* (2008) was to develop a planning model that integrated sales, production, distribution and procurement activities in order to maximize profit. To measure profitability, the model was compared to a non-coordinated planning model. The case study applied to a Quebec OSB mill producing 11 product families using 8 raw materials supplied by 19 raw material suppliers. Products were delivered to 140 customers across 5 different regions by 8 shipping companies using 5 different vehicle types via 2 distribution centres. The company had two types of demand, contract (annual commitment) and non-contract. Experiments were therefore conducted to evaluate the impact of integrating sales and procurement in the planning model.



The results showed that the gains obtained with the integrated planning model ranged from 0.5 to 3.1%. The transportation cost was reduced by 5.7 to 19.2%, worth $528,565 to $1,928,706. However, the benefits of the integrated planning model varied in relation to market conditions and supply chain costs. They increased with higher unit shipping cost and procurement cost, and with lower spot market prices.

6.2 Planning Decisions

Each business process involves specific planning decisions (namely what, when and how) that can be implemented from a short– and a long-term perspective (Ballou, 2004). For example, a delivery plan or the update of a forecast can be executed within a week, while the selection and implementation of a particular strategy can necessitate a couple of months, or even years. This is why planning decisions are generally classified into one of three major levels: strategic, tactical and operational.

6.2.1 Planning at a Strategic Level

The strategic level focuses on a time horizon that is usually greater than a year and the length of the time horizon varies from one industry to another. For those industries that require many years to plan and construct plants and facilities, and to install specific processes, the time may be from 5 to 10 or more years. For other industries in which the ability to expand capacity is shorter, the time horizon may be two to five years or less.

For the forest products industry, strategic planning is very long term. For example, the rotation of forest growth can take more than 80 years, and a new pulp or paper mill is normally intended to last more than 30 years. Thus, strategic decision-making includes the choices related to forest management strategies, silvicultural treatments, conservation areas, road construction, the opening/closing of mills, the location/acquisition of new mills, process investments (e.g., machines, transportation equipment, information technology), product and market development, financial and operational hedging, planning strategies (e.g., Make-to-Stock, Make-to-Order, Cut-to-Order) and inventory location (e.g., position of decoupling point , warehouses).

Each of these decisions will influence network configuration, and this is particularly true for planning strategies, which have a major impact on all investment decisions. For example, the required capacity and the type of equipment needed to support a Make-to-Stock strategy would be different than those needed to support a Make-to-Order strategy. Therefore, the planning approach defines important parameters with respect to the necessary technology, capacity, inventory levels and maximum distances to customers. Such decisions naturally involve evaluating how the investment will fit into the whole network, including deciding which markets are available for the products based on anticipated market trends, how the distribution of the products should be carried out and at what cost, and how the production units should be supplied with the necessary wood fibre (i.e. wood or pulp). Other elements, such as energy supplies, might also be crucial.

The type of forest land tenure may also affect the way strategic decisions are made. Wood can come from public lands, private lands or both, with each type requiring different procurement programs. Other factors may also have to be considered. These would include government rules over the amount of forest land to be set aside for bio-diversity purposes, recreational use and/or carbon sequestration (D'Amours *et al.*, 2008).

6.2.2 Planning at a Tactical Level

The tactical level involves an intermediate time horizon and focuses on tactical issues pertaining to aggregate workforce and material requirements for the coming year. Depending on whether a forest management problem or a production/distribution planning problem is addressed, the tactical decision-making will be slightly different.

In forest management, hierarchical planning approaches are widely implemented, as they allow for a tactical planning problem to be addressed early on, without spatial issues having to be taken into account. Once this has been done, the problem can be tightly constrained spatially. While strategic forest management planning problems generally span 100 years, tactical planning problems are often reviewed annually over a five-year planning period.

In planning problems dealing with production/distribution issues, tactical planning normally addresses the allocation rules that define which unit or group of units is responsible for executing the different network activities, or what resources or group of resources will be used. It also sets the rules in terms of production/distribution lead times, lot sizing and inventory policies. Tactical planning allows these two types of rules to be defined through a global analysis of the value creation network. Tactical planning also serves as a bridge between long-term comprehensive strategic planning and short-term detailed operational planning that has a direct influence on actual operations in the chain (e.g., truck routing, production schedules). Tactical planning should also ensure that subsequent operational planning conforms to the directives established during the strategic planning stage, even though the planning horizon is much shorter. Other typical tactical decisions relate to allocating customers to mills and defining the necessary distribution capacity. The advanced planning required for distribution depends on the transportation mode. For example, ship and rail transportation typically need to be planned earlier than truck transportation.

Another important reason for tactical planning is tied to the seasonality of the value creation network, which increases the need for advance planning. Seasonality greatly affects the procurement stage (i.e. the outbound flow of wood fibre from the forests). One reason for such seasonality is weather conditions, which can make it impossible to transport logs/chips at certain times of the year due to the limited carrying capacity of forest roads (e.g., spring thaw). In many parts of the world, seasonality also plays a role in harvesting operations. In the Nordic countries, for example, only a relatively small proportion of the annual harvest is conducted in the summer months (July-August). Operations during this period are instead focused on silvicultural management, including regeneration and cleaning activities. A large proportion of the wood is harvested in winter, when the ground is frozen, which reduces the risk of damage when forwarding (or moving) the logs out of the forest. Seasonality can also affect the production stage (e.g., in Nordic countries, as in Canada, air drying times will vary with the season) or the demand process (e.g., again in Nordic countries, building construction projects are not usually conducted during the winter period).

Budget projection is another area in which tactical planning can be useful. Most companies undertake a major planning task when projecting the annual budget for the following year, deciding which products to offer to their customers, and in what quantities. In the process of elaborating these decisions, they need to evaluate the implications of their decisions on the whole network (procurement, production and distribution) with the aim of maximizing net profits. It is therefore worthwhile taking these activities into consideration to extend the planning horizon to a multi-period (multi-seasonal) horizon, in order to identify how the budget should best be defined for each of the business units within the supply chain.

6.2.3 Planning at the Operational Level

The operational level is considered short-range, with decisions frequently made on an hourly or daily basis. As with strategic planning, the length of the time horizon for tactical and operational level planning will vary from one industry to another. The concern is how to move the product efficiently through to the strategically planned logistics channel (Ballou, 2004).

Operational decision-making is usually distributed among the different facilities, or units in the facilities. Within the production process, one type of operational planning problem deals with cutting and must be solved by many of the wood product mills (e.g., lumber, dimension parts), as well as pulp and paper mills. Scheduling the different products moving through the manufacturing lines is also a typical operational planning problem, as is process control involving real-time operational planning decisions. Process control is particularly critical in the pulp and paper industry, as the characteristics of the output products depend greatly on the precision of the chemical-fibre mix. Another type of operational planning problem deals with issues related to transportation, specifically the routing and dispatching done at several points in the supply chain. For instance, it is necessary to route the trucks used for hauling wood from the forest to the mills or for shipping finished products from mills to customers or distribution centres.

Table 12 summarizes some examples of strategic, tactical and operational decision-making.

Table 12: Examples of strategic, tactical and operational decision-making (Adapted from Ballou, 2004)

Decision area	Level of decision		
	Strategic	Tactical	Operational
Facility location	Number, size and location of mills, warehouses, distribution centres, etc.		
Inventories	Stocking locations, control policies	Safety stock levels, seasonal inventory target	Replenishment quantities and timing
Transportation	Mode selection, investment strategies (e.g. roads construction, trucks, wagons, ships, planning system, etc.)	Seasonal equipment leasing, route definition, transhipment yard location and planning	Routing, dispatching, vehicle loading, daily carrier selection
Order processing	Order entry, transmittal and processing system design, order penetration point strategy		Processing orders, filling back orders
Customer service	Setting standards, customer segmentation, pricing and service strategy, investment in information technology and planning systems	Priority rules for customer orders, customer contracts, allocation of products and customers to mills	Expediting deliveries
Warehousing	Handling equipment selection, layout design, allocation of markets/customers to warehouses, investment in information technology and planning systems	Seasonal space choices, warehouse management policies	Order picking and restocking
Procurement	Wood procurement, forest land acquisitions and harvesting contracts, silvicultural regime and regeneration strategies, development of partnerships	Sourcing plan (log classes), allocation of harvesting to cutting blocks, allocation of products/blocks to mills, log yard management policies, contracting, vendor selection	Order releasing, expediting supplies, detailed log supply planning

Case study 7: Optimization of the tactical planning problem of a furniture company

A study was conducted to analyze the supply chain tactical planning problem of an integrated furniture company located in the province of Quebec. The objective was to determine manufacturing and logistics policies that would allow the company to offer a competitive level of service at minimum cost.

The supply chain studied in this industrial case included more than 40 logs suppliers, 2 sawmills, 16 kilns, 10 customers (furniture plants), 11 raw materials and 135 finished and semi-finished products. The company had to deal with a divergent process (i.e. from each hardwood log, several boards were produced depending on the sawing policy in use) as well as seasonal capacity variations, in addition to seasonal demand variability. The sawmill sawed more than 10 different species. As a result, the planning of the furniture supply chain was very complex. A decision support system was therefore developed to facilitate decision making. The resulting mixed-integer program aimed to minimize total cost, including procurement cost, transportation cost, inventory cost and production cost, while satisfying different constraints such as capacity and flow conservation constraints. The model was run using Cplex for a total planning period of 52 weeks.

The decision support system contributed **to reducing total operating cost by more than 22%**. Furthermore, the tool showed that sawing and drying capacities were sufficient, and that the company had **no need to outsource any sawing and drying operations**. The model has also contributed to decreasing the supply chain inventory level while capturing seasonal fluctuations in known customer demand and supplier capacity. Finally, the material flows between business units was optimized, leading to reduced transportation costs.

Using this tool, planning managers can now answer all challenging tactical planning questions efficiently in a few minutes.

6.3 Some Planning Problems Faced by All Business Units in the Wood Fibre Value Creation Network

Properly planning and managing all the business processes of a value chain to synchronize product and information flows are no easy tasks. Irrespective of the decisions companies make, problems arise and interfere with the planning procedure. Observation of the business units in the wood fibre value creation network reveals problems they face at each planning level (strategic, tactical, operational and execution, Figure 59).

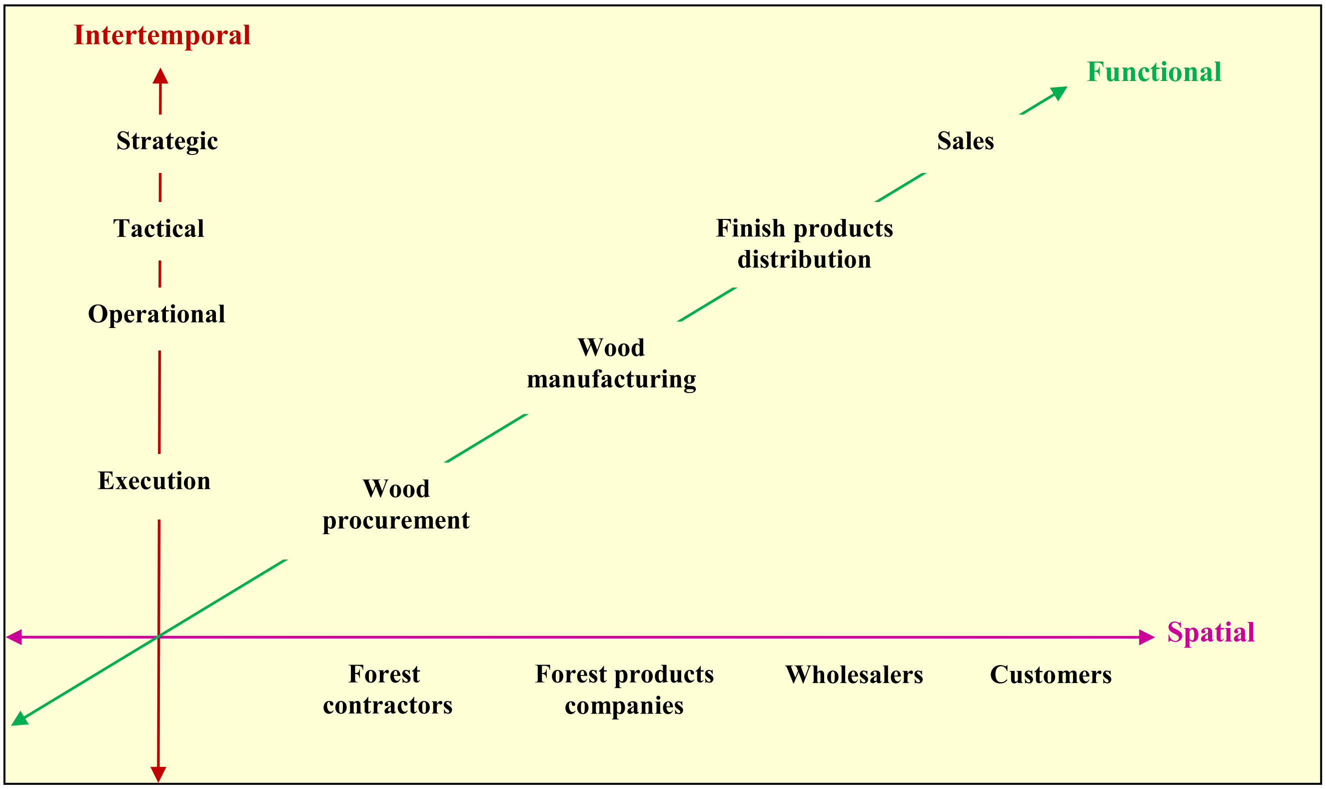


Figure 59: Supply chain dimensions of the wood fibre (Adapted from Santa-Eulalia, 2009)

6.3.1 The Forest

One of the first major problems with managing woodlands from a long-term perspective relates to the way the fibre is allocated to the various users. Decisions are complex and must attain societal targets defined to meet sustainable socio-economic development objectives. As the chosen strategies may span several forest rotations, it may be necessary to plan for more than 100 years. Over time, these plans have a great impact on the quality and volume of the fibre. Another problem relates to forest use, i.e.: harvesting areas; allocations and silvicultural treatments; and their socio-economic consequences, such as environmental problems, non-declining yield, continued employment, industrial competitiveness, etc.

Once a forest management strategy has been determined, tactical and operational decisions need to be made, integrating the requirements of the other supply chains (pulp and paper chain; lumber, panel and engineered wood chain; and energy chain). Thus, the harvesting sectors and the transportation infrastructure must be precisely defined, all subject to spatial constraints in addition to constraints set by the strategic plan.

From a mid-term perspective, a key problem is deciding how to treat standing timber. It involves the selection and sequencing of stands for harvesting (cutting blocks) to satisfy temporal demands for timber. It also involves the design of forest roads to provide access to harvest areas.

In a short-term perspective, the assignment of a road for truck travel, and the schedule of each trip need to be defined. Forwarding operations also have to be considered. In addition, bucking patterns need to be optimized, as they will condition the basket of forest products available at any one time.

However, different tools are now available to assist decision makers with planning. Simulation, linear programming models and multi-agent approaches are some examples of the systems that can be used to analyze actual problems and offer solutions that take multiple criteria into account.

6.3.2 Pulp and Paper

Pulp and paper companies have to define how they manufacture and sell products to customers. In a long-term perspective, one of their main problems therefore relates to designing the production and distribution network. This will involve determining the number of mills in operation, the number of warehouses needed, whether the use of a distribution centre is necessary or not, the geographical locations of the different units to better respond to market demand, the investment in technology and equipment, and so on. They also have to deal with national taxation legislation, transfer pricing regulations, environmental restrictions, trade tariffs and exchange rates. Moreover, a larger market will involve a more complex design (different transportation modes, more financial and environmental constraints, more sophisticated technology, etc.). Another major issue relates to the procurement of appropriate wood fibre for the desired products. The wood needs to be sorted into different categories with specific properties. However, multiplying the number of assortments tends to significantly increase costs. A balance must therefore be found, with due consideration given to network costs and revenues.

Typical problems in a mid-term perspective relate to production planning, such as product sequencing in campaigns and their duration, optimization of the paper roll assortment, lot-sizing policy, etc. Some external factors such as seasonality or breakdown also have to be considered in this analysis.

From a pulp and paper perspective, short-term problems refer to the establishment of daily plans for individual facilities, better integration of the production and distribution plans, optimization of the roll cutting/production process, vehicle loads, etc. Optimal control is also a critical aspect of management planning. The production of pulp is sensitive to the quality of input products as well as to the control of the process. Chemicals and process control are used to ensure that the desired characteristics are obtained.

In view of the large number of parameters and constraints that need to be considered in the decision-making process, different systems are available to efficiently solve problems and identify desirable alternatives.

6.3.3 Lumber, Panel and Engineered wood

Much like pulp and paper companies, lumber, panel and engineered wood companies have to define the way they should process and sell their products to customers. This involves designing the supply chain efficiently, and taking into account the divergent aspects of manufacturing processes. Typical questions that have to be addressed include: Can we keep the plant open or should we shut it down? What kind of technology and equipment should we buy? How should we allocate the assortment of products to our facilities? And so on.

Tactical decision-making usually deals with the challenge of integrating different activities such as bucking, sawing, drying, planing and grading processes, in the network at minimum cost. Companies are generally located on multiple sites and offer a large number of products, which contributes to the complexity of the planning problem.

In a short-term perspective, the cutting problem is often critical. Whether dealing with timber, hardwood or softwood lumber, panels or engineered wood products, optimal cutting of incoming products is crucial in terms of material yield management as well as demand satisfaction. In addition, difficulties stemming from wood defects and wood grading must be considered. This is why advanced technologies are commonly used to solve these problems.

6.3.4 Biomass Energy

To be useful in energy production, biomass must be produced at a competitive cost, with minimum environmental impact and at the best quality for energy conversion and end use. This can be accomplished in part through appropriate harvesting technologies or post-harvest treatments. Biomass transportation to the plant is an important portion of the energy cost which must be considered.

A company's decision to use the forest biomass as an energy source highly depends on a) the guaranteed availability and stability in the supply, and b) alternative uses for that biomass (Côté, 2005). In view of existing potential uses of wood industry residues and by-products, prices have gone up from no charge to significant amounts. For some residues, it is more cost-effective to sell them to other companies than to use them for energy. Typical questions that a mill must answer in regards to biomass use include:

- Which types of sub-products should be used to produce energy and which ones should be sold?
- Up to what distance is it profitable to haul in a given type of biomass?
- How much of each type of biomass should be kept in inventory?
- What is the biomass quantity that should be purchased from each potential supplier?
- What is the impact on biomass cost of an increase in transportation cost?
- What are the best uses for the company's different residue categories?

In modelling for the optimal biomass inventory level and replenishment, many factors are to be considered (Quirion-Blais, 2008). Some are related to the type of biomass and its current properties, e.g.: energy value per unit, moisture content on delivery and, while in a pile, quality (cleanliness), age, ease of grinding and replenishment cost. Other factors include biomass availability, the price of electricity, the season, the mill's energy requirements and the availability of biomass storage space.

6.4 Planning and Anticipation

Given that the different planning decisions seem to be well understood by most organizations, and decision support systems are readily available, why do trains, planes and cars continue to run late? Why are production plans frequently changed? And why are the results so different from planned targets? In fact, a business may control its own operations, but it has no power over the weather, global economy fluctuations, countries' policies (see the section on risk), or even the actions of other network members. Success requires activity planning combined with anticipation. While planning is necessary for organizing the future, anticipation is essential to consider present conditions, opportunities and threats. Anticipation is also indispensable to balance planning and adaptability. Thus, businesses must develop the ability to sense, predict, plan and prepare (Figure 60).

For example, a company may first identify an objective under specific circumstances. The next step is to determine what, when and how this objective will be reached. The company then needs to evaluate which risk factors or network members' behaviours are out of control or could affect the plan. And an anticipation strategy is developed and integrated into the planning process.

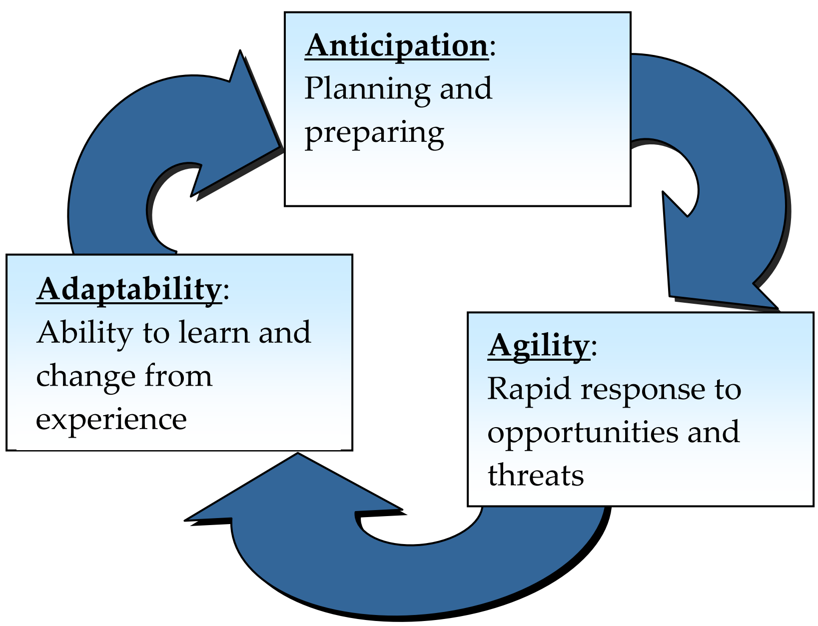


Figure 60: Planning and anticipation, an illustration (Adapted from Patten, 2005)

For forest management, for example, these events can include ongoing growth stochastics, delay in regeneration, cover type changes at regeneration, fire, insects, disease outbreaks, and so on (Gunn, 2007).

In addition, from a supply chain point of view, companies usually have access to private information that they can choose to exchange or not depending on circumstances (e.g.: a forest contractor has access to daily harvest volumes; a forest products company has access to customer demand, etc.). Such knowledge is generally necessary to correctly plan activities (see the bullwhip effect in the "information flow" section). Anticipation is an attractive way to deal with this situation. For example, a company can anticipate the capacity or delivery date of a supplier, the future needs of a customer, etc., and then take into account these "potential" factors in the planning process.

Due to the integrated characteristics of supply chains and since a decision at one level will have an impact on other decision levels, combining planning and anticipation is a good way to protect oneself from uncertainties and unknown events.

6.4.1 Approaches to Forest Management Planning

The planning of forest management rarely considers the needs of other supply chains (i.e.: lumber, panel and engineered wood supply chains; pulp and paper supply chain; energy supply chain). Efforts focus on sustainable forest management, harvesting optimization, bucking and wood transportation, etc., with no consideration given to the fact that forest products companies have specific needs, constraints, capacities and demand to satisfy. On the other hand, when forest products companies optimize the design and management of their own supply chain, they take the forest supply chain as exogenous (Gunn, 2009, Carlsson and Rönnqvist, 2007). Efficiency demands that these main supply chains be simultaneously considered to ensure adequate synchronization of activities.

One way of doing this involves anticipating the fibre needs of forest products companies as well as the impact of forest planning decisions on the whole value creation network. Moreover, by using a rolling horizon, it may be possible to update the long-term plan so as to integrate field observations, incorporate opportunities and take potential threats into account.

For a better understanding of this concept, let us consider two different forest management approaches: push and pull. When a push approach is used, forest managers first plan over a long-term horizon with the objective of maximizing net present log value, without anticipating the needs of the mills or estimating the impact of these decisions on the whole network. Next, mill managers plan over a short term business planning horizon with the objective of maximizing profit (Figure 61).

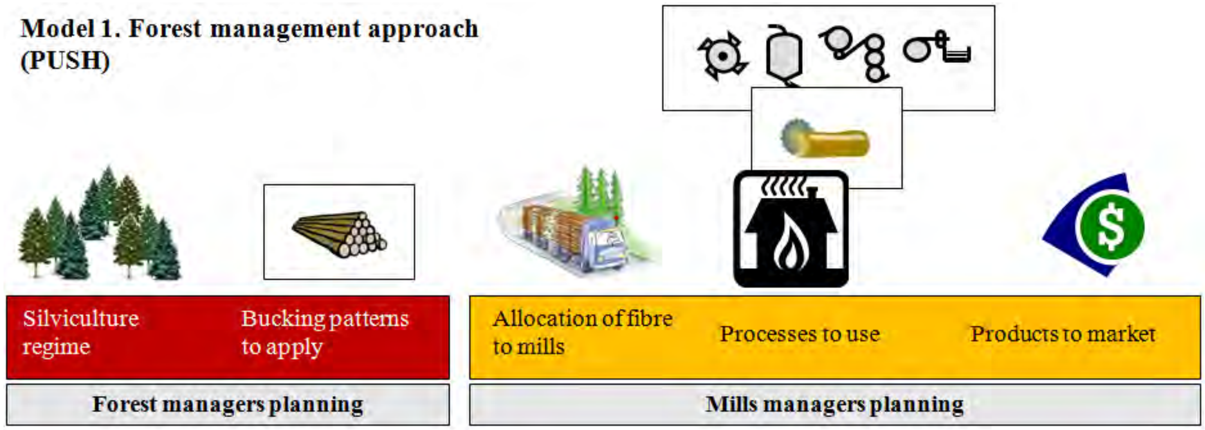


Figure 61: Illustration of the "push" approach to forest management

With a pull approach, on the other hand, forest managers and mills managers jointly plan forest decisions over a long-term horizon as well as a short-term business planning horizon with the objective of maximizing net present value (Figure 62). In this way, fibre needs and operational constraints are taken into consideration, as are the constraints related to sustainable forest use. Plan updates will allow for integration of new market opportunities, field observations, and so on.

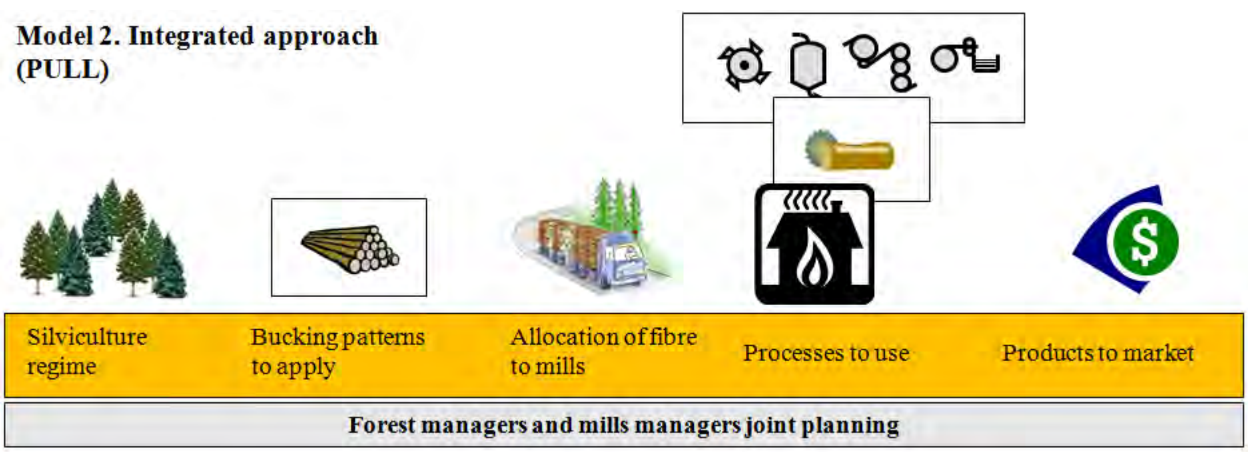


Figure 62: Illustration of the "pull" forest management approach

6.5 Strategic Options for Network Management

To describe a company's different planning decisions, one typically details how operations proceed, how the capacity level is planned or how the supply chain is designed. Thus, a description is provided of the way to optimize and manage the organization. However, prior to this, an effort has to be made to determine which operations should be performed and/or controlled by the company, and which should be entrusted to others. From a value creation network perspective, this is referred to as the strategic options of making, not making, outsourcing or collaborating (Table 13).

To be more specific, companies need to identify their skills as well as the business processes they can conduct efficiently. Activities that can be performed well, at low cost, while creating value for the organization should be classified as "make" operations. Companies should actually choose to perform these operations internally (optimization of internal network). On the other hand, activities that may not be performed economically or that require skills not available within the organization should be outsourced (use of external network), performed in collaboration with other organizations (development of network synergy) or just avoided ("not made").

Table 13: Strategic options and impact on the organization (Poulin *et al.*, 1995)

Strategic option	Impact on the organization
Make	Own network The network does not necessarily have to change Some activities or operations could be optimized or adapted Some new activities or operations could also be performed The organization can choose to acquire new business units
Outsource	External network Based on a relationship with a partner A new relationship can be created with an old partner A relationship can also be created with a new partner
Collaborate	Based on a relationship with a partner A new relationship can be created with an old partner A relationship can also be created with a new partner Some new activities or operations could also be performed
Not Make	Stop the operation Use resources for other activities

When the "not make" option is chosen, the company has to buy material from an external source (e.g., order lumber or chips rather than convert the wood). The transaction can be made through the market place on a day-to-day basis or through a standard contract with a supplier.

On the other hand, a company may decide to outsource specific operations to one or several companies with some form of control depending on circumstances.

A company can also choose to collaborate with other organizations for different reasons:

- Economy of scale;
- A better response to change;
- The potential acquisition of new skills and competencies;
- Sharing costs and risk for some activities; or
- Streamlining the organization's structure.

Like outsourcing, collaborating implies: less control over the manner in which activities are conducted; information sharing; the need for metrics; and, in the case of strategic partnerships, profit sharing.

6.6 The Case of the Forest

It is worthwhile describing the forest supply chain by means of the planning issues as well as the strategic options described above (Table 14 summarizes the different planning decisions applying to the forest).

Table 14: Description of planning decisions concerning the forest supply chain

Nature of decisions	Activities involved
Strategic direction	Rules and forest policies defined to preserve natural ecosystem processes
Forest management	Land acquisition and long-term procurement contract
	Silvicultural treatments in a long-term perspective
	Amount of wood to allocate to business units, companies or partners
	Global forest road network
Tactical planning of forest operations	Choice of harvesting process
	Equipment acquisition
	Silvicultural plan for the next five years as well as for the current year
	Harvesting plan for the next five years as well as for the current year
	Manpower/equipment planning
	Location of the forest camp
	Location of the log yard
	Main forest roads to be built and maintained
	Choice of a transportation mode

Table 14: Description of planning decisions concerning the forest supply chain (cont'd)

Nature of decisions	Activities involved
Tactical planning of forest operations	Selection of forest contractors Selection of transportation companies Demand planning
Scheduling and control of forest operations	Silvicultural operations scheduling Forest operations scheduling Maintenance scheduling Transport scheduling Demand fulfillment

Let us start with the strategic direction for the forest. In Canada as in many countries, the government sets rules and policies to protect the forest. Therefore, the forest landowner must consider these constraints in the planning and management of his activities (Figure 63).

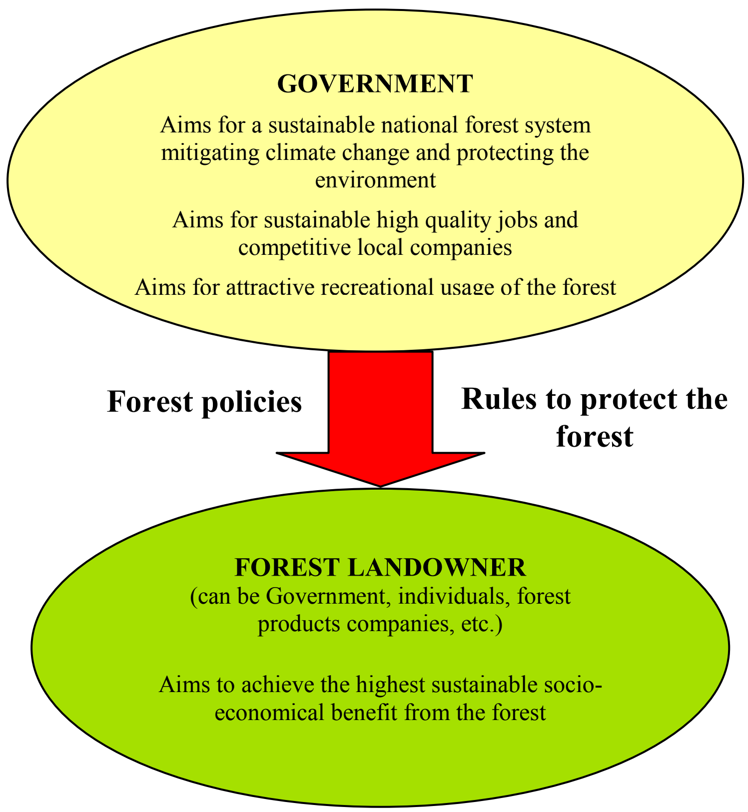


Figure 63: Relationship between the government and the forest landowner

Within applicable regulations, the forest landowners, which could be the government (public forest) or individuals, families, corporations, etc., have to plan for the long-term capacity required for future years (i.e. allowable cut), the types of products to be generated (specific volumes to be available at different locations for the production of logs, chips, biomass and other wood products), and the strategies to be implemented (silvicultural treatments) as well as the infrastructure required (road network) to ensure product quality and competitiveness (forest and/or wood products). The forest landowner must then determine, based on its business strategies, how the forest will be managed over the following years (Figure 64).

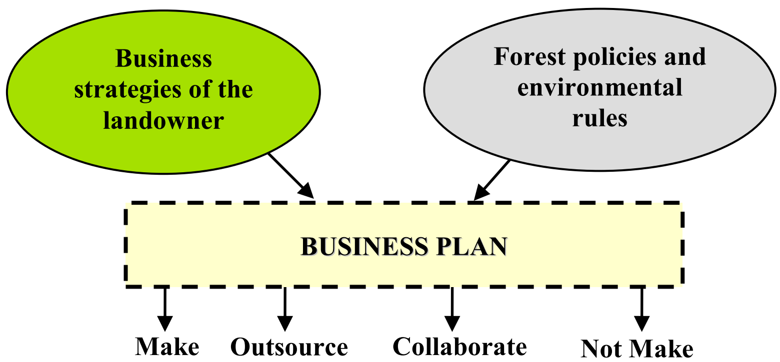


Figure 64: Illustration of strategic options available to forest landowners

Decisions particularly need to be made in connection with the harvesting plan, the location of the log yard, the forest roads to be used, the allocation of forest areas to other companies, the associated fee structure, etc. The forest landowner can choose to conduct all the operations himself (develop the harvesting plan, determine the transportation mode, convert trees into wood products, etc.), or outsource/collaborate with other organizations, or not make some or all of these activities (see Table 15).

Table 15: Some examples of strategic decisions and options to manage the forest

Nature of decisions	Strategic options			
	Make	**Not Make**	**Outsource**	**Collaborate**
Strategic direction	Establish forest rules and policies to protect the forest	Let the forest companies decide how to take care of the forest	Hire experts to determine how to protect natural resources	Collaborate with associations, organizations, etc., to define forest rules and policies
Forest management	Determine the allowable cut, the products to be offered to customers, the silvicultural techniques, the road network, etc.	Keep the forest “as a forest” for future projects	Hire management consultants, associations, etc., to determine allowable cut, for example	Determine with other organizations the allowable cut, the silvicultural system to be implemented, etc.
Tactical planning of forest operations	Define the harvesting plan, the location of the log yard, the forest roads to be used, etc.	Keep the forest “as a forest” for future projects	Outsource some or all the activities (such as harvest planning) to others	Collaborate with other organizations to determine a harvesting plan, share certain resources and information, etc.
Scheduling and control of forest operations	Schedule the silvicultural and forest operations as well as the transportation activity, fulfil demand	Keep the forest “as a forest” for future projects	Outsource some or all the activities to different stakeholders: silvilcutural workers, transportation companies, etc.	Work with other organizations to optimize operations (transportation, harvesting) and share resources, costs and risk

In the following paragraph, three different scenarios will be discussed to show how different strategic options impact on value creation network planning. Scenario 1 addresses a case when the planning of harvesting operations is outsourced; Scenario 2 discusses a crown land situation; and Scenario 3 illustrates a situation involving multiple forest owners. All these scenarios are unique and cannot be generalized. The purpose of discussing them is to show that forest planning decisions remain the same, whether the forest is “public” or “private”. However, the decision drivers and constraints may change depending on the strategic options chosen by the forest owner.

Scenario 1

The forest landowner can decide to outsource harvest planning to one or several companies (management consultant, association, etc.) and then use their work to plan all activities involved in forest exploitation (Table 16). This could apply to **a** company **that is both a forest landowner and a forest products producer** (Figure 65). Even then, the forest landowner has no control over the strategic decisions made by the government.

Table 16: Strategic decisions and options to manage the forest: outsourced harvest planning

Nature of decisions	Business unit	Task	Strategic option
Strategic direction	Government	Establish forest rules and policies to protect the forest	MAKE
		Establish financial rules and industry policies to protect the public	MAKE
Forest management	Forest landowner and producer	Determine the allowable cut, the products to be offered to customers, the silvicultural techniques and the forest road network	MAKE
Business Management	Management consultant/Association	Identify business strategies that will lead to a competitive advantage, the infrastructure needed, the office location, the services to be offered to companies, etc.	MAKE
Tactical planning of forest operations	Forest landowner and producer	Define the harvesting process, the location of the log yard, the forest roads to be used, etc.	MAKE all the activities, but OUTSOURCE harvest planning to management consultant/association
Tactical planning of operations	Management consultant/Association	Determine the level of financial, material and human resource needed	MAKE harvest planning
Scheduling and control of forest operations	Forest landowner and producer	Schedule silvicultural and other forest operations as well as the transportation activity, fulfil demand	MAKE
Scheduling and control of operations	Management consultant/Association	Schedule the operations and services to be performed for clients, determine payment options, fulfil demand, etc.	MAKE

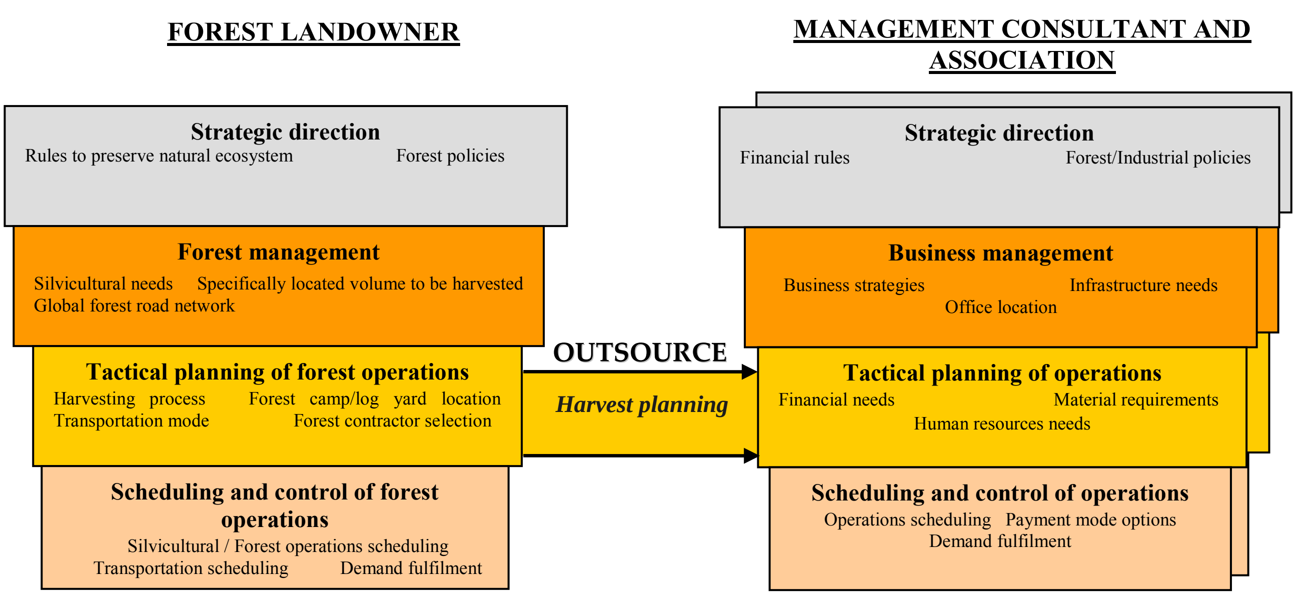


Figure 65: Example of outsourced activity

Scenario 2

The forest landowner can also choose to "not make", that is, keep the forest "as a forest" (e.g., for future projects), or sell specifically located volumes to other companies (i.e. outsource) and let them take charge of tactical planning of forest operations under certain conditions (Table 17). It will therefore be these companies' responsibility to determine the harvesting plan, convert trees into products, etc. This applies to **Canadian public forests,** where the government is the forest landowner and sells timber tights to forest products companies (Figure 66). The government determines the forest rules and policies as well as the specific volumes to be allocated. Even if the tactical planning of operations is outsourced, the government has control over activities. Furthermore, some incentives and penalties are defined so as to guarantee environmentally sustainable behaviour (e.g., credit for silvicultural treatments, penalties if the volume harvested is higher or lower than agreed, etc.).

The decisions related to tactical planning as well as scheduling and control of forest operations are made by various business units. In turn, these companies may choose to make/outsource/not-make in collaboration with other organizations some or all of the activities involved. For example, a forest products business may decide to collaborate with other companies to define the future harvesting plan, share some products (e.g., specific tree species) or resources (e.g., hire the same forest contractor), and optimize different activities (e.g,. backhauling for wood transportation). The forest products company can also decide to plan its procurement needs and then not make the scheduling and control of forest operations. Consequently, the forest contractor becomes responsible for performing forest operations; in turn, he is free to schedule and control all operations by himself, outsource some activities (e.g.: silvicultural treatments, wood transportation, etc.) or collaborate with another organization.

Table 17: Strategic decisions and options to manage the forest: Canadian public forest

Nature of decisions	Business unit	Task	Strategic option
Strategic direction	Government	Establish forest rules and policies to protect the forest	MAKE
		Establish financial rules and industrial policies to protect the public	MAKE
Forest management	Government	Determine the allowable cut, the silvicultural techniques and the forest road network policies	MAKE
Business management	Forest products companies	Determine the business strategies that will lead to a competitive advantage, the value proposition, the location of mills and warehouses, etc	MAKE
Business management	Forest contractors	Determine the business strategies that will lead to a competitive advantage, the type of equipment to buy, the services to offer to forest products companies, etc.	MAKE
Tactical planning of forest operations	Government		OUTSOURCE tactical planning to forest products companies
Tactical planning of forest operations	Forest products companies	Define the harvesting process, the harvesting plan, the fibre needs, log yard locations, the forest roads to be used, etc.	MAKE the tactical planning
Tactical planning of operations	Forest contractors	Determine the level of financial, material and human resources needed	MAKE
Scheduling and control of forest operations	Government	Establish a regulation-based control system for operations	NOT MAKE the scheduling and control of forest operations
Scheduling and control of forest operations	Forest products companies	Define the procurement plan	NOT MAKE the scheduling and control of forest operations
Scheduling and control of operations	Forest contractors	Schedule silvicultural operations, schedule and control forest operations, schedule transportation activities, etc.	MAKE the scheduling and control of forest operations

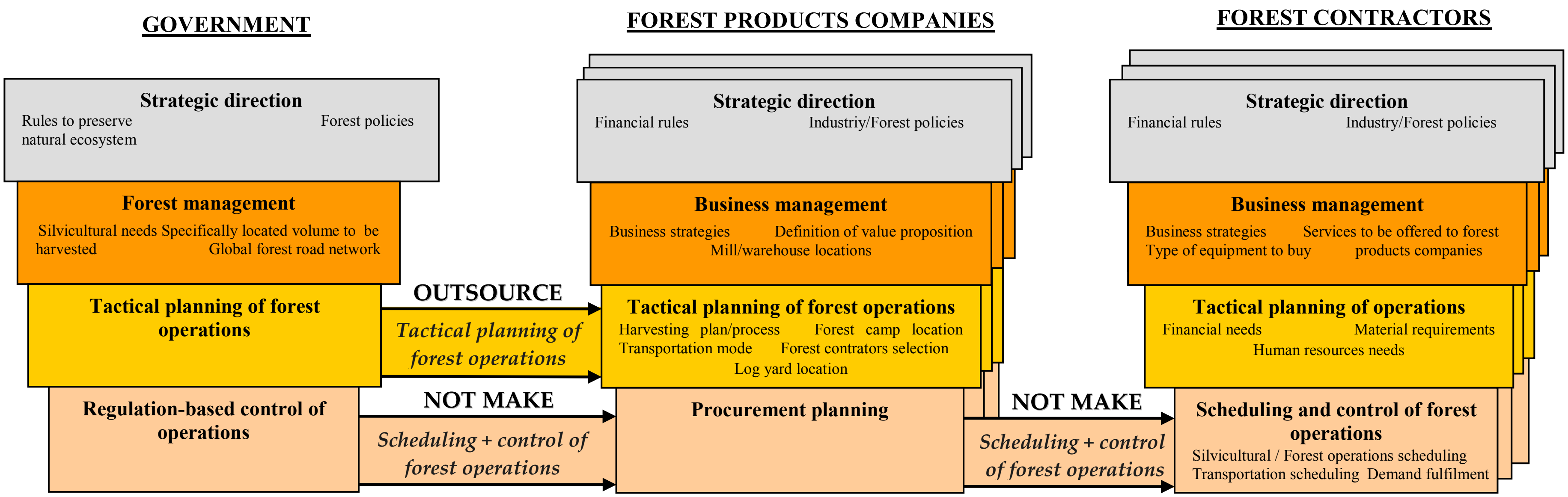


Figure 66: Example based on the Canadian public forest

Scenario 3

A third scenario applies **to forest landowners who choose to work together,** forming a co-operative (Table 18) to efficiently develop and manage the forest as well as allocate fibre to several forest products companies. They consequently have to jointly plan all forest operations as well as share the benefits of their association (Figure 67).

Table 18: Strategic decisions and options to manage the forest: the case of multiple forest landowners

Nature of decisions	Business unit	Task	Strategic option
Strategic direction	Government	Establish forest rules and policies to protect the forest	MAKE
		Establish financial rules and industrial policies to protect the public	MAKE
Forest management	Forest landowners Forest co-operative	Determine the volume to be harvested, the silvicultural techniques to be implemented, the required forest road network, etc.	COLLABORATE

Table 18: Strategic decisions and options to manage the forest: the case of multiple forest landowners (cont'd)

Nature of decisions	Business unit	Task	Strategic option
Business management	Forest products companies	Determine the business strategies that will lead to a competitive advantage, the value proposition, the locations of mills and warehouses, etc	MAKE
Tactical planning of forest operations	Forest landowners Forest co-operative	Establish the harvesting plan, the harvesting process, fibre needs, log yard locations, the forest roads to be used, etc.	COLLABORATE
Tactical planning of operations	Forest products companies	Determine the level of financial, material and human resources needed to satisfy demand	MAKE
Scheduling and control of forest operations	Forest landowners Forest cooperative	Schedule silviculture operations, schedule and control forest operations, schedule transportation activities, etc.	COLLABORATE and MAKE the scheduling and control of forest operations
Procurement planning and scheduling	Forest products companies	Define the procurement plan	NOT MAKE the scheduling and control of forest operations

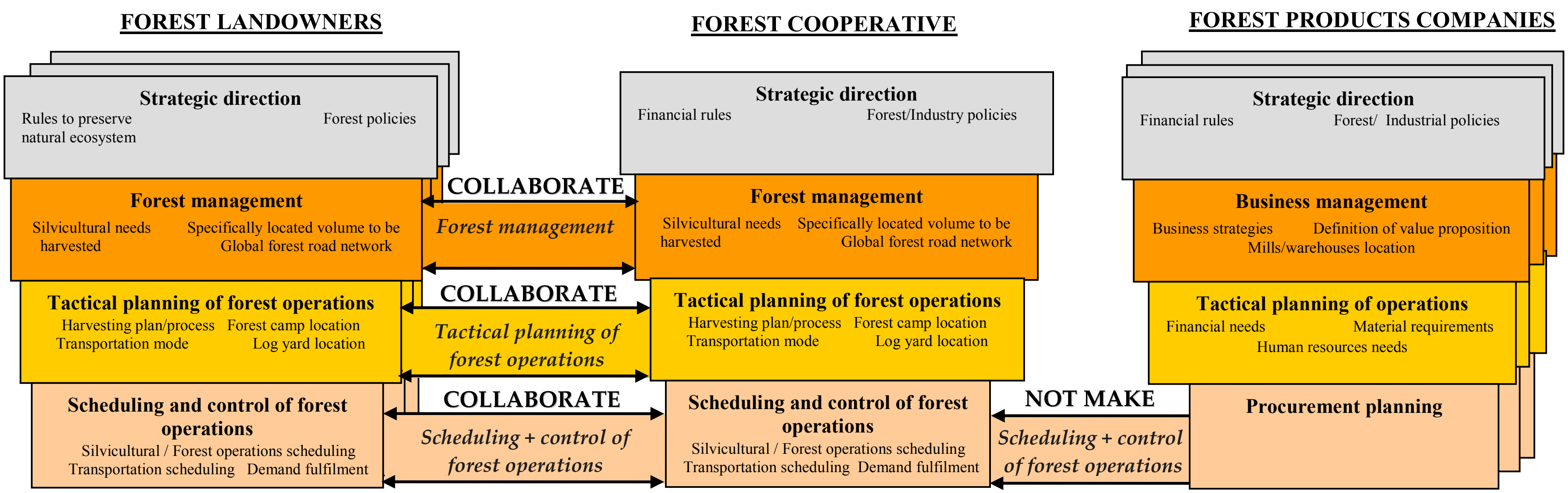


Figure 67: Example based on multiple forest landowners

Depending on circumstances, stakeholders of the forest supply chain may therefore be responsible for planning and performing various activities, or they may decide to outsource some operations, or perform them in collaboration with other organizations. Figure 68 summarizes the concept.

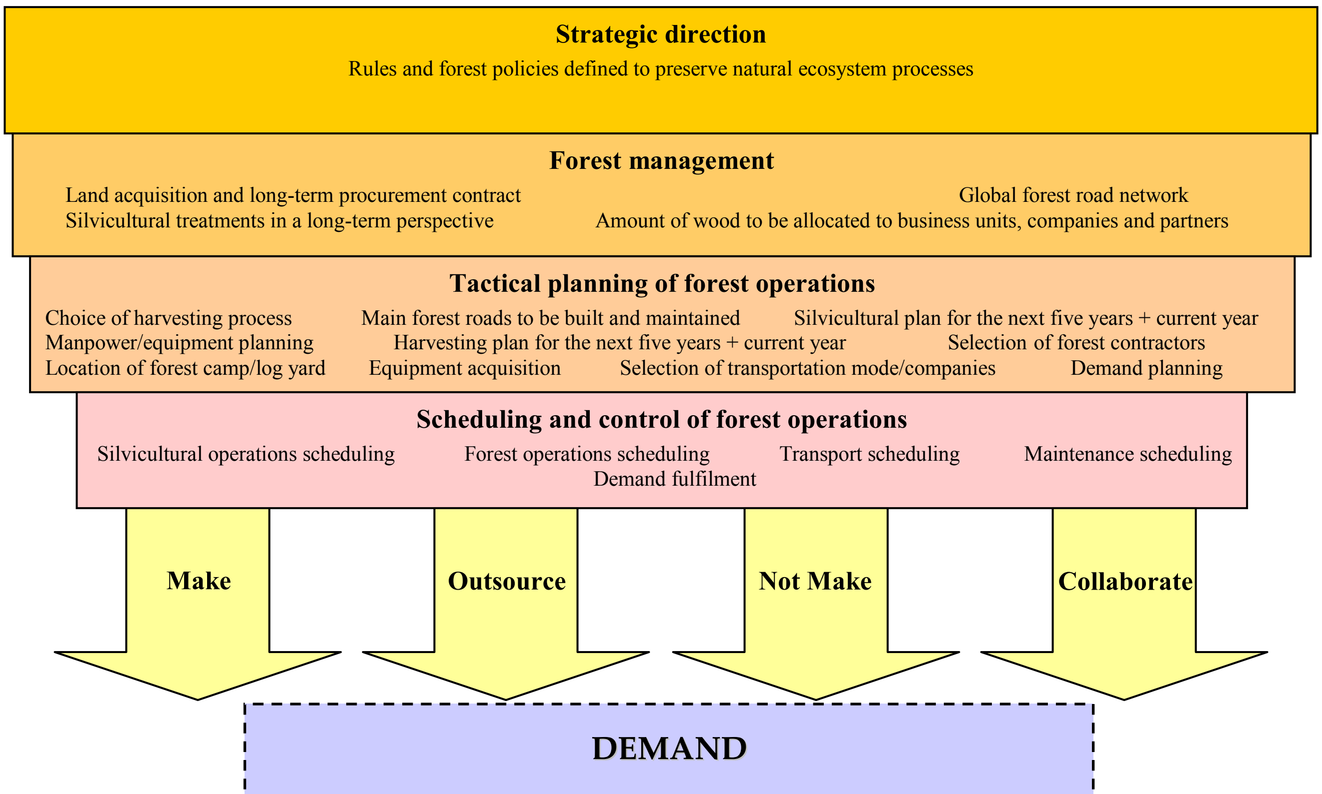


Figure 68: Evolution of forest planning decisions and strategic options

7 Business Relationships

Under current economic conditions, optimization of network activities does not guarantee competitiveness in the global market. Given that raw materials are typically bought from different suppliers, products are sold to multiple wholesalers, merchants and customers, and goods are moved from mills to markets via transportation companies, the establishment and management of business relationships is a key success factor. Rather than sell or buy without any collaboration scheme, companies must work together to better coordinate activities and respond promptly to customer demand.

7.1 Effect of Decentralized Planning

When companies make planning decisions, they primarily try to maximize their own profit rather than the profit of the value creation network. Let us consider, for example, the case of a pulp and paper producer and its merchant. The producer has to correctly plan all operations in order to satisfy the demand of the merchant as well the demand of other clients. Since production and distribution capacities are usually limited, the producer's plan also has to take this factor into consideration. The plan will therefore aim to design operations for maximum revenue generation; minimize procurement, production, distribution and inventory costs; and satisfy demand as well as capacity constraints (Figure 69).

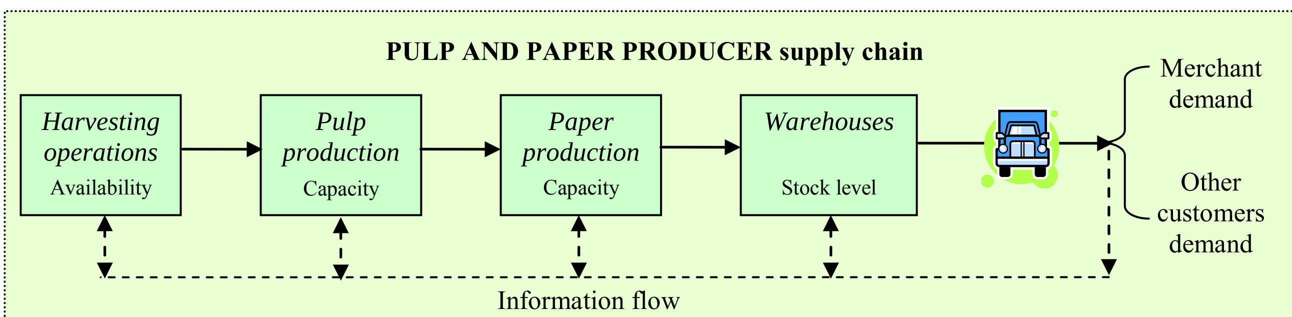


Figure 69: The pulp and paper producer supply chain

The merchant also has to efficiently plan activities to satisfy printer and retailer demand, taking a number of operational constraints into account. Thus, the resulting plan will aim to maximize revenue; minimize buying, ordering and inventory costs; and satisfy demand as well as inventory constraints (Figure 70).

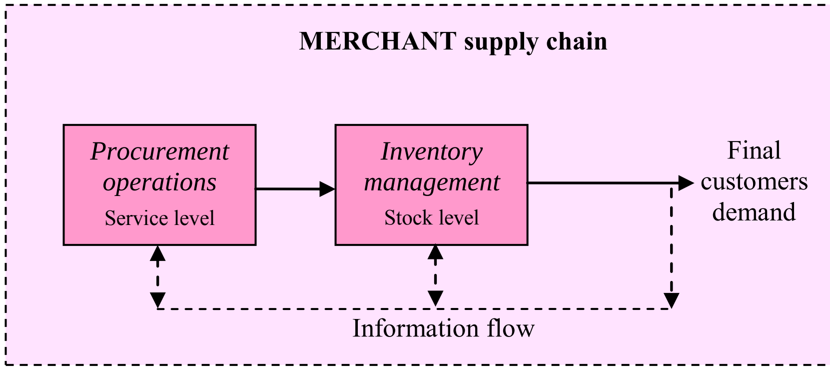


Figure 70: The merchant supply chain

In the absence of any collaboration scheme or coordination mechanism, operations will be processed with no consideration given to the value chain. Consequently, the products may not be available on time and at the right price; the value creation network inventory will not be optimized; and so on. The bullwhip effect is certainly a good illustration of this phenomenon (see the section on "information flow"). But if stakeholders exchange information and make decisions that take into account the other organization's circumstances (e.g.: its inventory, capacity, demand, etc.), their operations will be better synchronized, their lead time will decrease and customer service will improve.

This is why companies need to create key business relationships with their suppliers, distributors and customers, in order to improve not only their own operations, but also those of the whole network (Figure 71). This can be achieved by implementing collaboration approaches as well as different incentives.

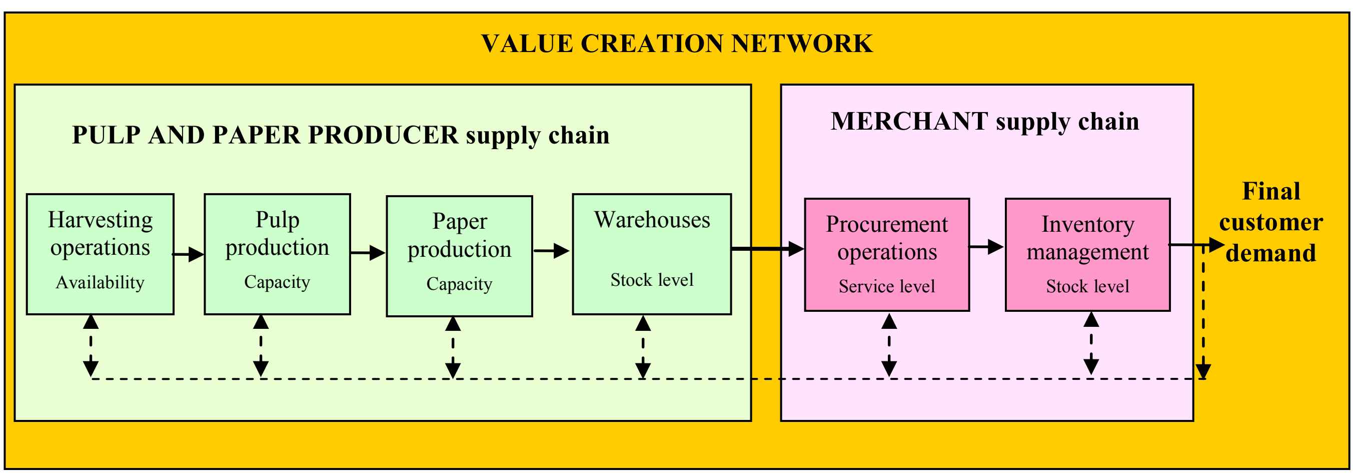


Figure 71: The value creation network with information exchange

7.2 Company Collaborations

Collaboration occurs when two or more entities form a coalition and exchange or share resources (including information), with the goal of making decisions or performing activities that will generate benefits that they cannot (or can only partly) generate individually. Various forms of collaboration are possible. The nature of the information to be exchanged as well as the degree of interaction between partners will vary with the type of relationship implemented (D'Amours *et al.*, 2004) (Figure 72).

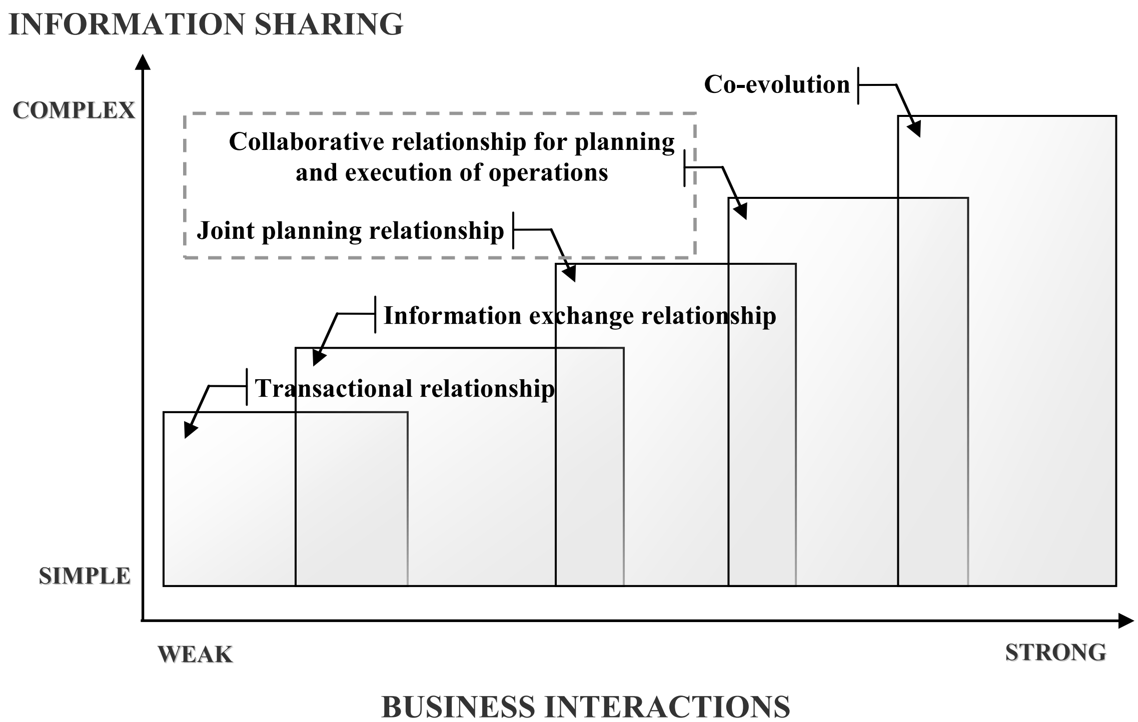


Figure 72: Evolution of business relationships (D'Amours *et al.*, 2004)

For example, two companies that choose to adopt a simple form of collaboration may exchange only transactional information such as orders, payments, delivery confirmations, etc. (Figure 72). On the other hand, companies that decide to jointly plan operations need to agree on objectives; share strategic information such as customer demand, forecasts and operational capacities; and decide on key performance indicators. A strategic alliance or co-evolution relationship also involves a more complex form of partnership that can lead to the creation of a new entity such as a consortium or a joint venture. A consortium is a type of alliance designed to create a set of competencies; it necessitates an investment in terms of capital, resources and technologies. On the other hand, a joint venture is a long-term agreement joining two or more parties for the purpose of a particular business undertaking (e.g., decrease transportation and inventory costs, access new markets, etc.). In addition, all parties agree to share in the profits and losses of the enterprise.

7.2.1 Forms of Collaboration

Inter-firm relationships can bring together business entities which are competitors, collaborators or supplier/customers (Lehoux *et al.*, 2009b). Collaboration may be vertical and horizontal. Vertical collaboration occurs with business units belonging to the same supply chain. Information sharing to reduce the bullwhip effect is a typical example of vertical collaboration between business units located at different levels in the same supply chain. Horizontal collaboration occurs with business units outside the supply chain, such as a competitor with whom a company can share warehousing capacity. Group purchasing organizations are a typical example of horizontal collaborations among buyers belonging to different business units. A third dimension combines both vertical and horizontal collaborations.

In all cases, the partnerships will be related to certain forms of interdependence. They are listed and briefly described in Table 19.

Table 19: Forms of interdependence (Frayret *et al.*, 2004)

Type of relation	Description
1. Pooled interdependence	Occurs when each part of a system makes a discrete contribution to the whole, while each part is supported by the whole
2. Producer-consumer relationship or sequential interdependence	Links two manufacturing activities for which the output of one is the input of the other
3. Reciprocal relationships	Concerns activities whose outputs are the reciprocal inputs of the other activity
4. Intensive interdependence	Relates to the intrinsic sophistication of activities that are imbedded
5. Task/sub-task interdependencies	Relates to the decomposition of tasks into sub-tasks
6. Simultaneity interdependence	Occurs when activities need to be performed, or not, at the same time, such as for meeting scheduling

7.3 Collaborative Strategies

In recent years, different strategies have been developed to help businesses work together better and achieve collaboration benefits.

7.3.1 Vendor Managed Inventory (VMI)

VMI is an approach developed in the eighties whereby the supplier is responsible for managing the inventories of its products for the customer (Figure 73). The supplier is responsible for taking care of the entire replenishment process, and is vested with the necessary authority. This method aims to efficiently use production and distribution capacities, increase visibility, improve the replenishment process and decrease value chain costs (such as stock-out costs, distribution costs, etc.).

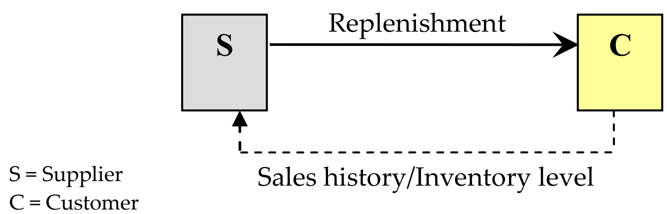


Figure 73: Illustration of the VMI mode (Adapted from Lehoux *et al.*, 2008)

However, implementing this collaboration scheme necessitates multiple stages:

1. **Changes to management**. As the supplier acquires new tasks, the customer loses responsibilities (loss of control of own inventories). So partners need to be ready to accept change as well the additional costs associated with the method.
2. **Synchronization of information**. The partners have to share different types of information through a standard format that can be processed by their respective systems (e.g.: same products list, same product codes, etc.).
3. **Information exchange**. Key information such as sales history and stock levels need to be exchanged to correctly plan operations and the replenishment process. Up-to-date and accurate information has to be available at the right time.
4. **Management policies**. To establish a successful relationship, the partners have to agree on the replenishment plan, the desired service level, the frequency of deliveries, etc.
5. **Exchange of sales history**. The customer must send its sales history to the supplier covering at least one year, so that the supplier can plan operations adequately.
6. **Management of the relationship**. The relationship must be managed in such a way as to ensure that the information is exchanged as well as the service and stock level observed.

Several forest products companies have recently implemented this method with success. For example, the Broadleaf company has established a VMI relationship with one of its main customers, a builder merchant in Canada. The new collaboration mode has improved operating margins across sites thanks to better inventory management practices and reduced capital costs. Moreover, the company has improved its ability to control and decrease lead times. IKEA is another example of a company that has implemented the VMI method in order to optimize the delivery chain. With this approach, inventories at the distribution centres and at the stores are now managed by wood suppliers. This has led to an enhanced service level combined with lower inventories. The VPK Packaging Group has also created a VMI partnership with some of its customers so as to optimize both its own supply chain and that of its customers. The company has achieved significant benefits such as lower operating costs, better network visibility, a decrease in stock shortages, etc.

7.3.2 Collaborative Planning, Forecasting and Replenishment (CPFR)

CPFR is a collaborative process whereby trading partners can jointly plan key supply chain activities, from the production and delivery of raw materials to the production and delivery of final products to end customers. Collaboration encompasses business planning, sales forecasting and all operations required to replenish raw materials and finished goods. The objective is to share information such as sales history, product availability, lead times, etc., to better synchronize activities and eliminate excess inventory (Figure 74). This technique is also useful to rapidly identify any changes in the forecasts or inventory, in order to correct problems before they negatively impact sales or profits.

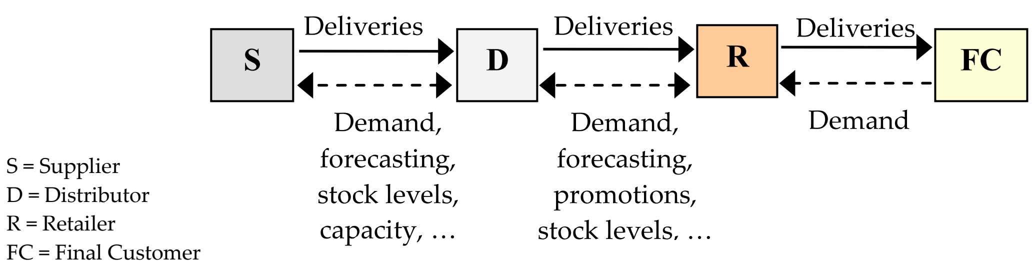


Figure 74: Illustration of the CPFR method (Adapted from Lehoux *et al.*, 2008)

Proper implementation of this method can be very complex, and it involves significant investments in time and resources:

1. **Front-end agreement**. Participating companies have to decide what constitutes a successful program: goals and objectives, resources needed, products targeted, merchandising method, etc. The establishment of a contract at this stage is a good way to ensure adequate commitment to the collaboration. In addition, key performance indicators are needed to measure the efficiency of the program.
2. **Joint business plan**. It is necessary to agree on management rules, the schedule of activities, inventory policy changes, plans for promotions, etc., in order to support the program. Each partner enters the details of the joint business plan into its own

planning system, and makes adjustments on a regular basis, as market conditions shift and logistical problems occur.

3. **Sales-forecast collaboration**. The partners have to share consumer demand forecasts, and identify and resolve areas in which their plans do not match.
4. **Order-forecast collaboration**. Once initial sales are made, the partners determine replenishment plans, taking inventory policies into account. These plans also include a process to resolve exceptions, including instances where actual orders greatly deviate from expected demand. The short-term part of the forecast is used to generate the order, while longer-term forecasts are used for planning purposes.
5. **Order generation**. Finally, orders are generated and delivered. Results data such as point-of-sale information, orders, shipments and on-hand inventory are shared. Moreover, forecast accuracy problems, overstock/understock conditions, and operational issues are identified and resolved.

Several companies have gradually been implementing this new collaboration mode. Kimberly Clark and Metro-Group, Procter and Gamble and Wal-Mart, Sears and Michelin, West Marine and ITT Industries are examples of companies that have chosen to work together so as to share more information and improve supply chain performance. In the forest products industry, nobody has yet adopted this technique, maybe because of the implementation cost, or due to the “trust” and resources needed. However, companies such as Domtar have implemented some forms of collaboration with their customers in order to increase the profitability of the entire network. This is a first step that could lead to more sophisticated techniques such as CPFR.

7.4 Collaboration Incentives

The establishment and management of efficient inter-firm collaborations can be difficult. The partners have to choose the right collaboration approach depending on their circumstances, and make sure that the relationship is profitable for everyone. It cannot be a case of “I win/you go and figure out how you win”, since a partner who does not gain enough benefits from the relationship will probably choose to work with someone else. Long-term collaborations have to be based on mutual benefits and risk sharing. This has raised the need for optimized collaboration incentives.

Many researchers have studied the use of incentives to improve the effectiveness of supply chain collaborations. A detailed review of these methods and their impacts can be found in Cachon (2003).

7.4.1 Price Agreements

One frequently used incentive considers the price charged by the supplier to the customer. The idea is to offer a lower price before a high demand period (e.g., the sale season), and a higher price during the high demand period to properly use production capacity and share inventory costs (Figure 75). If adequately defined, this incentive can play an important role in the coordination of the value creation network depending on conditions (demand pattern, product life cycle, price volatility, etc.).

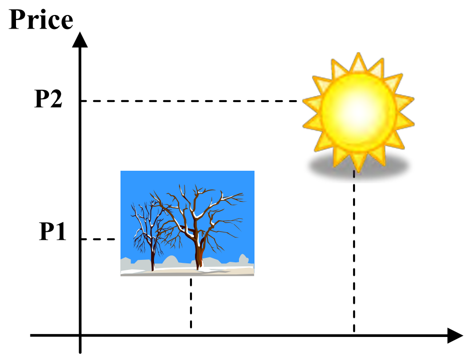


Figure 75: Price agreement for a supply chain

7.4.2 Buyback Contracts

This incentive is based on product returns. The retailer (or merchant or customer, etc.) can return some or all unsold items for compensation (Figure 76). The supplier recovers the salvage value of the returned items at a given rate per unit. In this way, the retailer is encouraged to order the optimal quantity for the value creation network.

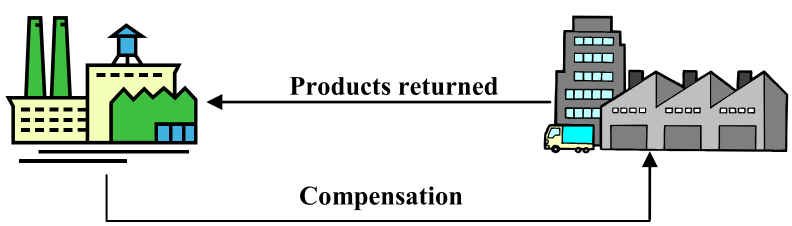


Figure 76: Illustration of a buyback contract

7.4.3 Revenue Sharing Contracts

With a revenue sharing contract, the retailer shares the revenue generated from sales with the supplier in return for a lower supplier price. Such incentives have become more prevalent in the video/DVD rental industry relative to the more conventional wholesale price contracts.

7.4.4 Quantity Flexibility Contracts

The quantity flexibility contract is a method for coordinating material and information flows in supply chains operating under dynamic environments. Under such contracts, the retailer has to commit to a minimum order, but this can be adjusted as more accurate information of the demand becomes available.

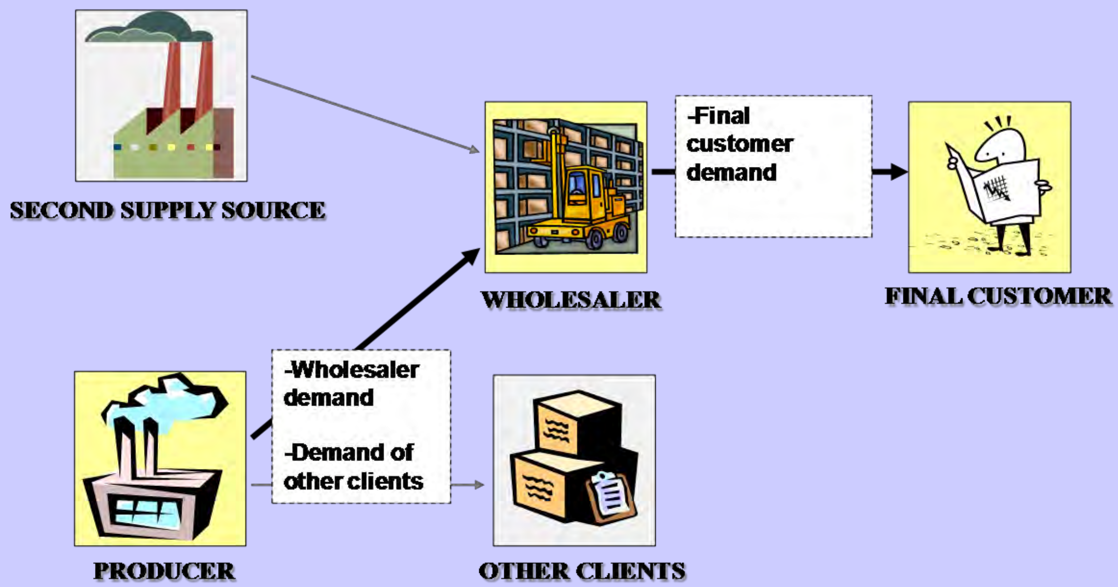
7.4.5 Quantity Discounts

Quantity discounts can be described as reductions in unit prices. They are commonly used to encourage buyers to order the best quantity for the network.

Other incentives have also been used. They all have the same objective, which is to: coordinate stakeholder decisions, and maximize profit in the value creation network.

Case study 8: Collaboration approaches in the pulp and paper industry

This case study conducted by Lehoux *et al.* (2009a) relates to a pulp and paper producer that decided to establish a partnership with one of its clients.



The objective was to identify which collaboration model would ensure an efficient exchange of products and information as well as maximum benefits for the network and for each partner. Four potential approaches were selected: a traditional system without any collaboration scheme, CR (Continuous Replenishment), VMI (Vendor Managed Inventory) and CPFR (Collaborative Planning, Forecasting and Replenishment). For each approach, decision models from the point of view of both the producer and the wholesaler were developed and compared.

The results showed that CPFR generated the greatest total system profit through optimization of both transportation and inventory costs. CPFR inventory costs were reduced by as much as 44% as compared to other approaches, while CPFR transportation costs were reduced by as much as 18%. VMI was second best, with reductions in transportation costs. CR and the traditional system yielded the lowest total system profit.

Following comparisons of profit at the network level, the investigation looked into the profits of individual partners. It revealed that CPFR generated the greatest profit for the producer, while the CR technique was the most beneficial for the wholesaler. For this reason, a method for sharing benefits was defined, based on transportation savings, so that CPFR collaboration should be profitable for both partners.

8 Survey of published work

Many of the issues covered in the previous sections have been addressed by both the international and the national scientific communities trying to develop concrete tools and strategies for improving industry performance.

8.1.1 National and International Research

National and international researchers typically address a specific problem relating to one or more business units of the forest products value creation network from a strategic, tactical or operational point of view.

Forest management
A first set of papers deals with forest management, and explores different methods to optimize the long-term planning process. Some of these models are based on operational research (e.g.: harvest planning, road construction and maintenance planning). For example, Martell *et al.* (1998) explained how operational research models can be used to support strategic forest management planning as well as short-term forest planning, forest operations and forest fire management. Other models are based on simulation (e.g., simulations of growth or ecological impact). In the public forest environment, governments generally use simulation models to consider multiple criteria when evaluating different forest management strategies. Davis *et al.* (2001) described this technique in detail. Some economic models have also been used to connect fibre availability to the value of the forest products (see for example the work of Gunn, 2007).

However, given the very large number of possible scenarios that can affect forest management planning, and the mass of information required, some researchers have proposed a hierarchical planning approach. As mentioned by Gunn (2005), the hierarchical planning approach follows from the observation that there is a natural hierarchy in decision problems, and that this decision hierarchy frequently corresponds to the management hierarchy. In the first step, treatments are decided with respect to volume, and this first set of decisions becomes constraints for spatial planning in the second step (see for example Weintraub and Cholaky, 1991, Hof and Pickens, 1987, Church *et al.*, 1994, Gunn, 1991, 1996 and 2005).

Spatial and environmental issues

Much work has also been conducted on the spatial and environmental aspects of the forest. With the advent of Geographic Information Systems (GIS) and associated spatial data, integrated forest management and harvest planning practices have begun to show increasing concern for spatial relationships and environmental conditions. Particular issues of interest include: promoting the richness and diversity of wildlife; creating favourable habitats for flora and fauna; ensuring soil and water quality; preserving scenic beauty; and guaranteeing sustainability. Tactical models seek to address these issues, implicitly or explicitly, by structuring the necessary constraining relationships and limiting spatial impact.

One of the main approaches to the modelling of spatial relationships and environmental conditions at the tactical level has involved adjacency restrictions with green-up requirements. Specifically, a maximum local impact limit is established to restrict local activity over a given period of time. In the case of clear cutting, for example, this corresponds to a maximum open area, which is imposed on any management plan. Another important example relates to wildlife and the requirement that patches of mature habitats (i.e. contiguous areas of a certain age) must be maintained to allow animals to live and breed. To this end, potential areas must be grouped to form patches (see Öhman and Eriksson, 1998).

A number of models incorporate the maximum open area and adjacency constraints. They can be divided into two groups: unit restriction models and area restriction models. In the first approach, harvest areas are defined in such a way that if two adjacent areas are cut, they would violate the maximum open area restriction (see Murray, 1999). In the second approach, the harvest areas are not predetermined, but are generated using smaller building blocks. With such a model, it is possible to harvest adjacent areas, but the restrictions on maximum open areas must be dealt with directly when defining the areas. The second approach has the clear advantage of including many more possibilities (see for example McDill *et al.*, 2002, Murray and Weintraub, 2002, Goycoolea *et al.*, 2005 and Gunn and Richards, 2005).

Although strategic forest management decisions are supported by timber supply models, such models typically lack the ability to integrate the transformational capacity of the forest owners or their customers (e.g., sawmills, pulp mills) and the value and cost of forest products, both of which are tightly linked to the location of the mills and the markets. Gunn and Rai (1987) examined this issue and proposed a model supporting long-term forest harvest planning in an integrated industry structure. Schwab *et al.* (2009) used an agent-based model to analyze the impacts of a market downturn in the US forest products market on forest industry structure and mountain pine beetle salvage harvesting in British Columbia. For each simulation year, the model proceeds from growth and yield modelling, over production planning, harvesting, and manufacturing, to product pricing and market trading.

Harvesting and transportation

Several studies have been devoted to the optimization of forest road systems and the selection of the transportation infrastructure (see Epstein *et al.*, 2007). For example, Richards and Gunn (2000, 2003) explained the challenges of designing a forest road network, while Andalaft *et al.* (2003) presented a model called OPTIMED, designed to simultaneously optimize the harvesting plan, seasonal storage and road network deployment over a two- to three-year planning horizon. In addition, Olsson (2004) and Henningsson *et al.* (2007) showed models based on operational research techniques that include decisions about restoring existing forest roads and transportation in order to provide access to available harvest areas during the spring thaw when only certain roads are useable. The model used by Henningsson *et al.* (2007) is the basis for the decision support system RoadOpt (see Frisk *et al.*, 2006a), developed by the Forestry Research Institute of Sweden.

Because transportation is a major part of forest operations, harvest planning is sometimes combined with transportation and road maintenance planning, with an annual planning horizon. Karlsson *et al.* (2004) proposed a model based on mixed-integer linear programs that can be used to solve this multi-element planning problem. A previous article by the same authors (Karlsson *et al.*, 2003) had presented a model that integrated the handling of crews, transportation and storage. Other important issues in transportation include the possibility of integrating truck transport with other modes of transportation, specifically ship and rail (see Forsberg *et al.*, 2005 and Broman *et al.*, 2006). Transportation operations provide the operational link between the forest supply chain and other supply chains. Given that transportation costs account for a large proportion of the total cost of wood fibre delivered to a mill, many research teams around the world have been working on these problems in order to reduce the cost of transportation through optimal backhauling (see for example Carlsson and Rönnqvist, 2007).

Different advanced systems have also been created to address this type of problem. Good examples could be the equipment and road planning system PLANS (see Twito *et al.*, 1987) or a similar system introduced in New Zealand and described by Cossens (1992). These two systems are used to simulate harvest area choices, roads to be built to harvest the areas, and the volumes of timber that could be harvested. The user suggests equipment locations, and, in a visual, interactive way, the system determines the areas to be harvested by each machine, the roads that need to be built and the timber volumes that can be harvested. Jarmer and Sessions (1992) developed a system to analyze the feasibility of cable logging configurations. Epstein *et al.* (2006)

developed a system that incorporated equipment location decisions. Their system, based on user-GIS interaction and a heuristic for determining good solutions, has been used successfully by forest firms in Chile and Colombia.

The issue of matching standing timber and specific product orders has also been addressed by some researchers. For example, Carlgren *et al.* (2006) developed a model that integrates transportation and sorting at the harvest level. Sorting the logs in the forest leads to higher harvesting and transportation costs, but it provides better quality logs for sawmill production. By improving transportation planning (e.g., by using backhauling), higher harvesting costs can be mitigated. Moreover, bucking decisions are frequently integrated into the decisions regarding which stands should be harvested. For example, different bucking methods have been explored by McGuigan (1984), Eng *et al.* (1986), Mendoza and Bare (1986), Briggs (1989) and Sessions *et al.* (1989). Successful applications are reported to have been used in New Zealand by Garcia (1990) and in Chile by Epstein *et al* (1999). Bucking can be carried out at sawmills, where each tree is scanned and analyzed individually, or in-forest by fitting mechanized harvesters with optimizers. Marshall (2007) studied two basic approaches: Buck-to-Value, in which specific prices are assigned to each product, and Buck-to-Order, in which products are harvested to satisfy specific orders. Commercial codes have been developed for such processes and are now used by forest firms.

Marinescu *et al.* (2005) analyzed how to allocate the timber to different forest products companies in order to maximize both the profit and the employment values generated by processing the timber into lumber products. They examined a case study involving three forest products companies to validate the model. In a second article, Marinescu and Maness (2008) proposed a more complex model as a decision tool to analyze tradeoffs between five forest management criteria (i.e. profit, employment, wildlife, recreation and visual quality). They showed that, with this model, timber allocation may contribute to profitability by promoting manufacturing efficiency and flexibility to adapt to fluctuating market conditions.

<u>Operational routing</u>

Efficient systems have also been developed to optimize operational routing. For example, ASICAM (see Weintraub *et al.*, 1996) is a decision support system for logging trucks that received the Franz Edelman Award in 1998. This system is currently used by several forest companies in Chile and other South American countries. It relies on a simulation-based heuristic to produce a one-day schedule. Also, the Swedish system RuttOpt (see Flisberg *et al.*, 2007 or Andersson *et al.*, 2007) establishes detailed routes for several days and integrates a GIS with a road database. Tests of this system showed cost reductions between 5% and 20% compared to manual solutions. In addition, researchers Palmgren *et al.* (2003, 2004) used a mathematical method to solve a problem characterized by one truck type and a one-day planning horizon, while Murphy (2003) formulated a general integer programming model for routing optimization, but used it only for tactical planning. Gronalt and Hirsch (2005) described a method for determining routes given a set of fixed destinations. Their formulation includes time windows and multiple depots for solving small problems involving only one time period.

Dispatching involves determining routes (or partial routes) continuously during the day, taking real time events (e.g., queuing, bad weather, truck breakdowns) into account. Rönnqvist and Ryan (1995) described a solution method for dispatching, which finds solutions for a fleet of trucks within seconds.

The Åkarweb and MaxTour systems are based on tactical flow models, and their results are used to support manual routing and scheduling. Åkarweb (see Eriksson and Rönnqvist, 2003) is a web-based system that computes potential transport orders each day by solving an LP-based backhauling problem. MaxTour, developed in Canada by FpInnovations-Feric and CIRRELT (presented by Gingras *et al.*, 2007), combines predefined loads in origin/destination pairs. In this system, the log destination has already been determined and MaxTour is primarily used to establish single backhauling routes rather than schedules.

Forwarding operations are another type of routing problem. Flisberg and Rönnqvist (2007) recently suggested a system designed to support forwarding operations at harvest sectors. Using a decision support system, they developed better routing selections, and observed an improvement in forwarding operations (about 10%). In addition, the system yielded better information on supply locations and volumes that could be used in subsequent truck transportation planning.

Pulp and paper

Issues of supply chain design in the pulp and paper industry have only recently started to attract the attention of practitioners and researchers. One reason for this may be that the industry has typically been driven by a push model in which the main decisions relate to when and where to cut the trees, followed by decisions about processing and selling the resulting products.

Bender *et al.* (1981) were among the first to address the design of production/distribution networks in the pulp and paper industry. Their paper explained how International Paper analyzed and solved its network design problems using mathematical programming models. Martel *et al.* (2006, see also the Forac research section) proposed an operational research model for optimizing the structure of multinational pulp and paper production/distribution networks. In their report, the authors identified the main factors having an international impact on the industry, and showed how these factors can be taken into account when designing a supply chain. However, adding these features to the planning model considerably increased the complexity of the problem. The authors used a general production/distribution network model dealing with many-to-many processes to illustrate how this kind of problem could be solved. In their model, harvesting decisions are not optimized and the fibre supply is a constrained input.

Gunnarsson *et al.* (2007) developed a strategic planning model for the Södra Cell kraft pulp supply chain. The main objective of this model was to optimize allocation of the various products to the different mills. Södra Cell has five pulp mills, three in Sweden and two in Norway, all producing kraft pulp. The entire pulp supply chain is described using a mixed-integer linear model. On the demand side of the model, all potential contracts with individual customers are defined, together with the expected net prices to be obtained. The user defines whether a given contract has to be taken in its entirety or if a part of the contract can be chosen. Various modes of transportation can be selected to deliver the pulp to its final destination. Pulp recipes are allowed to vary within a min/max range in terms of the amounts of the different fibre types used to make different products. This model is used by Södra Cell's management to evaluate different scenarios of fibre availability and cost, or to optimize the composition of the product portfolio. In fact, since transition costs are relatively high, a kraft pulp mill suffers significant costs due to having to produce many different products, especially when mixing hardwood and softwood on the same production line.

Gunnarsson *et al.* (2006) dealt with the strategic design of the distribution network at Södra Cell, which operates three long-term chartered ships just for pulp distribution. The efficiency of the ship routing depends on the terminal structure. With a few large-volume terminals, there is a greater chance that the ships can be unloaded at a single terminal, whereas, if there are many small-volume terminals, ships will probably have to stop at two or more terminals to be unloaded. The authors developed a model in which terminal location is combined with ship routing. This is an example of strategic planning, in which it is also important to account for some operational aspects (i.e. ship routing).

Philpott and Everett (2001) presented their Fletcher Challenge work, which was to develop a model (PIVOT) for optimizing the paper supply chain. PIVOT is used to optimally allocate supplies 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 were added to model specific mill conditions, such as interdependencies between paper machines in a mill and distribution cost advantages in certain directions due to backhauling opportunities. Successful implementation of PIVOT led to further development of the model by the authors in cooperation with the Fletcher Challenge management team.

Everett *et al.* (2000) proposed the SOCRATES model, 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 are the introduction of capital constraints and the use of a multi-period planning horizon. This model was further developed in the COMPASS model (see Everett *et al.* 2001), implemented in three Norske Skog mills in Australia and New Zealand. The objective function was modified to account for taxation in the two countries, and a feature was added to allow the paper recipe to vary in terms of the wood pulps used, depending on capital investment decisions. The intention was to evaluate the potential use of a less costly recipe based on capital investment for the paper machine.

Other models of interest have also been developed to support tactical planning in the pulp and paper industry. For example, Bredström *et al.* (2004) developed one for the Swedish pulp producer, Södra Cell. This model can be used to plan with respect to individual wood sources, mills and even aggregate demand zones, or to produce individual production schedules for the mills. Compared to manual planning, the optimized schedules reduce global storage and logistics costs, despite an increasing number of changeovers.

At the operational level, Murthy *et al.* (1999) optimized the multiple stage production planning problem of paper manufacturing. Here, "planning" includes assigning orders to machines (possibly at different locations), sequencing the orders on each machine, trim scheduling for each machine and load planning. The authors reported several real-world implementations in US-based Madison Paper Inc., resulting in substantial savings in trim loss and distribution costs. Keskinocak *et al.* (2002), Menon and Schrage (2002) and Correira *et al.* (2004) also contributed to the idea of integrated scheduling and cutting approaches in a Make-to-Order strategy. Martel *et al.* (2005) offered a general discussion of the synchronized production/distribution problem, defining the planning problem under three different strategies: Make-to-Stock, Sheet-to-Order and Make-to-Order. Bredström *et al.* (2005) dealt with operational planning for pulp distribution. Their model focuses on routing and scheduling ships, in coordination with other means of transportation, such as truck and rail.

Bergman *et al.* (2002) studied roll cutting in paper mills. Roll cutting is a well-known academic problem for which efficient solution methods exist. However, in an industrial setting, there are many practical issues to consider, such as a limited number of knives in the winder, products that must (or must not) be cut in the same pattern, different product due dates or limited inventory space. Another practical issue is that, given a minimum number of rolls, the objective is to use as few cutting patterns as possible in order to limit setup costs and times. This article describes a system that takes these issues into account and provides the results of tests with a set of case studies. Other roll cutting models particularly suitable for the paper industry have been presented by Sweeney and Haessler (1990).

Finally, Flisberg *et al.* (2002) described an online control system for the bleaching process in a paper mill. The problem involves determining the number of chemical charges in the different bleaching steps. The objective of the system is to help operators minimize chemical use, thus reducing the cost of chemicals, and improve pulp brightness (over time) before it reaches the paper machines.

Lumber, panel and engineered wood

For the lumber, panel and engineered wood supply chain, researchers have addressed a number of issues.

In the area of secondary manufacturing, for example, Farrell and Maness (2005) used a relational database approach to create a decision support system. This system, which is used to analyze short-term production planning issues, is able to evaluate production strategies in the highly dynamic environment typical of a wide variety of secondary wood product manufacturing plants. Donald *et al.* (2001) analyzed the benefits of integrating primary and secondary manufacturing. They developed two different production planning models, one for non-integrated value-added facilities and another that optimized production from the sawmill log yard through to secondary manufacturing. They demonstrated that production decisions in the value-added facility had a significant influence on production decisions in the sawmill. Integration of the two facilities yielded a 10% increase in revenue.

For timber and lumber products, Maness and Adams (1993) proposed a model integrating the bucking and sawing processes. Formulated as a mixed integer program, this model links log bucking and log sawing for a specific sawmill configuration. The proposed system can handle the raw material distribution of one sawmill over one planning period for a final product demand that is known. Maness and Norton (2002) later proposed an extension to this model capable of handling several planning periods.

Reinders (1993) developed a decision support system for the strategic, tactical and operational planning of one sawmill, where bucking and sawing operations take place in the same business unit. This model does not take into account other processes, such as planing and drying.

To tackle the impact of different strategic design and planning approaches on the performance of lumber supply chains, Frayret *et al.* (2007, see also the Forac research section) and D'Amours *et al.* (2006, see also the Forac research section) proposed an agent-based experimental platform for modelling different lumber supply chain configurations (i.e. many mills and generic customer/supplier relations). This model represents the sawmilling processes as alternative one-to-many processes constrained by bottleneck capacity. The drying processes are also represented as one-to-many processes, in which green lumber is divided into groups according to specific rules, and extended drying programs, including air drying, are considered. Like the first two processes, the finishing processes are modelled as one-to-many processes, but this time, with setup constraints. The researchers used different business cases to validate the system, including industry implementation to test the platform's scaling capacity. In addition, simulations were conducted to evaluate different strategies for the lumber industry, given different business conditions. The simulator was able to deal with many sawmills, drying and finishing facilities. During the simulation, wood procurement was set as a constraint and demand patterns were stochastically generated according to different spot market and contract-based customer behaviours. To help planners make strategic and tactical decisions, the platform simulates the supply chain at the operational level, planning the procurement, production and distribution operations to be conducted during every shift or day in the planning horizon.

Tactical planning in the lumber, panel and engineered wood products industries has also been analyzed by the scientific community. Lidén and Rönnqvist (2000) as well as Singer and Donoso (2007) explored the complexity of integrating the different business units in the lumber supply chain. Lidén and Rönnqvist (2000) introduced CustOpt, an integrated optimization system allowing a wood supply chain to satisfy customers' demand at minimum cost. This integrated system, which is a tactical decision support tool with a three-month planning horizon, was tested under conditions involving two to five harvesting districts, two sawmills and two planing mills.

From a similar perspective, Singer and Donoso (2007) recently presented a model for optimizing planning decisions in the sawmill industry. They modelled a supply chain composed of many sawmills and drying facilities, with storage capacities available after each process. In this problem, each sawmill is treated as an independent company, making it imperative to share both the profitable and unprofitable orders as equitably as possible. The model allows transfers, externalizations, production swaps and other collaborative arrangements. The proposed model was applied at AASA, a Chilean corporation with 11 sawmills. Based on the results of the testing, the authors recommended using transfers, despite the explicit transportation costs incurred. They also recommended that some plants should focus almost exclusively on the upstream production stages, leaving the final stages to other plants.

At the operational level, many researchers have studied cutting problems. Difficulties stemming from wood defects and wood grading make it desirable to tackle complex 2D or even 3D problems. One example dealing with such problems is the Todoroki and Rönnqvist study (2002), which attempted to find the optimal cutting pattern for dimension parts from Pinus radiata. Clearly, given the typically high production rates found in the forest products industry, the different cutting problems must be solved rapidly.

In the furniture industry, many studies have attempted to optimize the cutting list at the mill level in order to meet demand and minimize wood loss (see Buelmann *et al.*, 1998, Carnieri *et al.*, 1993 and Hoff, 1997). The cutting lists define how the dimension parts should be grouped together to optimize material usage.

<u>Energy</u>

Governments, industry and the research community have only recently shown serious interest in the use of biomass as a result of increasing energy costs and rising concerns about sustainable energy options in North America. A great number of studies are underway on biomass production and conversion processes. Some research centres are beginning to pay more attention to the supply chain aspect of biomass use. Many of these are located in Europe, particularly in Sweden and Finland, where forest fuel has been used more extensively and for a longer time than in North America.

Back in 1989, Eriksson *et al.* (1989) looked at the supply chain design for a forest-fuel supplier in Sweden. The network had several forest supply regions, four different raw materials, one central processing site and one consumer. Storage is required as the annual demand cycle does not follow the supply cycle. Also, microbiological and physiological processes during storage affect the energy content of the stored material. The raw materials may be processed at the terminal using stationary equipment, or by contractors using different types of mobile chippers that can operate at any location between the source and the consumer. The problem is solved mathematically with a linear programming model.

Gunnarsoon *et al.* (2004) presented a supply chain model for forest fuel in Sweden from the point of view of the supplying company (Figure 77). The model's objective is to minimize the total cost of satisfying the demand given by the contract. The problem is a true supply chain problem with multiple sources (harvest areas, sawmills and import harbours), several intermediate terminals, several demand nodes (heating plants), different types of forest fuel and several time periods. The supply chain problem of the company involves decisions concerning the type of fuel to be used, the timing of forwarding and chipping, the location of chipping facilities, storage at the terminals, and the design of transportation patterns. Key decisions also relate to whether or not a harvest area or a sawmill should be the object of a contract, and if a terminal is to be used.

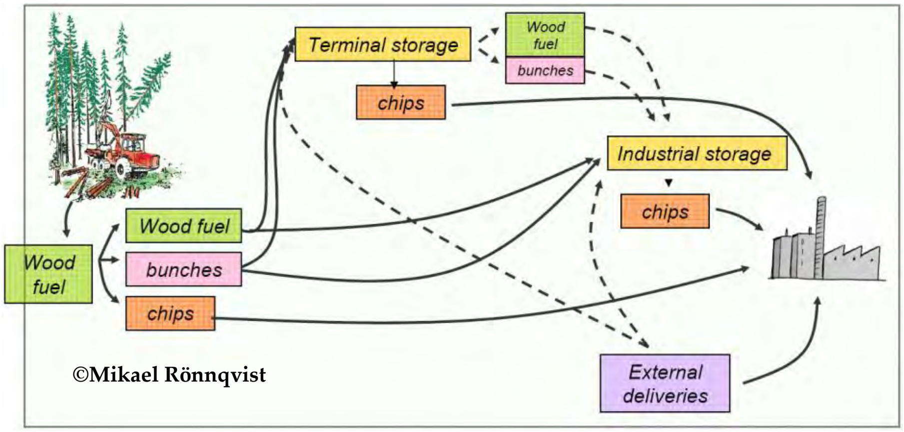


Figure 77: Forest fuel supply chain in Sweden (Gunnarsson *et al.*, 2004)

Gronalt *et al.* (2007) proposed a stepwise heuristic for the design of a regional forest fuel network for one state of the Austrian Federation. The network consists of several forest areas and a number of energy plants. On the basis of the regionally available forest fuel and the potential number of heating and energy plants, the method evaluates the different supply lines for the woody biomass from the forest to the plants by calculating the system cost for a number of alternative configurations. They, in particular, compare the benefits of central and local chipping.

Forest products companies and collaborations

Even if business collaborations are a fundamental aspect of network optimization, it is only recently that operational research techniques have been used to evaluate the potential of collaboration for the forest products industry.

Fibre allocation has been one of the first aspects to be studied. As many companies obtain their fibre from unevenly aged forests owned by the state, they often need to agree on a common in-forest harvesting plan. Beaudoin *et al.* (2007, see also the Forac research section) addressed this problem, proposing collaborative approaches to help the negotiation process generate a profitable, balanced solution. They first suggested a planning approach designed to help each company establish its own optimal plan for various scenarios. And then, they illustrated the value of collaboration for determining a final harvesting schedule.

The benefits of collaboration have also been explored in the context of transporting logs to mills. Companies often operate in different parts of the country, which provides opportunities for optimizing backhauling operations. This opportunity has been addressed in different parts of the world, using the specific fibre allocation and trucking constraints found in each region. Frisk *et al.* (2006b) (Sweden), Palander and Vaatainen (2005) (Finland), and Audy *et al.* (2007, see also the Forac research section) (Canada) have all worked on different aspects of this problem. They have also proposed models for sharing risks and benefits.

In addition, collaboration between paper mills and customers has been explored by Lehoux *et al.* (2009a, see also the Forac research section). Four different approaches to integration were simulated and optimized, starting with the traditional Make-to-Order, and then moving towards Continuous Replenishment, VMI and finally CPFR. Of all the scenarios tested, CPFR showed the greatest overall benefit. Under certain economic conditions, a continuous replenishment approach may generate greater benefits for the customer, yet the CPFR approach remains more advantageous for the producer. For this reason, the researchers have developed three different incentives, e.g.: bonuses, savings sharing and quantity discounts, as a tool to alter partner behaviour and increase network profit. In this way, the same collaboration scheme was the most profitable approach for all the stakeholders.

Finally, supply chain management models are being used more and more frequently to better coordinate network activities and increase value added for the end-user. Haartveit *et al.* (2004) investigated and defined the concept of supply chain management through a literature review. They also proposed two supply chain mapping methods: one focused on the supply chain structure and relationships among stakeholders, and the other focused on lead time. They then used these methods to map the supply chains of three western Canadian companies from the solid wood sector. Vahid and Maness (2010) proposed a review and classification of existing approaches for modelling customer demand in supply chains. They also identified promising approaches for the forest products industry.

9 Student and Research Professional Projects of the Forac Research Consortium

The students and research professionals of the Forac Research Consortium have also conducted much work on current decision-making problems for the forest products industry.

9.1 Research Focussing on the Forest

To begin with, different projects concentrate on forest challenges. For example, research professional Mathieu Bouchard worked on the development of a decision-making tool to properly plan tactical and strategic forest operations (Project F-1). To be efficient, the tool took into account sets of prescribed silvicultural treatments and their costs; growth information; industry needs and location; wood transportation costs; as well as forest road building costs. The aim was to select the proper treatment and harvesting plans in order to meet industry needs as much as possible while maintaining a sustainable forest program.

Another research professional, Line Simoneau, works on the design of a value adding merchandising yard (Project F-2). More specifically, she has been assessing the potential benefits of using a central unit to prepare and convert wood so as to satisfy the demand of sawmills, pulp and paper mills, engineered wood plants, etc.

Ph.D. student Jean-François Audy studies transport collaborations (Project F-3). He has, in particular, been exploring how different companies can work together to better coordinate transport operations, reduce costs and shorten lead times. He is also investigating how the costs and benefits of a coalition can be shared among the various members.

M.Sc.F. student Pierre-Samuel Proulx works on a geographic information system for a harvesting territory that takes into consideration forest roads, harvest blocks and topographic data (Project F-4). Using this system, the student also evaluates the benefits of determining the location of harvesting teams based on the needs of the conversion unit.

Ph.D. student Daniel Beaudoin has worked on planning the harvesting schedule and allocating the cutting blocks to the different mills, based on demand plans (Project F-5). One of the contributions of his work has been to take into account the freshness of the fibre, which affects production costs as well as revenues. The operational decision model he has developed allows for efficient wood allocation, with maximum mill profit and minimum harvesting and transportation costs.

Finally, M.Sc.F. student Véronique Coudé has worked on improving forest operational planning through better knowledge of forest inventories and their location (Project F-6). Her model contributes to better targeting of harvest areas, lower inventory levels, improved operational decision-making and reduced production costs.

9.2 Pulp and Paper Projects

Several studies deal with the pulp and paper industry. Research professional Philippe Marier studies the gains that could be achieved by implementing an optimization system for the procurement of wood chips (Project P.P.-1). He hopes to demonstrate that procurement costs can be reduced significantly through proper daily planning.

Ph.D. student Wissem M'Barek is developing a strategic planning model for a pulp and paper multinational so as to maximize added value (Project P.P.-2). His model considers exchange rates, transfer pricing and taxes to reflect the multinational's circumstances. The impact of the strategic decision-making process on tactical decisions related to production and distribution activities is also analyzed.

Ph.D. student Nadia Lehoux studied different collaboration approaches between a pulp and paper producer and its client (Project P.P.-3). She proposed seven decision models from the point of view of both stakeholders in order to identify which collaboration mode is more profitable for the network and for individual businesses. She also defined three forms of incentives designed to modify the partners' behaviour and increase network profit.

Ph.D. student Nafee Rizk explored the coordination of production and distribution planning decisions for a pulp and paper enterprise, taking into account the economy of scale in transport and different transportation modes (Project P.P.-4). He demonstrated that, if production and distribution operations are well synchronized, significant gains can be achieved and costs can be reduced.

Post-doctoral student Hanen Bouchriha analyzed decisions relating to the volume of wood chips that should be bought on the spot market as opposed to a contract (Project P.P.-5). In her planning model, she took into account the buying cost, distribution cost and inventory cost, as well as the capacity of the system. She also developed a production planning model for fixed duration production campaigns (Project P.P.-6). The objective of the study was to fix the campaign duration on a single paper machine at a North American fine paper mill.

Post-doctoral student Satyaveer Singh Chauhan analyzed the tactical demand fulfilment of sheeted paper in the fine paper industry (Project P.P.-7). He adopted a sheet-to-order strategy, where parent rolls are produced to stock and the sheeting is done as customer orders are received. He proposed a model for determining the best assortment of parent rolls to be kept in stock in order to minimize expected inventory and trim loss costs. When tested on actual data from one of the largest fine paper mills in North America, the model was able to substantially reduce inventory holding costs, while at the same time achieving a slight reduction in trim loss costs.

Finally, M.Sc. student Glenn Weigel presented a model optimizing wood sourcing decisions, including wood sorting strategies as well as technology investments, in order to maximize profit across the value creation network (Project P.P.-8). He showed that optimally allocating fibre types to the right process stream increased mill profit, even though forest operation costs also increased.

9.3 Lumber, Panel and Engineered Wood Projects

The lumber, panel and engineered wood chain has also been explored. In connection with the lumber industry, Ph.D. student Jonathan Gaudreault studied the distributed planning process, and more specifically situations where each business unit makes its own planning decisions (Project L-1). He proposed a method whereby the different businesses jointly create a synchronized production plan based on industry data obtained from different Canadian sawmills, and demonstrated the gains that could be achieved.

Ph.D. student Luis Antonio De Santa-Eulalia proposed a simulation concept to evaluate different planning and design strategies for the forest products value creation network (Project L-2). His approach included mechanisms, procedures and tools that could be useful to experiment with and compare various scenarios. He also applied his methodology to the FORAC Virtual Lumber Case.

Ph.D. student Pascal Forget used the Forac agent-based experimental platform to simulate different behaviours and negotiation schemes between network members of the lumber supply chain (Project L-3). His work demonstrated that, if stakeholders carefully adjust planning decisions to their own specific circumstances, important benefits can be achieved.

Ph.D. student Dhia Eddine Boughzala is working on a conceptual framework for sawmills (Project L-4). He particularly wants to develop a decision tool that will help companies to evaluate their abilities and weaknesses, especially when a change in the environment occurs.

Ph.D. student Masoumeh Kazemi Zanjani has studied the uncertainty of demand and productivity (Project L-5). Using advanced operational research techniques, she has developed a production planning model for multiple products and multiple periods to reflect actual sawmill conditions.

Ph.D. student Rodrigo Schalk Cambiaghi Azevedo is exploring the concept of revenue management for the lumber industry (Project L-6). The goal of the project is to develop an order management mechanism in a short-term perspective, taking the production capacity as well as sales and revenues into consideration.

M.Sc. student Sébastien Lemieux is working on the development of a multi-agent model to simulate customer demand (Project L-7). This agent will then be integrated into the Forac platform to simulate different customer behaviours. He also works on a method to evaluate the output of a log, with specific emphasis on the end products that could be obtained in relation to the log's diameter, length, origin, etc. (Project L-8).

M.Sc.F. Jovani Jacques explored a modelling framework related to the wood conversion processes and markets, with the purpose of facilitating forest decision making (Project L-9).

Ph.D. student Didier Vila proposed a generic method for designing the lumber chain, including the opening/closing of mills, technology investments and market decisions (e.g., product substitution). Three different sub-markets were considered in the model: contract markets, Vendor Managed Inventory markets and spot markets. The proposed method positions the company favourably to earn high-value market shares (Project L-10).

Ph.D. student François D'Amours worked on demand management and proposed a tactical planning model to optimize demand allocation to different mills (Project L-11).

In connexion with the panel industry, Ph.D. student Yan Feng is analyzing the concept of sales and operations planning for the value chain (Project Pn-1). She uses sales decisions to investigate opportunities to profitably match and satisfy demand in a supply chain, given the chain's production, distribution and procurement capabilities. She develops and compares three different planning models for different sets of conditions, based on a simulation approach, so as to evaluate the benefits of choosing integrated S&OP planning over the traditional decoupled planning process. The data used in the experiments were obtained from a Canadian OSB panel plant.

Some projects also relate to the engineered wood chain. In particular, Ph.D. student Matheus Pinotti Moreira proposes a conceptual framework based on the concept of competency management (Project VA-1). When applied to the furniture sector, this framework serves to illustrate the competencies needed to implement mass customization as well as the mechanisms required to develop these abilities.

The furniture sector has also been studied by Ph.D. student Mustapha Ouhimmou (Project VA-2), who has worked on the development of a planning model for an integrated enterprise, taking into account factors such as production capacity, distribution cost and demand fluctuation. Based on an actual industry case, this project has demonstrated all the benefits available to an integrated company as a result of proper planning in such areas as procurement, sawing, drying and transportation.

Ph.D. student Marc Lapointe is exploring the strategy of mass customization and the use of an advanced planning system for the modular home industry (Project VA-3).

Ph.D. student Aurélia Lefaix-Durand studied the supplier-customer relationship as a means of creating value (Project VA-4). She described different types of relationships between wood suppliers and modular home companies as well as the factors that influence their success such as the environment, distance, coordination mechanisms, etc.

Finally, Ph.D. student Égide Karuranga explored the Chinese market and how Canadian forest products companies can sell their products in that country (Project VA-5). He described the business culture and organization as well as the characteristics of products required by Chinese buyers.

The following table summarizes the projects conducted by students and research professionals of the Forac Research Consortium.

Table 20: Student and research professional projects of the Forac Research Consortium

Supply chain studied	Student/Research professional name	The project
Forest	Mathieu Bouchard	F-1: Decision-making tool to properly plan tactical and strategic forest operations
	Line Simoneau	F-2: Creation of a value added centre to prepare and convert wood on the basis of demand from sawmills, pulp and paper mills, engineered wood plants, etc.
	Jean-François Audy	F-3: Study of collaboration to better coordinate transport activities and decrease costs
	Pierre-Samuel Proulx	F-4: Development and use of a geographic information system to determine the location of harvesting teams based on the needs of the conversion unit
	Daniel Beaudoin	F-5: Operational decision model to efficiently allocate cutting blocks to mills, based on demand plans
	Véronique Coudé	F-6:Improvement of forest operations planning based on better knowledge of forest stocks and their location
Pulp and paper	Philippe Marier	P.P.-1: Analysis of the use of an optimization system for the procurement of wood chips
	Wissem M'Barek	P.P.-2: Strategic planning model for a pulp and paper multinational, taking exchange rates into account as well as transfer pricing and taxes
	Nadia Lehoux	P.P.-3: Decision-aid models from the points of view of both a pulp and paper producer and its client based on four collaboration schemes
	Nafee Rizk	P.P.-4: Production and distribution planning model that takes into consideration different transportation modes and economies of scale
	Hanen Bouchriha	P.P.-5: Optimization of contracts between sawmills and pulp and paper companies + P.P.-6 : Production planning model in a context of fixed duration production campaigns
	Satyaveer Singh Chauhan	P.P.-7: Optimization of parent roll inventory assortment and their allocation to finished products based on customer demand
	Glenn Weigel	P.P.-8: Strategic decision model to properly classify and allocate wood fibre in relation to customer demand
Lumber	Jonathan Gaudreault	L-1: Development of a technique allowing individual businesses to conjointly create a synchronized production plan
	Luis Antonio De Santa Eulalia	L-2: Simulation concept to evaluate different planning and design strategies for a value creation network
	Pascal Forget	L-3: Analysis of different agent behaviours and benefits of better network adaptation
	Dhia Eddine Boughzala	L-4: Conceptual framework to help sawmills in evaluating their abilities and weaknesses

Table 20: Student and research professional projects of the Forac Research Consortium (cont'd)

Supply chain studied	Student/Research professional name	The project
Lumber	Masoumeh Kazemi Zanjani	L-5: A production planning model for multiple products that takes into account the uncertainty of demand and productivity
	Rodrigo Schalk Cambiaghi Azevedo	L-6: The study of revenue management and the development of an order treatment mechanism that considers production capacity as well as sales and revenues
	Sébastien Lemieux	L-7: Development of a multi-agent model to simulate customer demand + L-8: Evaluation of the output of a log in relation to its diameter, length, origin, etc.
	Jovani Jacques	L-9: Modelling framework related to wood conversion processes and markets so as to facilitate forest decision making
	Didier Vila	L-10: Generic method for designing the lumber chain, including the opening/closing of mills, technology investments and market decisions
	François D'Amours	L-11: Demand management in the lumber industry
Panel	Yan Feng	Pn-1: Development and simulation of three different sales and operations planning models for the OSB panel industry
Furniture industry	Matheus Pinotti Moreira	VA-1: Conceptual framework applied to the furniture sector and used to illustrate the competencies necessary to implement mass customization
	Mustapha Ouhimmou	VA-2: A planning model for an integrated enterprise that takes into account all operations as well as transportation costs, capacities, etc.
Modular homes	Marc Lapointe	VA-3: Study of a mass customization strategy and the use of an advanced planning system for the modular home environment
	Aurélia Lefaix-Durand	VA-4: Analysis of the relationships that can be established between wood suppliers and modular home companies
	Égide Karuranga	VA-5: An exploration of the Chinese market and opportunities for Canadian forest products companies

10 Application Software for the Forest Products Industry

This section reviews tools and application software available to the forest products industry. For the most part, the information provided comes from FORAC's industrial and research partners, Internet searches and a literature review. A list of the tools is given in Appendix B, and only the findings will be presented in this document.

The main objective of this review is to develop a broad description of what has been developed to help the forest products industry in various fields, from the forest to the mills and to the customers, from a strategic perspective down to operational day-to-day planning and activities. Generic software not specific to the industry (but that could be used by the industry) has not been considered in this review. As stated by Carlsson *et al.* (2006), many standard commercial packages offer planning and decision support, but they cannot deal with all the planning issues specific to the forest industry supply chain.

The software and tools are presented in two main categories. The first category consists of software developed and mainly available and used in North America. The second category presents tools that are available and used in other countries. The list is not exhaustive as some countries known to have a major forest products industry (such as China and Russia) are not represented in the list. They probably have specific software products, but either the information was not available on the Internet or it was not available in English or French. Still, the list gives an idea of what is being used in countries such as Chile, New Zealand, Finland and Sweden.

10.1 Software Classification

The different tools and software technologies have been classified on the basis of decision levels and application domains specific to the industry. The table below shows the classification matrix. It should be noted that a single software tool can be found at many decision levels and appear in more than one application domain.

Table 21: Table used to classify software tools

Decision level	Application Domain							
	Forest management	Harvesting	Transportation	Manufacturing	Traceability	Supplier Customer relationship	Supply Chain management	Inventory management
Strategic								
Tactical								
Operational								

Many definitions have been given in the literature to differentiate between decision levels, and although some commonalities may be found between these definitions, no one definition is more widely accepted than another. Thus for this paper, we have used the following simple criteria to classify applications according to decision levels:

Operational: The application may involve data collection and pertains to day-to-day work. In most situations, satisfactory performance of the work almost makes the use of this application mandatory.

Tactical: An application for tactical decisions makes use of data from the operational level. It often involves simulation or planning, and may be used to optimize operational parameters.

Strategic: Software that is used to help make decisions involving large investments or considerable changes, and taking a fir amount of time to implement.

On the other axis, the application domains are as follows:

Forest Management: The application manages activities (planning, decision-making or operational) that take place before actual harvesting.

Harvesting: The application manages activities linked to harvesting operations. By extension, it includes all operations conducted in the forest from the time the trees are cut till a truck picks up the wood at the roadside to forward the timber to a yard or mill. Such operations can include sorting, bucking and chipping. The application may plan such activities or acquire data related to it for management.

Transportation: The application manages activities related to the transportation of the fibre from the forest to the mills, including forest road network development and maintenance.

Manufacturing: The application manages activities that take place at the mill. These may include planning, scheduling, monitoring and data acquisition.

Traceability: The application has a specific functionality to keep track of the origin of the wood.

Supplier/Customer Relationship: The application manages activities or information related to the supply chain partners and customers, including contractual activities.

Supply Chain Management: The application is used to coordinate the flow of products between different business units or the work of stakeholders of different business units.

Inventory Management: The application keeps track of the volume of wood and its location. The wood may be located in the forest or in a yard.

Many application domains have not been considered as they do not require constraints specific to the forest products industry. Such application domains include sales, finance, accounting, etc.

Software and tools are further classified as being either analytical or transactional. They are classified as transactional if they acquire or monitor data from day to day operations.

For the purpose of this report, classification has been based solely on the description of the tool found in journal articles, on the Internet or on the documentation provided by the distributor. A more thorough review of some tools might have resulted in slight classification changes, but our purpose was only to provide a broad view of the domains and decision levels for which most of the current tools are available.

10.2 North American Tools

This list includes 140 tools. It should be noted, however, that two of the tools, from FPInnovations-Feric, are catalogues of applications rather than software tools. TransITS lists applications for transportation, and the other catalogue (with no specific name) contains applications related to wood characteristics identification and measurement. In addition, some of the tools mentioned are still at the research stage, hence not currently available for distribution. These include FPInnovations-Feric's FMMT (Forest Multimodal Transportation Model), and FORAC's SPE (Simulation and Prototyping Environment) and VTM.

The tool classification shown in Table 22 below indicates that *Forest Management* has received the most consideration for strategic applications. On the tactical level, *Forest Management* is still included in many tools, followed closely by *Harvesting* and *Transportation*. Many of the tools looking at *Harvesting* from a tactical point of view also consider *Forest Management*. The high number of tactical tools in the manufacturing area is the result of many applications developed by FPInnovations-Forintek to determine best operational parameters in specific processes.

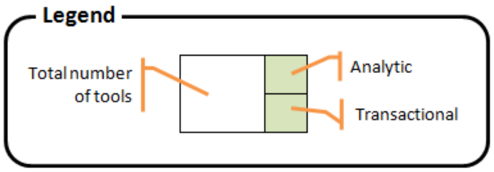


Table 22: Tools available for optimizing the wood fibre supply chain in North America

Decision level	Application Domain																							
	Forest management			Harvesting			Transportation			Manufacturing			Traceability			Supplier Customer relationship			Supply Chain management			Inventory management		
	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional
Strategic	25	25	0	1	1		1	1		3	3	0	0			0			4	4	0	0		
Tactical	18	16	2	16	14	2	15	14	1	23	22	1	0			3	2	1	10	9	1	2	0	2
Operational	12	2	10	17	2	15	31	2	29	26	2	24	7	0	7	26	0	26	1	0	1	26	0	26

The *Supplier/Customer Relationship* and *Inventory Management* areas are well covered from an operational point of view. Looking at supply chain management, only 11 tools had functionalities related to this domain. The four tools designed to aid strategic decisions are included in the 10 listed as having solutions for the tactical level.

Not surprisingly, very few or no tools apply to the strategic or tactical decision levels in the *Traceability*, *Supplier/Customer Relationship* and *Inventory Management* domains. Strategic or tactical decision making in these domains rarely requires a computer program, except maybe for *Inventory Management*. But good tactical or strategic inventory management cannot be done without considering the whole supply chain, so, at these decision levels, it is more of a supply chain management issue.

10.3 Software from Other Countries

We have listed 29 tools in this category, most of them found in the literature. As much of the literature dealing with the forest products industry has been devoted to *Forest Management*, most of the tools relate to that particular application domain. Globally, however, the tool distribution in the matrix is very similar to that obtained for North American tools.

Many of these tools come from government agencies and research centres, with very few from privately-owned companies. It is apparent that tool development for the forest products industry in Canada follows the same pattern as in the rest of the world.

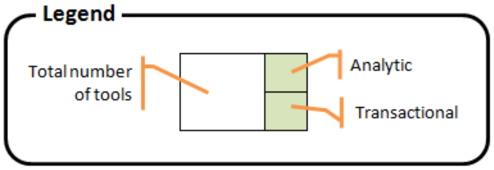


Table 23: List of software from other countries developed for the forest products industry

Decision level	Application Domain																							
	Forest management			Harvesting			Transportation			Manufacturing			Traceability			Supplier Customer relationship			Supply Chain management			Inventory management		
	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional	Total	Analytic	Transactional
Strategic	10	10	0	3	3	0	1	1	0	0			0			0			2	2	0	0		
Tactical	4	4	0	3	3	0	6	4	2	1	0	1	0			0			4	3	1	1	0	1
Operational	3	1	2	2	0	2	7	0	7	2	0	2	0			2	0	2	1	0	1	2	0	2

10.4 Software and Optimization Models

Optimization models play a key role in the software used for *Forest Management*, perhaps because they were relatively easy to apply and gain expectations were high, given that, at one point, no tools were available for this task and there was a real need for such applications. In other areas such as *Transportation*, *Manufacturing* or *Supply Chain Management*, software not specific to the forest industry exists and can be utilized. Sometimes, heuristics and approximation methods are used for this application.

With increasing competition and the rising cost of material supply and distribution, there is a greater incentive to maximize profits by considering solutions closer to optimum values. The scientific community has thus undertaken to develop the necessary models for the forest products industry, and some are being integrated in software applications. The impact of such improvements remains limited, however, as most problems are being considered independently of each other.

More improvements are yet to come with research on models and methods integrating the various activities of the many interconnected business units that are constrained by divergent processes. In addition, supply chain planning needs to integrate strategic, tactical and operational decision making.

Three Canadian software companies offer products using operational research models for strategic or tactical decision making, and integrating activities from forest operations, transportation and manufacturing. The first product is *Harvest Scheduler/Wood Flow* from Cengea (Vancouver & Winnipeg). Although they are not specific about the technology they are using, the description of the product mentions *optimization tools* which are typical of systems using operational research models. Another useful feature of this system is that it can be used to analyze the impact of changing wood quantity and mill destinations on harvesting schedules. There is also a mention of *'mills receiving a reliable supply of the right kind of wood'*, which indicates that the software can consider demand at individual mills and/or each mill's equipment capacity and capabilities, as different types of equipment may produce different sets of products from the same kind and quantity of wood entering the mill.

The second product is *SawSim-LP* from Halco Software (Vancouver). Using linear programming, this product helps determine which logs should be processed according to which sawing patterns to get the right product to the right customer in a timely manner. Although this product does not integrate planning of harvesting operations within the same model, the company's *WoodMan* system, which includes *SawSim*, provides a broader view of all the operations.

The third product is *OperMAX*, from Force/Robak Associates (New-Brunswick). It uses linear programming to provide a plan including decisions on harvesting, transportation, silviculture, road construction, wood purchases, mill yard inventory levels, roadside sales, sublicensee sales, and mill-to-mill wood deliveries. The system can also be used to analyze strategic or tactical decisions such as mill shut-down or expansion, and new potential markets or product specifications.

ATLAS, a New Zealand company, also makes fair use of operational research in its product suite. In particular, *ATLAS Market Supply* uses mixed-integer linear programming optimization to improve the ability to deliver the right log to the right customer at the right time in the most profitable way. The system selects which units should be harvested and which crews should be assigned to which harvest unit; it determines optimum logging patterns and assigns logs (from logging operations or inventories) in relation to mill demand.

10.5 Current Research and Gaps in Software Development

Research is ongoing on problems ranging from long-term strategic forest management to very short-term operational problems such as planning for real-time log/chip transportation or cutting. Some of the solutions and models developed in these studies can be found in today's software applications. But the vast majority of the models were developed in relation to a specific environment, and the effort required to generalize their applicability and integrate them into commercial software packages is far from negligible.

For companies already in the software business for the forest products industry, there are numerous opportunities to integrate models capable of helping with management/planning/ decision making in various application domains. Our software search shows, however, that software package availability is particularly limited in the areas of *Traceability*, *Supply Chain Management*, *Supplier/Customer Relationship* and *Inventory Management*. Since forest certification has been a hot topic for several years, we might see more packages with specific functionalities helping with *Traceability*.

Collaboration is not an application domain that we specifically considered in classifying the tools, as very few of them refer to collaboration. It is, however, an important factor in successful supply chain integration. The ERP (Enterprise Resource Planning) system, from IPS, is not specific to the forest products industry, but it has had a few successful implementations in the pulp and paper industry, and the product provides collaborative solutions within their package, including Vendor Managed Inventory, Collaborative Planning and Collaborative Project Management.

11 Discussion and Conclusion

The purpose of this paper was to describe the Canadian wood fibre value creation network. It first explained what constitutes a value creation network in terms of business units, product flow, information flow and financial flow. It then detailed how to model a value creation network so as to better understand interactions between the various stakeholders as well as the impact of change over the system. Different modelling approaches were described as well as key performance indicators to measure the value of the network. It also explained how to manage the value creation network. More specifically, it detailed key business processes and different planning challenges, in addition to suggesting different forms of relationships commonly used to efficiently synchronize network activities. Information was provided on studies by national and international researchers as well as projects conducted by Forac students and research professionals. Finally, the paper reviewed different technologies that can be very useful to facilitate the decision-making process.

Future work should address different challenges faced by the industry. A first issue lies in the need to better integrate decisions relating to forest management and forest operations into the other downstream supply chain decision-making processes. As mentioned by Gunn (2009), the design of the supply chain requires balancing wood acquisition costs, transportation costs and capital costs, but, for many organizations and government agencies, all timber types have the same value, and the objective is just volume maximization with no discounting. This is why it is so critical to understand what constitutes the wood fibre value creation network and the interactions taking place between the different business units and processes.

A second key issue concerns information. Efficient planning decisions must be based on a good understand of what is in the forest; which attributes are needed; what are the customer's needs as well as the customer's needs; what is the capacity available to satisfy such needs; and where the product is at each stage of the production process. A better approach is required to capture, share and use such knowledge. And this will be possible if key technologies such as GIS and communication standards such as papiNet are implemented in the value creation network. With better anticipation of market needs and product value, as well as risk and uncertainties, the industry will be in a better position to efficiently re-engineer the supply chains of the wood fibre value creation network.

Another challenge involves collaboration between network members. Companies that are willing to share resources and information as well as risk and benefits, undoubtedly stand to gain from working together. In addition, some barriers to creating value are specific to the forest sector. For example, the forest industry depends on the capabilities of its workforce, and there is a real need for skilled workers. According to the 2006 Census (Statistics Canada), almost 46 percent of forest products workers were 45 years of age or older. Other competitive disadvantages contribute to limiting the value created, including: high transportation costs to access the forest resource; the increasing strength of the Canadian dollar against the US currency; and the lack of capital investment in the industry. Much work therefore has to be done to help the industry manage its network in a "green" and efficient way.

This report can serve as a tool to better understand the Canadian wood fibre value creation network and become more familiar with: 1-the concept of value creation network; 2-operational research techniques used to analyze and solve planning problems; 3-typical problems faced by companies in a short-term, mid-term or long-term perspective; 4-different strategies to properly manage the value creation network; and 5-the technology and tools currently available to help companies with their planning efforts. All the forest industry stakeholders now have access to a broader view of the wood fibre value creation network and a better understanding of their role in creating value. The strategies and methods described may encourage some key stakeholders to adopt new methods as allowing them to better use the wood resource. They may also facilitate discussions on forest and operations planning between stakeholders from different backgrounds. This report could also be used to improve relations between the government and its industry partners.

In addition, readers wishing to learn more about the forest, supply chain management or business processes could examine a number of key references. For example, the Handbook of Operations Research in Natural Resources is a useful book that documents how operations research and management science have been applied to areas such as agriculture, forestry and mining. A book written by Simchi-Levi e*t al.(1999)* is also a must for those who want to become more familiar with supply chain management and value creation network concepts. Moreover, the notion of modelling a supply chain is clearly explained in Shapiro (2006). Finally, the Handbook of Operations Research and Management Science on supply chain management (see Cachon in the reference section) is a key tool for a better understanding of information exchanges and the importance of using incentives in a value creation network.

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Appendix 1: The Virtual Lumber Case

The virtual lumber case is an enterprise test bench which is basically a detailed supply chain model of a typical Canadian business in the softwood lumber industry. It was developed using data based on different existing eastern Canadian sawmills that describe manufacturing processes, products and transportation resources. A distributed multi-agent system named the FORAC Experimental Planning Platform was used to test and analyze the virtual case. The goal of the study was to simulate different market situations and evaluate the impact of various planning strategies.

Description of the FORAC Experimental Planning Platform

The FORAC Experimental Planning Platform is composed of agents that interact with each other to solve typical lumber supply chain planning problems (Figure 78). Using different coordination protocols and agent behaviours, the Platform creates detailed production schedules to fulfil the demand of final customers within existing operational constraints.

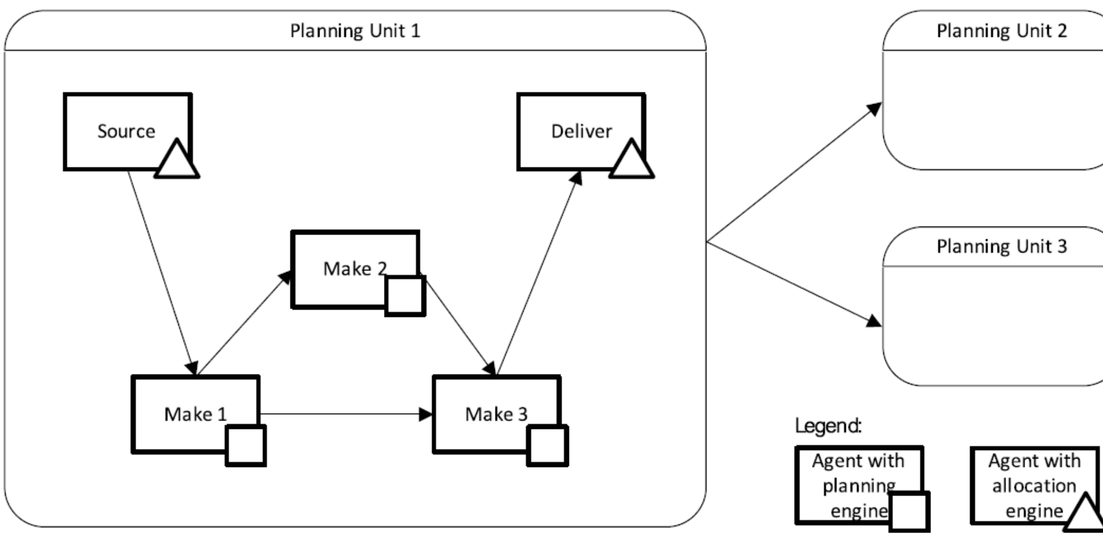

Figure 78: Overview of the FORAC Experimental Planning Platform

Four basic types of agents have been developed: planning unit, source, make, and deliver. The planning unit leads agents in a global environment so as to help communicate with external agents, namely agents that are in a different planning unit. It is like a site in a company. The source agent plans the procurement of products needed by the other agents in the planning unit and allocates them to the desired location. The deliver agent manages the relationships with customers and sells finished products. Make agents are responsible for production planning operations for products within the planning unit. In the lumber supply chain, for example, they represent the sawing, drying and finishing units.

Each agent uses operational research algorithms to plan its activities. These are depicted in terms of objective function, processes, planning parameters and optimization method (Table 24).

Table 24: Planning engines for each agent (Santa-Eulalia, 2009)

	Sawing Agent	Drying Agent	Finishing Agent
Objective: Demand Propagation	Minimize lateness	Minimize lateness	Minimize lateness
Objective: Supply Propagation	Maximize production value	Maximize production value	Maximize production value
Processes features	Divergent product flow; coproduction; alternative process selection; only compatible processes can be performed within the same production shift	Divergent product flow; coproduction; alternative process selection	Divergent product flow; coproduction; alternative process selection; only compatible processes can be performed within the same production shift
Planning parameters	Machine capacity calendar; frozen jobs; maximum sales per product; inventory costs; raw products costs	Machine capacity calendar; frozen jobs; operations cost	Machine capacity calendar; frozen jobs; exploitation mode in the solution tree (for the optimization method); minimum production lead-time per family
Optimization method	Mixed Integer Programming	Constraint programming	Heuristic

The sawing agent aims to identify the right mix of log types to be processed considering the inventory of logs and sawn products as well as the demand for sawn products.

The drying agent is batch-oriented and simultaneously tries to find the best type of rough green lumber to allocate to the kilns and the best drying process. This approach tries to find a feasible solution in a short time, but when more time is available, it will continue its search for a better solution using an algorithm through a solution tree.

The finishing agent employs a heuristic approach to find what rough dry lumber type will be used and how much it should be planed considering setup time.

Modelling Components of the Virtual Lumber Case

In order to analyze the impact of different planning strategies on the system, a production and distribution network called Virtual Lumber Inc. was modelled in the FORAC Experimental Planning Platform. This is a complete supply chain test case where one can perform experimentation for a softwood lumber supply chain. It consists of six sawmill complexes (with nine sawing lines, 47 dryers and six finishing lines), four warehouses and 141 products for the American and Canadian markets (Figure 79).

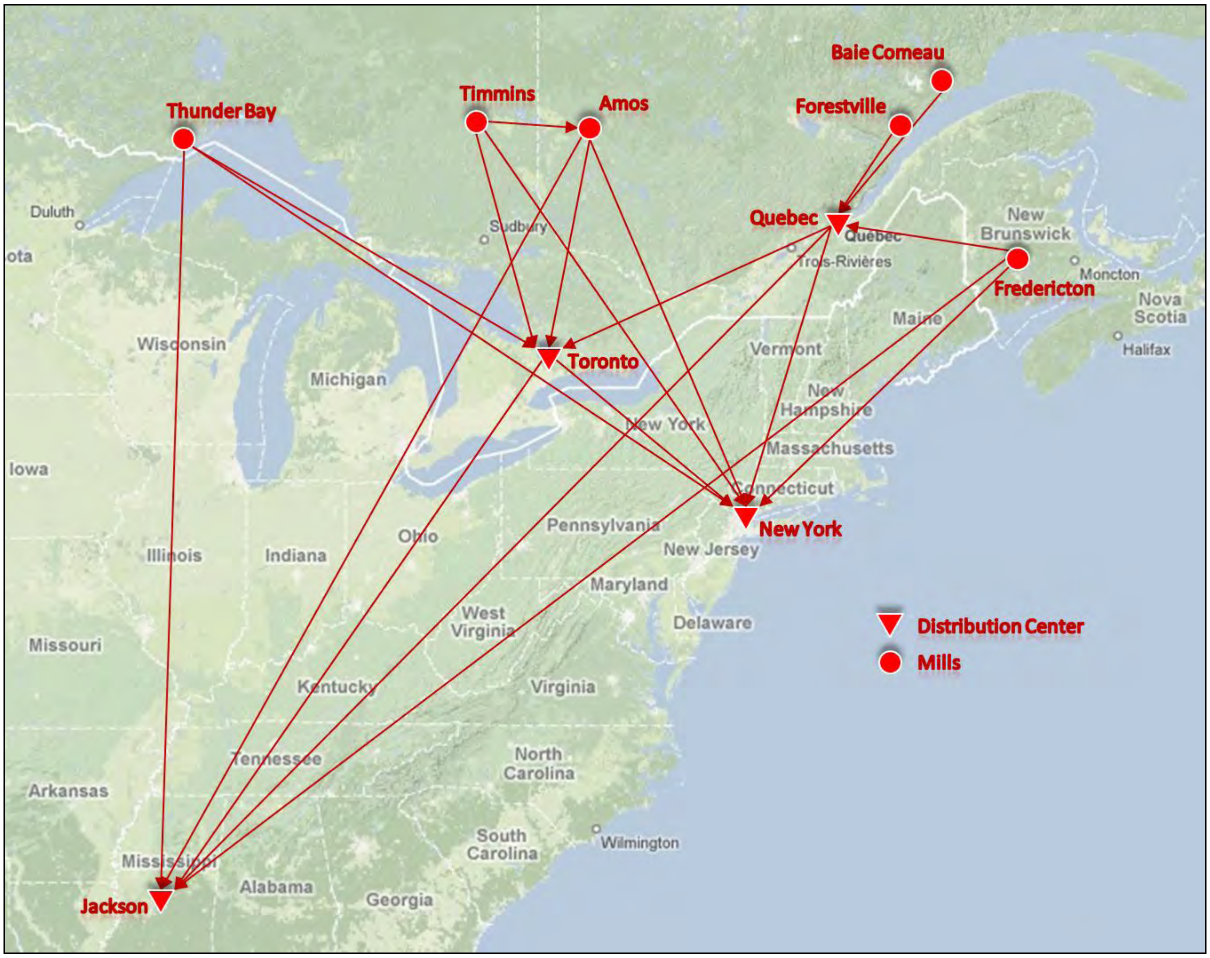

Figure 79: Virtual Lumber Supply Network

The Virtual Lumber case is composed of sawmill complexes located in Thunder Bay, Timmins, Amos, Fredericton, Forestville and Baie Comeau. Each sawmill complex represents an internal supply chain which can have sawing, drying and finishing units as well as a local warehouse (or lumber yard). In addition, large warehouses are located in Toronto, Québec, New York and Jackson. All sawmill facilities and warehouses are connected by a transportation network based on railways and roads.

In a given sawing complex, operations are planned from log reception to final delivery, using all agents, from source agent to deliver agent, and on to the simulated customer agent (Figure 80).

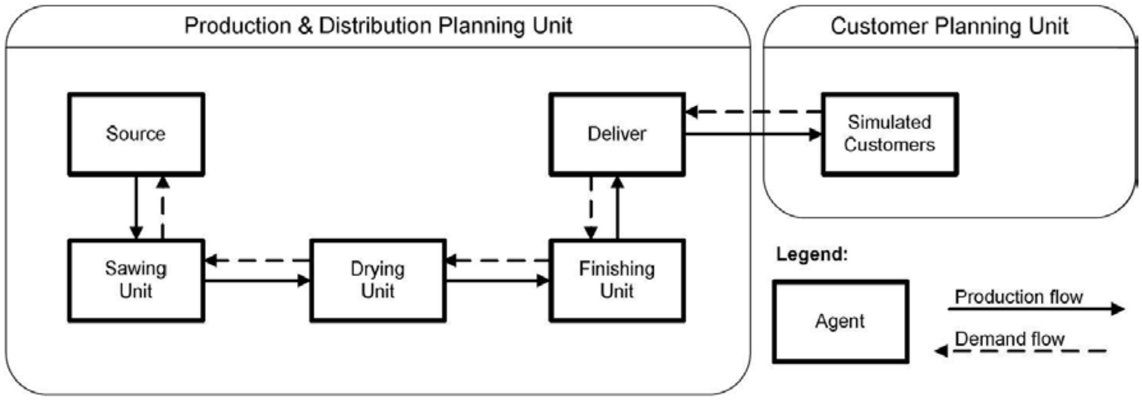

Figure 80: Production and distribution network modelled in the FORAC Experimental Planning Platform

Planning decisions made by each agent can therefore be described as follows: The logs are first procured by the source agent, which sends the supply plan to the sawing agent. Next, the volumes and classes of logs to be converted during each production shift are decided, and cutting patterns are selected (Figure 81).

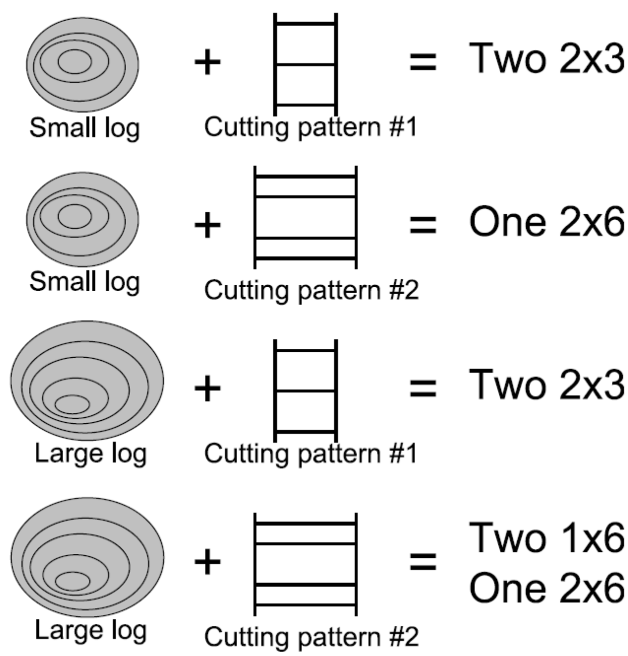

Figure 81: Example of a sawing decision

Expected outputs from the sawing production plan then serve to decide which bundles of lumber should be placed into which kiln according to a specific loading pattern (Figure 82).

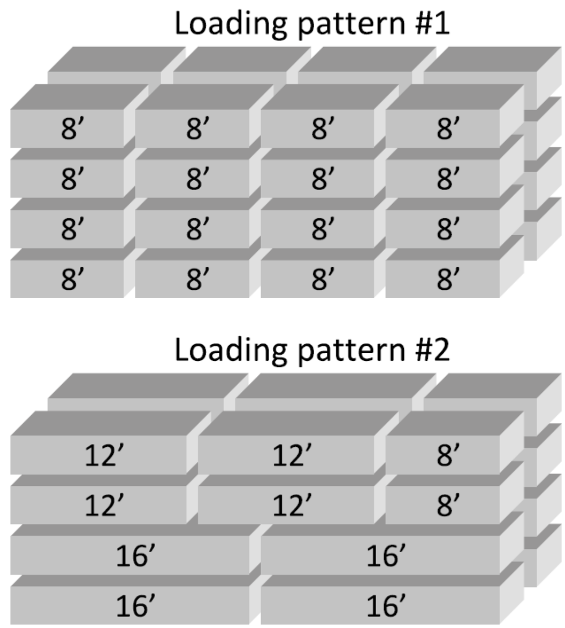

Figure 82: Example of possible loading patterns

The finishing agent determines the final characteristics of the products, and schedules the finishing processes to be applied to the dried products. The deliver agent plans deliveries of finished products to final customers. To perform all these operations, the agents need to manage information about products, inventory levels, equipment and activities in each unit of the network. Table 25 shows the characteristics of the sawing complex used in the simulation.

Table 25: Definition of sawing, drying, finishing and deliver units

	Sawing	Drying	Finishing	Deliver
Number of consumed products	8	15	15	45
Number of products made	15	15	45	45
Processors	1 Sawing Line 8’ 1 Sawing Line 8’-16’	5 small kiln dryers 2 large kiln dryers Air drying area	1 Finishing Line	Not applicable
Processes	37	180	15	Not applicable

<u>Sawing unit</u>

The sawing unit is equipped with two sawing lines and can process eight different types of logs. For each type of log entering a sawing line, several cutting patterns are possible and the choice of the cutting pattern will determine the mix of output products.

Drying unit
The drying unit is the bottleneck of the network. It can dry fifteen products at a time in one of its seven kilns, based on a loading pattern selected from the 180 available.

Finishing unit
The finishing unit can transform 15 input products into 45 final products. For each product input, a set of alternative processes is available and will be selected depending on demand, inventories and resource constraints.

Deliver unit
The deliver unit is responsible for planning and delivering products to final customers.

To simulate different market simulations, a customer agent has also been developed. More precisely, two types of customers have been modelled: a spot market customer and a contract-based customer. A generator of random numbers was developed to simulate the demand.

The spot market customer expresses its needs to some forest companies sporadically and at random intervals. Then, the customer and the chosen supplier negotiate the final price, volume and delivery date. The two participants display their own opportunistic behaviour, each trying to make decisions that maximize its own profit rather than the overall profit of the system.

The contract-based customer orders products based on a contractual setting. The contract can specify several requirements such as guarantees of purchase or deliveries, pricing conditions and payments. The demand for this type of customer occurs at relatively regular intervals compared to the spot market customer.

Description of Experiments

Experiments were conducted to study the effect of two different planning strategies on the system, namely a supply-driven method and a demand-driven method. The supply-driven approach is generally the planning strategy used by North American Lumber companies. In this approach, the corporate production planner first sets goals for each production facility in the form of production mix and yield targets over a given time period. Next, the local production planner in each facility uses these targets to define production plans. Even though demand may vary at the market end, production remains the same until the corporate planner revises targets.

With a demand-driven approach, on the other hand, the planner has to consider demand from final customers at the original planning stage. This involves finding a compromise between demands from all the customers and the available log supplies to create a production plan that meets operational constraints. Therefore, when the supply-driven scenario is tested, the Deliver agent is the only one aware of final customer demand. In contrast, when a demand-driven scenario is tested, all the different agents have access to final demand and take this information into consideration in their planning as well as anticipation of future demand. Consequently, before responding to a customer demand, the agent verifies that the current demand can be satisfied through changes in production or allocation without disturbing currently accepted demands. Agents also have to validate or change their plans until the best synchronized plan to satisfy the demand has been found.

The results of the tests show that a demand-driven method will enhance sales revenue. Analysis of these results further shows that the optimum quantity that can be bought via contracts is about 40%, while the optimum quantity that can be purchased via spot markets is about 60%. If more contracts are established, the revenue of the network will decrease.

Impact of Forest Policies and Market Conditions on Planning Decisions

The Virtual Lumber case has also been used to analyze how constraints that are not controlled by the enterprise, such as forest policies and market conditions, impact on planning decisions. Therefore, the business units defined in the Virtual case were used, but their names were changed.

Researchers Vila *et al.* (2006) proposed a generic method to design the supply chain of the lumber industry, taking into account the specificity of the industry's divergent manufacturing processes. Their method also allows for lumber market segmentation, i.e. the amounts of lumber sold through contracts, Vendor Managed Inventory (VMI) agreements and spot markets. The case study involved three sawmills (River Mill, Mountain Mill and Valley Mill), seven potential distribution centres (Rivière-Du-Loup, Sherbrooke, Toronto, Bangor, Boston, Colombus and Tampa), four spot markets, eight potential contracts (one signed) and seven potential VMI agreements (one signed) (Figure 83). The probabilities of getting the various contracts/agreements considered were randomly generated.

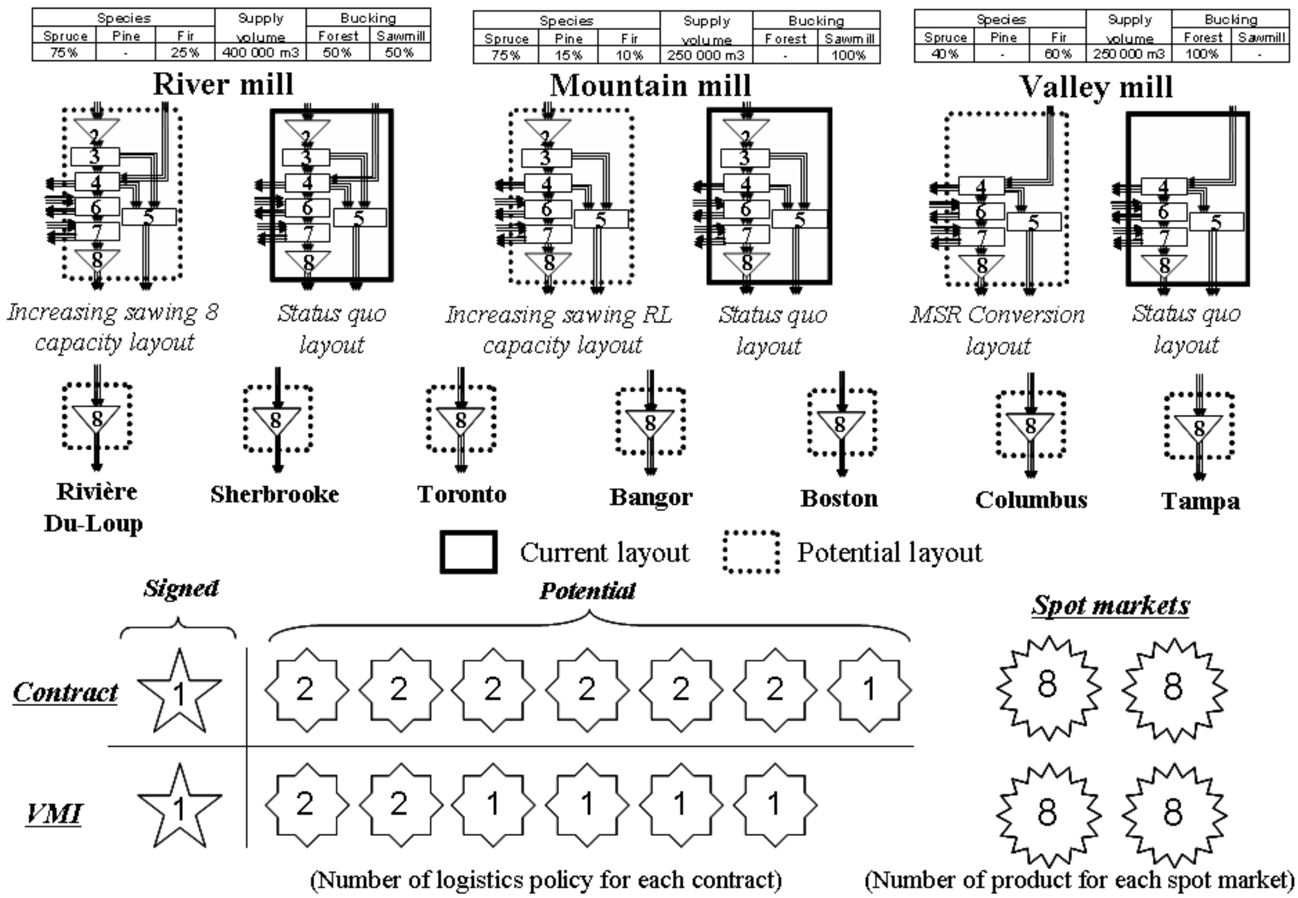

Figure 83: Design of a production-distribution lumber network (Vila, 2006)

As illustrated in Figure 83, the proportions of wood species available from each forest source and the corresponding volumes are given. The current layout is considered for each site, as well as an alternative potential layout. For example, the alternative layout for the River Mill would increase the 8′ sawing capacity, while the alternative layout for the Valley Mill would implement MSR grading.

To model government-related constraints, the researchers set a maximum value for the seasonal supply, and considered that each sawmill had to consume a minimum annual volume of wood from its supply agreement with government.

The results showed that shutting down one mill (River Mill) contributed to a considerable profit increase for the network, as the wood supply was very expensive at that particular facility. Shutting down the mill led to savings in terms of seasonal and annual fixed costs as well as operational costs, hence double gains in profits.

In addition, the authors observed that if a new sawmill was acquired (Lone Patch Mill in the case study) and merged with the River Mill, and supply flows were authorized between mills, network profit increased significantly (Figure 84).

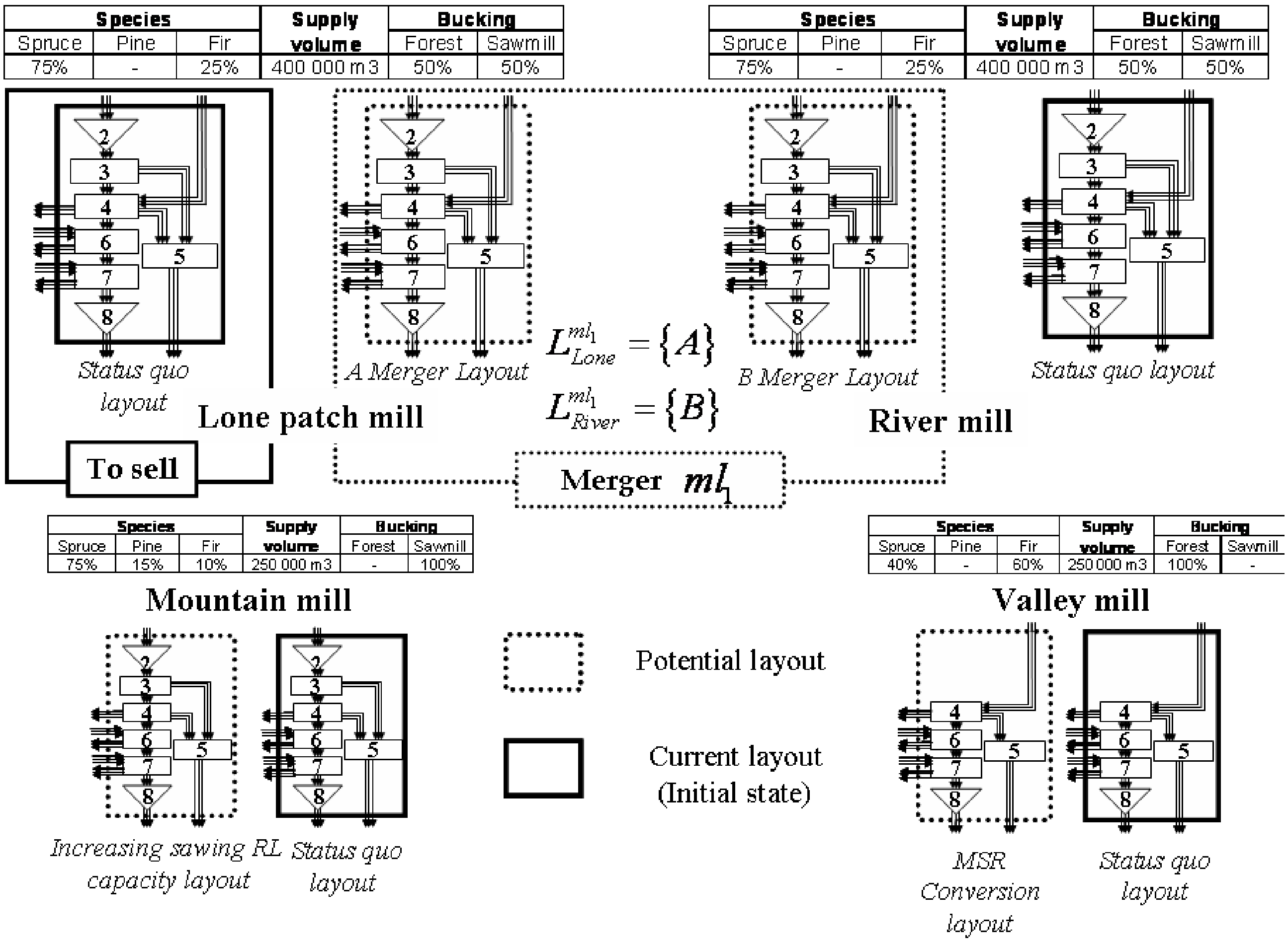

Figure 84: Merger and sawmill network

The River Mill supply was allocated to the merged Lone Patch Mill layout because the two sawmills were geographically close and logistics supply costs did not interfere. In addition, the high price of the River Mill supply was offset by a reduction in fixed and variable costs.

The model described in Vila *et al.* (2006) therefore appears to be a strong tool to manage acquisitions and rationalization in the fragmented lumber industry. The study shows that, under certain conditions, significant savings may accrue from shutting down or closing a mill. Sharing the available fibre among several mills also seems to be an efficient way for planners to provide more flexibility.

Appendix 2: Tools and Application Software for the Forest Products Industry

North American tools

Tool	Organization	Application
Allocation Optimizer	Remsoft products	Fibre allocation
BAM	USDA Forest Service, Land Management Planning	Near term forest planning
bisTrack	Progressive Solutions	Specialized ERP
BUCKPRO	Halco Software	Bucking Improvement System
Contractor / Settlements	Cengea	Contract management
Cruise Wizard	JRP Consulting Ltd	Cruise data collection
CTL-Sim	Halco Software	Cut-To-Length harvesting simulation program
CTS	Force/Robak Associates Ltd	Monitoring of forest activities
Custody Manager	ALDATA Software	Track the origin of each load of wood
DTAILS	Dtails: Cooperative Lumber Management Software	Lumber inventory control software
eLIMBS	elimbs	Lumber management (inventory and tracking)
Enfor Appraisals	Enfor consultants ltd	Stumpage rate prediction
EvaluTree	FPInnovations	Forest attributes
Felix EBOL	Exact Modus	Electronic bills of lading
Felix Harvesting	Exact Modus	Manage agreements with forest contractors
Felix Hauling	Exact Modus	Manages payments to wood haulers
Felix Lumber Sales	Exact Modus	Inventory and follow-up of orders
Felix Mass/Scaling	Exact Modus	Management tool that helps manage wood scaling on a sample basis
Felix Scaling	Exact Modus	Manage wood scaling data
Felix Tally	Exact Modus	Computerizes lumber tally
Felix Weighing	Exact Modus	Automates trucks weighing
Fiber Manager	Lanworth	Integrated fibre supply chain and environmental information management system
Fiber Track	Progressive Solutions	Log procurement and inventory management

Tool	Organisation	Application
FIS	Force/Robak Associates Ltd	Forest inventory system
Flaking	FPInnovations	Machine parameters that affect chip quality
FMMT	FPInnovations	DSS to evaluate multimodal transportation options
Forest Age Map	Lanworth	Identification of forest age and species across large areas
Forest Product Sector Model of Canadian Forests	Essa Technologies	Role of harvested wood products in the carbon balance of forests
ForMAX	Force/Robak Associates Ltd	Long-term, strategic planning of forests and forest estates
FORPLAN	USDA Forest Service	Stand-alone strategic planning tools
FSOS	Forest Ecosystem Solutions Ltd	Spatial planning software
GeoFor 2006	FPInnovations	Machinery monitoring; harvesting or silvicultural operations
GFB	Balance Bourbeau	Weighing, scaling, inventory, consumption
Harvest Scheduler / Wood Flow	Cengea	Integrated woodflow software
Harvesting spreadsheet	FPInnovations	Harvesting
Horsepower Calculator	FPInnovations	Assesses horsepower requirements for circular saws, bandsaws and chippers
IFMS	Force/Robak Associates Ltd	Forest management
Interface 2003	FPInnovations	Harvesting and regeneration systems
Interface MAP 2007	FPInnovations	Forest operations and supply to mills
ISIS	ISIS Wood Product Solutions	Lumber and panel inventory, sales and production software
Kiln Drying Planing Tool	FORAC	Wood drying tactical planning
LIMS	3Log Systems Inc	Log inventory and management system
LISA	LISA Lumber Systems	ERP, forest products industry
Log Pro Software	Primus Partners Inc	Log procurement and inventory management
Log Sort Optimizer	MPM Engineering Ltd	Log sorting
Logcon	FPInnovations	Simulation of log conditioning
LogLink	MOORE Software Solutions	Log procurement and inventory management
LOGSIM	Halco Software	Log-making simulation program
Lumber Sorter	MPM Engineering Ltd	Lumber sorting
Lumber Track	Progressive Solutions	Specialized ERP
Lumbergear	Unique Data Solutions	ERP without accounting or planning
LumberLink	MOORE Software Solutions	Lumber inventory management

Tool	Organisation	Application
Lumber-Net	Lumber-Net Software Solutions	Production & Inventory management
MatForm	FPInnovations	Simulation to optimize parameters for OSB panel production
MatPress	FPInnovations	Simulation to optimize parameters for OSB panel production
MaxTour	FPInnovations	Transportation of forest products
MGM	Department of Renewable Resources, University of Alberta	Individual tree-based stand growth model for the Boreal forest
MSR Toolkit	FPInnovations	Decision-aid tool for machine grading
MultiDAT	FPInnovations	Electronic data logger
OASiS	FPInnovations	Wood drying simulation
Operandi	Exact Modus	Inventory, wood procurement and traceability
OperMAX	Force/Robak Associates Ltd	Multi-year operations planning optimization system
OP-PLAN	Force/Robak Associates Ltd	Planning of forest activities
Opti-Grade	FPInnovations	Data logger; road construction
OPTIONS	D.R. Systems Inc	Land management planning tool
Optitek	FPInnovations	Simulation of sawing process
OSB Processing	FPInnovations	Simulation to optimize parameters for OSB panel production
OTTO	FPInnovations	Transportation; simulation
OXY	Génisys	Wood drying management
PanelSim	Halco Software	Panel mill simulation and optimization
PASCAL	FPInnovations	Harvesting, forestry equipment
Patchworks	Spatial Planning Systems	Spatial planning
PEP	FPInnovations	Analysis of capital expenditure for the lumber manufacturing process
Phoenix	D.R. Systems Inc	Forest activity tracking systems
PlaniRoute	FPInnovations	Harvesting
Planner/Resources/TFM	Cengea	Plan and track forest operations
Planning rail car loads	FORAC	Rail car loading
Plant Wizard	JRP Consulting Ltd	Tree planting administration software
PlantWizard.com	JRP Consulting Ltd	Seedling inventory
Private Woodland Planner	Enfor Consultants Ltd	Forest product values assessment
PrognosisBC	BC Ministry of Forests and Range	Growth and yield computer model
Provue 2005	FPInnovations	Harvesting, forestry equipment

Tool	Organisation	Application
RELMdss	USDA Forest Service, Land Management Planning	Forest planning
RoadLogger	Softree	Field data collection on forest roads
SawSim	Halco Software	Sawmill simulation program
SawSim-LP	Halco Software	Sawmill production planning and optimization system
Scale Boss	ALDATA Software	Weight scale management system
Scaler / Tester	Cengea	Track and manage scaled wood
ScaleWiz	3Log Systems Inc	Log scaling
Scoopsoft	GFI Business Solutions	ERP, forest products industry
SELES	Gowlland Technologies Ltd	Spatial raster event simulator
SFMM	Ontario Ministry of Natural Resources	Strategic forest management model
SILVIRR	D.R. Systems Inc	Silviculture investment rate of return system
SilviScan	FPInnovations	Forest attributes
Smart Lumber Grading	Exact Modus	Lumber grading solution
SNAP	U.S. Forest Service Cooperative Research	Tactical forest planning
SPE	FORAC	Supply chain design
SPEC+	FPInnovations	Transportation
Spectrum	USDA Forest Service	Stand-alone strategic planning tools
Stanley	Remsoft products	Spatial harvest scheduling
Survey Wizard	JRP Consulting Ltd	Silviculture survey software
Sylva II	Ministère des Ressources naturelles et de la Faune du Québec	Simulation for allowable annual cut
SYLVER	BC Ministry of Forests and Range	Stand level system
TAGASIS	ALDATA Software	Monitoring of mobile equipment moves and costs
TallyWorks	TradeTec Computer Systems Inc	Lumber sales and inventory management
TASS-TIPSY	Stand Development Modelling Group, BC Ministry of Forests and Range	Growth and Yield (GY) modeling tools
Terrain Tools - Forest Engineer	Softree	Forest survey and mapping functions plus cable logging analysis
The Cutting Edge	Caribou Software	Log management software
The Logger Tracker	BCS Woodlands System	Logging operation management
The Logger's Edge	Caribou Software	Logging

Tool	Organisation	Application
The Mill Tracker	BCS Woodlands System	Production management
The ScaleHouse Tracker	BCS Woodlands System	Scale house activity recording
The Trucker's Edge	Caribou Software	Manage a log hauling operation
The Woodlands Tracker	FPInnovations	Simulation to optimize parameters for OSB panel production
TIMBER	Edoc Systems Group	Forestry planning and production software
TimberWeight	Pacific Software	Weigh Scale Data Collection
TOPS/4	Enterprise Code Works	Automated weigh scales integration, purchase, sales and trading contracts, inventory tracking, quality testing, commodity and freight payables and receivables, management reporting and export, web access for supply chain partners.
TPCS Fuel Estimator	FPInnovations	Transportation
TransITS	FPInnovations	Catalogue of application for transportation
VDYP	BC Ministry of Forests and Range	Variable density yield prediction
VGrader	FPInnovations	Software to link wood and veneer characteristics to final LVL or plywood properties
Visual Landscape Planner	Enfor consultants Ltd	Forest visualization
Vpeel	FPInnovations	Optimise lathe settings for both hardwood and softwood veneer production
VTM	FORAC and FPInnovations	Transportation
VYield	FPInnovations	Simulates the effects of various parameters on veneer recovery
WALL2D	FPInnovations	Prediction of fire resistance in walls
WeighWiz	3Log Systems Inc	Log weighing
Wood characteristics identification & measure	FPInnovations	Catalogue of applications for wood characteristics measurements
Woodlot for Wondows	Enfor Consultants Ltd	Woodlot management
WoodMan	Halco Software	Sawmill Optimization
WoodManager	Pacific Software	Lumber and panel inventory, sales, production and purchasing
WoodResource	Pacific Software	Log and fibre purchases, settlements, inventory and sales
WoodScan	Pacific Software	Barcode based plant flow data collection
WoodSim	Halco Software	Log-Supply Simulation Program
Woodstock	Remsoft products	Forest modelling
WoodWork	Timber Soft	Software solutions for the wood veneer industry

Tool	Organisation	Application
WPMS	Workflow automation solution	Workflow automation solution
Yard Boss	ALDATA Software	Fibre accounting and inventory
Yard inventory	Cengea	Inventory management
Ccontrol systems for automated equipment	Opertech	Design, development and installation of control systems for automated equipment
DashBoard	Opertech	Display of operational data

International tools

Tool	Organization	Application
Åkarweb	Holmen Skog	Web-based planning of haulage
ASICAM	Epstein R., Morales R., Seron J., Weintraub A. (University of Chile)	Optimizes trucking in forest operations
ATLAS Cruiser	ATLAS Technology	Forest inventory software
ATLAS Forecaster	Forest Research Stand Growth Modelling Co-operative	Forest management
ATLAS GeoMaster	ATLAS Technology	Forest estate information
ATLAS Harvest Manager	ATLAS Technology	Managing harvest plans
ATLAS Harvest Scheduler	ATLAS Technology	Harvest scheduling with scenario analysis
ATLAS Market Supply	ATLAS Technology	Harvest scheduling to meet customer demand
ATLAS Permanent Sample Plots	ATLAS Technology	Forest management
ATLAS Roading Manager	ATLAS Technology	Forest road management
CPLAN	From: http://web.unbc.ca/~garcia/publ/handbook.pdf	LP forest management systems
FlowOpt	Skogforsk	Wood-flow logistics
FOLPI	Forest Research Institute, New Zealand Forest Service	Forest management planning
Forest Information and Planning System - FIPS	PFOLSEN	ERP
Forest Management Planning Package	Swedish University of Agricultural Sciences Faculty of Forestry Uppsala	Forest management
IFS	New Zealand Forest Research Institute	Interactive forest estate simulator
IFS Forest system	IFS Industrial & Financial Systems	ERP
MARVL (& GroMARVL)	New Zealand Forest Research Institute	Pre-harvest inventory system
MEDFOR	Epstein R., Morales R., Seron J., Weintraub A. (University of Chile)	Stand-alone strategic planning tools
MELA & JLP	Finnish Forest Research Institute (Metla)	Forest inventory and planning systems
OFSIM	H. K. Koesmarno School of Forestry, University of Canterbury, Christchurch	Forest stand structure simulator for management
OPTICORT	Epstein R., Morales R., Seron J., Weintraub A. (University of Chile)	Short-term planning system for forest companies
OPTIMED	Epstein, R., University of Chile	Tactical forest planning tool

Tool	Organisation	Application
PLANEX	Epstein, R., Weintraub A. (University of Chile)	Road design and harvesting machinery location
RegRAM-I	Tasman Forestry Ltd	Harvest scheduling and log allocation
RMSBO; RMS80/RMS85	NZ Forest Products Limited	Forest management planning and harvesting
RuttOpt	Skogforsk	DSS for routing of logging trucks
YTGen	Silmetra Ltd	Yield table
Integration and coordination in forestry transportation planning	Skogforsk	Transport coordination

List of Acronyms

AASA = Aserraderos Arauco Sociedad Anónima

B2B = Business to Business

CIRRELT = Centre Interuniversitaire sur les Réseaux d'Entreprises, la Logistique et le Transport

CP = Commitment Point

CPFR = Collaborative Planning, Forecasting and Replenishment

CTI = Central Tire Inflation

DP = Decoupling point

DSS = Decision Support System

ERP = Enterprise Resource Planning

EVA = Economic Value Added

FMMT = Forest Multimodal Transportation Model

GIS = Geographic Information Systems

Glulam = Glued Laminated Structural Timber

GSCF = Global Supply Chain Forum

IPCC = Intergovernmental Panel on Climate Change

LVL = Laminated Veneer Lumber

Mbf (ou Mfbm) = 1000 Board Feet (Foot Board Measure)

MDF = Medium density fibreboard

MMfbm (ou MMbf) = Million Board Feet (Foot Board Measure)

M.Sc. = Master of Science

M.Sc.F. = Master of Science in Forestry

OSB = Oriented Strand Board

PGW = Pressure Groundwood

Ph.D. = Doctor Philosophiæ

RMP = Refiner Mechanical Pulp

SCOR = Supply Chain Operations Reference-model

SKU = Stock-Keeping Unit

S&OP = Sales & Operations Planning

SPE = Simulation and Prototyping Environment

TMP = Thermomechanical pulp

VMI = Vendor Managed Inventory

VTM = Virtual Transportation Manager

XML = Extensible Markup Language

3PL = Third Party Logistics

Glossary

Agent
A software component with its own behaviour that represents an entity and can interact with similar entities.

Aggregation
Any process in which information is gathered and expressed in a summary form. In system modelling, aggregation may relate to different topics (e.g., products, time and location), and to varying levels within a topic. For example, the product may be aggregated at the species or family level; time may go from decades down to seconds in some applications; and the location may be broad (e.g., a province or a city), or it can be more specific (e.g., one level in a plant or even a specific location within the plant).

Air drying
The process of seasoning lumber in the open air – protecting it from the sun and rain with covering boards or an open sided shed. Air seasoning is sometimes required for most species prior to kiln drying.

Asymmetric information
One party is not in the same position as other parties, being ignorant of, or unable to observe, information which is essential to the decision-making process.

Biofuel
Fuel made from biomass, namely biological sources such as wood, that have completed their life cycle. Biofuel can be in liquid, gaseous or solid form.

Bottleneck
Department, facility, machine, or resource already working at full capacity, and which cannot therefore handle additional demand. Also called critical resource, a bottleneck limits the throughput of associated resources.

Bucking optimization
The process of converting tree stems into logs of the highest possible value.

Business process
A set of coordinated tasks and activities such as planning, production and sales, conducted by both people and equipment, that will lead to accomplishing a specific organizational goal.

Buyback contract
Incentive based on product returns by which the retailer (or the merchant, customer, etc.) can return some or all unsold items in exchange for compensation.

By-product
Secondary or incidental product deriving from a manufacturing process, a chemical reaction or a biochemical pathway, and is not the primary product being produced.

Capital cost
Measure of the return that the provider of capital expects to earn on its investment.

Cogeneration
A process in which an industrial facility uses its waste energy to produce heat and electricity.

Collaborative Planning, Forecasting and Replenishment (CPFR)
A collaborative process whereby supply chain trading partners can jointly plan key supply chain activities from production and delivery of raw materials to production and delivery of final products to end-customers. Collaboration encompasses business planning, sales forecasting and all operations required to replenish raw materials and finished goods.

Competitive advantage
Condition which enables a company to operate in a more efficient or otherwise more desirable manner than its competitors, and which results in benefits accruing to that company.

Consortium
Form of alliance between partners established to create a given set of competencies, and that necessitates an investment in terms of capital, resources and technologies.

Contract
An agreement with specific terms between two or more persons or entities in which there is a promise to do something in return for a valuable benefit known as consideration.

Coordination structure
A pattern of decision making and communication among a set of stakeholders who perform tasks in order to achieve goals.

Co-product
A valuable product that is created as a result of producing the main product.

Customer negotiation process
The set of activities starting with the initial customer enquiry and ending when the inquiry becomes an order.

Cycle time
The time elapsed between the beginning and the end of a process.

Decision Support System (DSS)
Specific class of computerized information system that supports business and organizational decision-making activities. A properly-designed DSS is an interactive software-based system intended to help decision makers compile useful information from raw data, documents, personal knowledge, and/or business models to identify and solve problems and make decisions.

Decoupling Point
The process/link in the chain up to which the customer order penetrates.

Demand point
The location where the demand for a product occurs. Depending on the model, the demand point may be a warehouse, a distributor or another facility.

Deterministic
Events that have no random or probabilistic aspects but rather occur in a completely predictable fashion.

Distributed planning
A process that allows multiple organizations to participate in the development of a single integrated plan.

Distribution Centre
Entity receiving, stocking and shipping products on their way from suppliers to customers.

Distribution System
Entire set-up consisting of procedures, methods, equipment and facilities, designed and interconnected to facilitate and monitor the flow of goods or services from the source to the end-user.

Distributor
Firm that sells or delivers merchandise to customers, such as retail stores. Distributors act as intermediaries between manufacturers and retailers. They maintain a warehouse of

merchandise that is often purchased from many different manufacturers, and is then sold (or distributed) among various retailers.

Economic Value Added
A tool to measure the economic rather than accounting profit created by a business after the cost of all resources including both debt and equity capital have been taken into account.

Electronic Data Exchange
The electronic transfer of information in a standard format between two or more entities.

Engineered wood
Engineered wood, also called composite wood, "man-made wood" or "manufactured wood", includes a range of derivative wood products which are manufactured by binding together the strands, particles, fibres, or veneers of wood, together with adhesives, to form composite materials. These products are engineered to precise design specifications which are tested to meet national or international standards.

Financial flow
The set of monetary transactions between different business units in a value creation network, such as payments, credits, transfer price, transaction costs, and so on.

Forest biomass
All the above-ground components of a tree such as tree tops, branches, foliage, etc., that can be used for energy.

Forest management
Scientific planning and administration of forest resources for sustainable harvest, multiple use, regeneration and maintenance of a healthy biological community.

Forest product
Any material derived from a forest for commercial use, such as lumber, paper or panel.

Forest road
A road built in the forest to access timber harvest areas.

Forestry operations
Workplace where work is done in relation to silviculture or tree harvesting, including constructing the means of access and transporting harvested trees to a facility where they are processed or from which they are shipped away.

Geographic Information System (GIS)
Integrated computer mapping and spatial database management system that provides several functions for geographic data, including storage retrieval, management, analysis and display.

GSCF
A supply chain model introduced by the Global Supply Chain Forum. It builds on eight key business processes that are both cross-functional and cross-firm in nature. Each process is managed by a cross-functional team, including representatives from logistics, production, purchasing, finance, marketing and research and development. While each process will interface with key customers and suppliers, the customer relationship management and supplier relationship management processes represent the critical linkages in the supply chain.

Heuristic algorithm
Algorithm that ignores whether the solution to the problem can be proven to be optimal, but which usually produces a good solution or solves a simpler problem that contains or intersects with the solution of the more complex problem. Heuristics are typically used when there is no known way to find an optimal solution, or when finding the optimal solution is not compatible with acceptable run time limits.

Information flow
The process by which information is exchanged either top–down along the supply chain towards the raw material suppliers or bottom–up towards the end customer.

Integrated company
Form of business organization in which all stages involved in the generation of a commercial product, from raw materials acquisition to final product retailing, are controlled by one company.

Inventory Replenishment process
A business process in which forecasts are updated, inventory levels measured, sourcing and manufacturing operations planned, and inventory distributed.

Inventory turnover
Ratio of average cost of goods sold to average inventory investment.

Joint venture
Long-term agreement joining together two or more parties for the purpose of achieving a particular business undertaking. All parties agree to share in the profits and losses of the enterprise.

Jumbo roll
A roll of paper, direct from the paper machine, wound on a machine winder spool as distinct from rolls that have been slit and rewound on cores.

Kiln drying
Artificial method of drying lumber by forcing heated air to circulate around the lumber in an enclosed building.

Kraft pulp
High-strength paper made from unbleached sulfate (kraft) pulp, usually brown in color.

Lead time
The time elapsed between receiving an order and shipping the product or service to the customer.

Lignocellulosic material
Refers to the organic matter produced by plants on the Earth in the form of grasses, shrubs, agricultural crops and trees.

Linear programming
A mathematical technique used to find the maximum or minimum of linear functions in many variables subject to constraints. Linear programming is used in particular to determine the way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model, given a list of requirements represented as linear equations.

Lumber
A wood product manufactured from logs by sawing and usually planing with all four sides sawn.

Transfer yard
An in-transit location for logs before they get forwarded to their final destination.

Make-to-Stock method
A manufacturing system in which finished goods are produced and stocked prior to receipt of a customer order.

Make-to-Order mode
A manufacturing process established to satisfy customer demand only after an order has been placed.

Manufacturer

Entity that makes a product through a process involving raw materials, components or assemblies, usually on a large scale, with different operations divided among different machine centres and workers.

Mathematical programming

Application of mathematical and computer programming techniques to the construction of deterministic models, mainly for business and economics. For models that only require linear algebraic equations, the techniques are called linear programming; for models that require more complex equations, it is called nonlinear programming. In either case, models frequently involve hundreds or thousands of equations.

Medium Density Fibreboard

A composite (or manufactured) wood product made by combining fine particles and resins (adhesives) under pressure to produce sheets that are sold in standard or non-standard sizes.

Merchant

An organization that buys products from different sources, and then sells them to consumers without transforming the product.

Mixed-integer linear program

A linear program with additional constraints that some of the variables must take on integer values.

Operational Research

The application of scientific methods and techniques to decision-making problems. A decision-making problem occurs where there are two or more alternative courses of action, each of which leads to a different and sometimes unknown end result. Operations research is also used to maximize the utility of limited resources. The objective is to select the best alternative, that is, the one leading to the most beneficial result.

Opportunistic behaviour

Refers to the suggestion that a decision-maker may unconditionally seek his/her self-interests, and that such behaviour cannot necessarily be predicted.

Order

An instruction that specifies a specific need from a specific business unit at a specific time. There are several different types of orders, each offering different conditions.

Order Fulfilment process
The sequence of steps involved in processing an order to the satisfaction of the customer and making the necessary changes in inventory records.

Oriented strand board
A type of particle panel product composed of strand-type flakes which are purposefully aligned in such a way as to make the panel stronger, stiffer and more dimensionally stable in the direction of alignment than a panel with random flake orientation.

Paperboard
A heavy weight, thick, rigid and single- or multi-layer sheet. What differentiates paperboard from paper is the weight of the sheet. Papers heavier than 150 grams per square metre are normally referred to as "paperboard" and paperboards heavier than 500 grams per square metre are called "board".

Paper conversion
The operation of treating, modifying or otherwise manipulating finished paper and paperboard so that it can be made into end-user products.

Paper mill
A factory devoted to making paper from wood pulp and other ingredients.

Paper roll
A compact roll of specified length or diameter that can be cut or sold directly to customers.

papiNet
Global communication XML standard for the paper and forest products industries.

Particleboard
A panel composed of small wood particles and wood fibre bonded together with synthetic resin adhesives in the presence of heat and pressure.

Performance measurement
The process of evaluating how well organizations are managed and the value they deliver for customers and other stakeholders.

Plan
Set of information defining when, where and how the different activities will be conducted within a business unit or a set of business units.

Planning decisions
Continuous and systematic process whereby people make decisions about intended future outcomes, how outcomes are to be accomplished, and how success is to be measured and evaluated.

Planning horizon
Length of time an organization looks into the future when preparing a plan.

Plywood
A type of manufactured wood made from thin sheets called plies or veneers. The layers are glued together, each with its grain at right angles to adjacent layers for greater strength and stability.

Point of Sales Data
Data that are captured at the time and place of sale.

Pressurized Groundwood Pulp
Mechanical pulp produced by treating logs with steam before defibration against a grindstone under externally applied pressure.

Price agreement
The price charged by the supplier to the customer to coordinate the system.

Procurement
Complete process of obtaining goods and services from preparation and processing of a requisition through to receipt and approval of the invoice for payment. Also called sourcing.

Production
Processes and methods employed to convert tangible inputs (raw materials, semi-finished goods or subassemblies) and intangible inputs (ideas, information, know-how) into goods or services.

Product flow
The movement of goods from a supplier to the end customer, as well as the customer returns or the service needs.

Product return process
Set of operations for receiving, sorting and analyzing a customer product return. The procedure is completed with the disposal of the product.

Pulp mill
A manufacturing facility that converts wood chips or other plant fibre source into a thick fibre board which can be shipped to a paper mill for further processing. Pulp can be manufactured using mechanical, semi-chemical or fully chemical methods (kraft and sulfite processes). The finished product may be either bleached or unbleached, depending on customer requirements.

Quantity discount
Reduction in price per unit, as an incentive for making purchases in larger quantities.

Quantity flexibility contract
A method for coordinating materials and information flows in supply chains operating under dynamic environments. The buyer has to commit to a minimum quantity, but may adjust the order when more accurate information on demand becomes available.

Raw material
Physical substances used as inputs to production or manufacturing.

Recycled material
Goods remanufactured to form a new product.

Refiner Mechanical Pulp
Mechanical pulp resulting from the grinding of wood chips between the plates of a refiner.

Revenue sharing contract
Supply chain incentive in which the manufacturer charges the buyer a low wholesale price in exchange for sharing in the revenue generated by the buyer.

Risk assessment
Activities that enable supply chain managers to identify, evaluate and measure risks on the value creation network.

Sales & Operations Planning process (S&OP)
Set of business processes and technologies that enable an enterprise to respond effectively to demand and supply variability with insight into the optimal market deployment and most profitable supply chain mix.

Sales forecast
The prediction, projection or estimation of expected sales over a specified future time period.

Sawmill
A mill in which machines (mostly saws) are used to convert logs into lumber or other forest products.

SCOR
A process reference model developed by the Supply Chain Council, which aims at integrating the well-known concepts of business process reengineering, benchmarking, and process measurement into a cross-functional framework.

Service level
The probability of being able to satisfy any order during the normal order cycle from the stock on hand.

Setup cost
The cost of preparing the equipment or machines to complete a job, including cleaning, adjusting, etc., but excluding the cost of the product itself.

Softwood
Wood of a coniferous tree, such as pine or spruce.

Stochastic
Situations or models containing a random element, hence unpredictable and without a stable pattern or order. For example, all natural events are stochastic phenomena.

Strategic Planning process
Decision-making process relating to the long-term mission and objectives of an organization, the resources used to achieve these objectives, and the policies and guidelines that govern the acquisition, use, and disposition of the resources involved.

Sulfite pulp
Chemical pulp for which various sulfites or bisulfites are used as main cooking chemical.

Supply Chain Management
The set of activities, tools and software that allows a company to more tightly integrate production across business partners within a value creation network.

Supply Chain risk
Potential variation of outcome that influence the decrease of added value at any activity cell in a chain, the outcome being described by the volume and quality of goods in any location and time in a supply chain flow

Sustainability
A state or process that can be maintained indefinitely. The principles of sustainability integrate three closely related elements, e.g.: the environment, the economy and the social background, into a system that can be maintained in a healthy state indefinitely.

Silviculture
The art and science of controlling the establishment, growth, composition, health and quality of forests to meet the diverse needs and values of many landowners or users, societies and cultures.

Thermomechanical Pulp (TMP)
Pulp obtained by steaming wood chips prior to and during refining, a process that results in higher yield and stronger pulp than regular groundwood.

Third-party certification
Specific set of criteria and processes that govern management plans and actions on the ground, as audited by a third-party agency. Forests can be certified under several recognized agencies.

Third Party Logistics (3PL)
A Third Party Logistics provider is a firm that provides outsourced or "third party" logistics services to other companies. Third party logistics providers typically specialize in integrated warehousing and transportation services that can be customized to customer needs.

Throughput
The rate at which something can be processed, or at which data is transferred through a system.

Transfer pricing
The price that is assumed to have been charged by one part of a company for products and services it provides to another part of the same company, in order to calculate each division's profit and loss separately.

Value added
Additional benefit being provided by some activity or service.

Value Creation Network
All the activities involved in delivering a product from raw material through to customer delivery, including sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across

all channels, delivery to the customer, and the information systems necessary to monitor all of these activities.

Value Proposition process
Utility that companies create for customers, from the price and functionality of the products or services to the convenience, speed, and reliability of delivery, the friendliness of customer service and the prestige or image associated with the product or service.

Vendor Managed Inventory (VMI)
Collaboration approach in which the supplier is responsible for managing the inventories of its products for the customer. The supplier is responsible for taking care of the entire replenishment process, and has the necessary authority to do so.

Veneer
Thin sheets of wood that are typically assembled with an adhesive to form sheets of plywood (See "Plywood"). They may also be glued onto core panels such as particleboard or medium density fibreboard (MDF) to enhance their appearance and value.

Wholesaler
Firm that buys large quantities of goods from various producers or vendors, and resells them to retailers or merchants rather than to the final customers.

XML
A flexible way to create common information formats, and share both the format and the data on the Web, intranets and elsewhere.