Timber Harvesting within a Supply and Value Chain Optimization Context

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1 Introduction

"A supply chain is a physical network of entities through which materials, information, and cash flow is distributed", (Ronnqvust, 2005). "Supply chain management implies planning, development, coordination, organization, steering and control of intra and inter-organizational processes from a holistic perspective and accounting for exchange of materials, information, cash, product development activities and marketing activities in a chain", (Haarvtveit, Kozak and Maness, 2008).

In the forest sector, the supply chain starts with growing stock and proceeds to single or multiple series of transformation. Value chain optimization is an approach that maximizes value across the entire supply chain (Karlsson, Ronnqvist and Weintraub, 2007). The chain starts with raw material (standing timber), where physical activities have been implemented to get the raw material to different markets.

This paper aims to discussing forest supply chain from an operative planning perspective within forest operations: timber harvesting, primary transport, and secondary transport to various markets. Short-term planning (harvesting and distribution) needs to become integrated with sawmilling planning and production.

In order to optimize value across the entire supply chain, it is crucial to realize that timber harvesting operations have a major influence on the value being optimized. Arguably, for a holistic supply and value chain optimization, harvesting operations should be aimed at value maximization in consideration of the entire supply chain. The real challenges in forest harvesting supply and value chain optimization are bucking, production and logistics planning.

2 Background Information

Supply chain planning and focusing has significantly contributed to improving the performance of many companies; however, the challenge of integrating the different planning problems still remains (Amours, Ronnqvist and Weintraub, 2007). It is therefore important to integrate timber production and distribution with sales (Michaelsen, 2010). The forest product supply chains are generally composed of many business units, which are linked together and constrained by various divergent processes (Amours, Ronnqvist and Weintraub, 2007). Due to the nature of forest management, many processes are involved in growing timber, harvesting and transporting it to various markets. These processes "raise the complexity of integrating the procurement as production, distribution and sales activities are always bounded by tradeoffs among yield, logistic costs and service levels", (Amours, Ronnqvist and Weintraub, 2007).

The nature of forest management requires planning in various time frames: strategic, tactical and operational planning. It is critical to integrate these planning levels within the supply chain planning. From a global perspective, forest operations have a great and direct impact on the performance of the different supply chains using wood fibre (Baskent and Keles, 2006).

2.1 Supply Chain Planning in the Forest Product Industry

2.1.1 Strategic Planning

This is a long term planning process that integrates tactical and operative planning. It is an important tool that management uses to maintain a competitive advantage, for example, by adopting different management tools to satisfy the organization's future objectives/goals. In forestry, strategic planning plays a fundamental role due to long timber rotations, as well as a volatile and dynamic business environment. In Canada for example, rotation lengths can span over more than 80 years, whilst in tropical plantation forests the rotation lengths can be from 8 – 22 years. In their research, Amours, Ronnqvist and Weintraub, (2007) notes that "Strategic planning decisions include forest management strategy, silvilculture treatment, identifying conservation areas, road construction, opening and closing of mills, location of new mills, and process investments".

Strategic planning has a significant impact on all future investment decisions and such decisions involve the evaluation of how the investment will fit into the whole supply chain (Mendoza and Luppold, 1993). Strategic planning helps to answer and plan for the following questions:

- How will the distribution of the products be carried out and at what cost?
- Which markets are available for the products, based on the anticipated market trends?
- How should the production be allocated within the wood supply chain?

2.1.2 Tactical Planning

"Tactical planning addresses the allocation rules which define which resource should be responsible for realizing the different supply chain activities. It also addresses the usage rules defining production, distribution delays, and lot sizing and inventory policies", (Mendoza and Luppold, 1993). The tactical plan needs to consider the allocation rules in a holistic manner where the entire supply chain is made a priority; therefore, a tactical plan can also be perceived as a planning tool that links the long-term strategic level plans with the detailed operative planning.

Tactical planning plays a significant role where there is a need for advanced planning, especially in areas where there is seasonality in the supply chain. Seasonality in forest operations context may be any circumstances that greatly influence the procurement of timber (Mendoza and Luppold, 1993). For example, frequent rain weather conditions will make transportation operations infeasible due to slippery roads.

2.1.3 Operative Planning

This is a short term plan, which “proceeds and decides real-world operative actions”, (Mendoza and Luppold, 1993). Precision is crucial in this planning process and activities are planned for monthly, weekly and hourly periods. Within the production process, scheduling of the different products on the manufacturing lines are typical operational planning tasks. Cossens (2007), makes the following observations concerning short term planning:

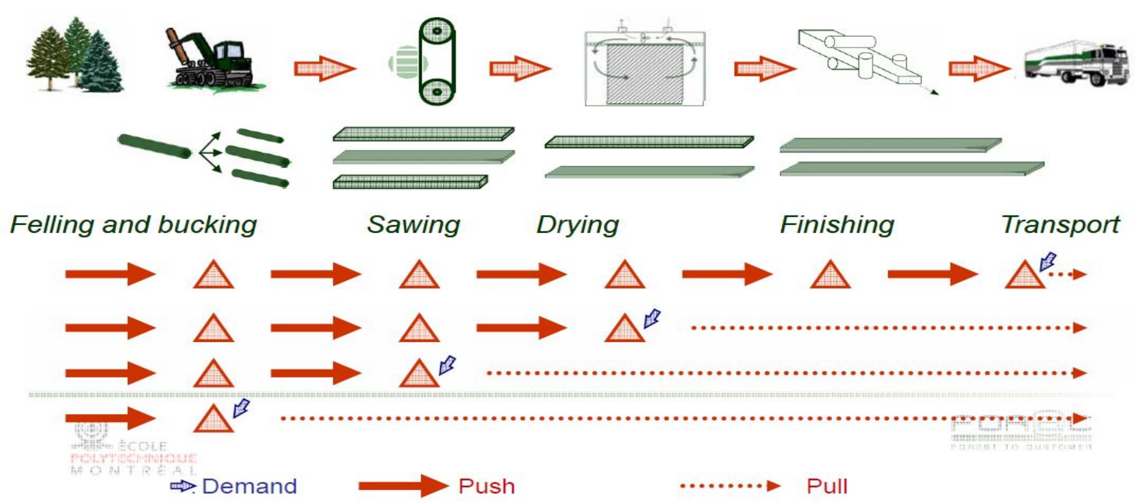
- Operative planning deficiencies are found in many wood products (saw milling).
- Transportation is a significant factor in operative planning due to dispatching inefficiencies that subsequently appear between several segments of the supply chain.

2.2 Operation Research

A full range of Operation Research (OR) methodologies are currently implemented to support the planning challenges of the forest product sector. These OR programs have been designed to address the different hierarchical planning methods: strategic, tactical and operative (Boyland, 2002). Boyland continues to state that "*heuristic, meta-heuristics* and easy to solve network approaches are typically used for operational problems, whilst *Mixed Integer Programming* (MIP) and *stochastic programming* serve better the tactical planning and strategic planning problems". He also notes that there is a trend in the forest sector where many OR models are implemented in different industrial "*decision support systems* (DSS) where these DSS are integrated with application specific databases holding all the information needed for the models and *geographic information system* (GIS) to enhance visualizing the input data and outcomes".

3 Overview of the Forest Supply Chain

Figure 1: *Management decisions that influence the supply chain*



(Mark, 2009)

Figure 1 shows the stages of supply and value chain optimization in forestry. Management needs to be aware of the current market trends and evaluate the extent of the supply chain that will optimize financial gains. For example, if the financial gains for round timber (logs) outweighs lumber prices, integrated firms (businesses that own forest lands and mills) might prefer to maximize log sales; therefore, the supply chain will be shortened or less complicated.

Figure 2: *Schematic of a forest supply and value chain Optimization*

(Michaelsen, 2010)

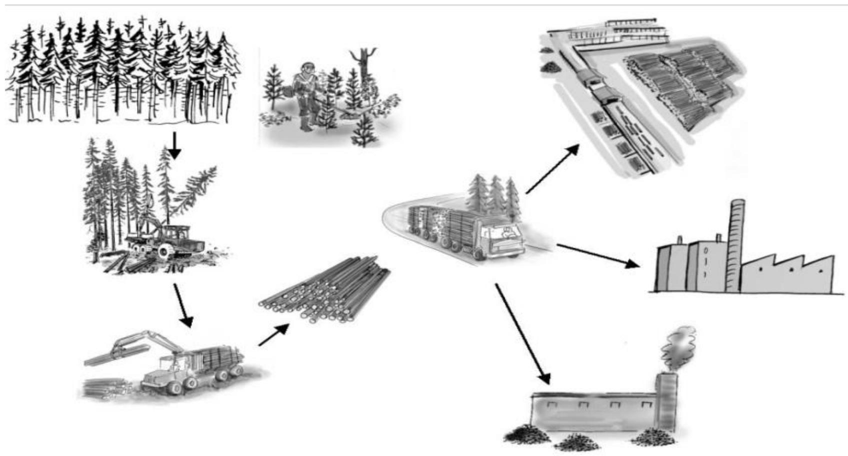
Figure 2 shows the forest sector value chain where all activities have been integrated. There are many complex variables that influence the supply and value chain management/procedures/processes and these can range from harvesting and log merchandizing to timber transport. Optimized processing, integration and logistics are crucial in making the entire supply chain efficient.

3.1 Harvesting and Log Merchandizing

This study will focus on fully mechanized forest operations where a cut-to-length harvesting system will be discussed. Depending on the harvesting system (tree length versus cut-to-length), timber harvesting can be categorized into:

- Falling
    - Feller buncher
    - Harvester or harvester processor
- Primary transport
    - Forwarder
    - Skidder
    - Cable yarder
- Chuting: timber slides structures, normally half cut culverts that are connected to form a straight line and are used to slide timber down a steep slope.
- Road side handling
    - Timber stacking (in the case of cut-to-length harvesting system)
    - Timber merchandizing (bucking of timber to maximize value)
- Secondary Transport
    - Timber loading
    - Transport to various mills or stockyard

Figure 3: *Cut –to-length harvesting system, transportation and various markets* (Ronnqvist, 2005)



In figure 3, harvesters are divided into two groups; single grip harvester and double grip harvester. The focus will be on single grip harvester where the equipment both fells and processes with a single boom-mounted unit.

Akay and Imam, (2004) have conducted a study on single grip harvesters where they concluded that its productivity is closely related to:

- Tree size: As volume increases, production rate will increase since processing time for big trees is same as the same as the small size trees.
    - In timber of less than 55cm diameter, the single-grip harvester is extremely productive at felling, delimbing and bucking.
- Slope: Steep slopes cause difficulties to harvester and that may increase handling time per tree.

Grammel, (1995) developed a regression equation that can be applied to predict the productivity of single-grip harvesters where tree handling time is a function of:

- Tree volume
- Slope class (26-40%)

$$Y = 56.62 \ln(X) + 322.09$$

Where:

Y= Cycle time per tree (cmin/m³)

X=Volume per tree (m³)

The above regression equation can be applied to slope class ranges of 26-40%; therefore, the constants could change other slope classes above and below this range. Since slope and tree volume are independent variables, it could be assumed that on relatively flat terrain and bigger tree size, productivity per machine hour should be directly proportional.

3.1.1 Forwarder

Forwarders are articulated vehicles used for transporting cut-to-length logs clear off the ground. As shown in figure 3, these machines are commonly used in cut-to-length harvesting system. Forwarders are also becoming increasingly utilized in thinning operations. In his study, Grammel, (1995) indicated that the productivity of forwarders is a function of:

- Travelling time
    - Distance
    - Machine horsepower
    - Load weight
    - Vehicle speed, influenced by:

- Tractive effort
- Resistance: rolling and grade resistance

- Loading time
- Other elements, including repositioning time, sorting time, delay time and brushing time

3.1.2 Downhill Unloaded and Uphill Loaded Speeds

To determine uphill unloaded vehicle speed (*Vup*) in meters per minute, the net flywheel (*HP*) of the vehicle and the estimated tire slip are the direct limiting factors:

$$Vup = \frac{HP6000}{(1+s)Rg + Rr}$$

Where:

Vup = Uphill vehicle loaded speed (m/minute)

HP=Net flywheel (Horsepower)

S= estimated tire slip

Rg = grade resistance (Newton)

Rr = Total rolling resistance

To determine a downhill loaded vehicle speed (*Vdown*) in meter per minute, vehicle speed must be computed based on engine brake horsepower (BHP).

$$Vdown = \frac{BHP60000}{Rg - Rr}(1+s)$$

Through the application of Grammel equations, the equipment travelling time (unloaded and loaded time) can be calculated as follows:

$$Unloaded\ travelling\ time = \frac{Forwarding\ distance}{Vup}$$

$$Loaded\ travelling\ time = \frac{Forwarding\ distance}{Vdown}$$

To determine loading time per cycle,

$$LT = \left(\frac{FLC}{0.7LC} + \frac{FLC}{0.9LC}\right)GT$$

Where:

LT= Loading time (min/load)

FLC= Forwarder load capacity (m^3)

LC= Grapple loading capacity (m^3/cycle)

GT=Average grapple cycle time (min/cycle)

0.7 and 0.9= The factors estimated for grapple loading and unloading capacities, respectively

Grapple loading capacity can be computed based on grapple capacity and log size (FAO, 1977)

$$LC = Area * L * f$$

Where:

Area=Area in closed grapple (m^2)

L= log length (m)

f= loading factor (varies depending on log length)

3.2 Secondary Transport

In comparison with other industries, the Canadian forest product transportation makes up 25% of the heavy haul industry. Timber transport does not only impact the supply and value chain optimization but it is also the biggest cost item in the cost of delivered wood. Therefore, transport efficiency is crucial in optimizing the supply chain. Michaelsen, (2010) concludes that transport inefficiencies are related to:

- Average delivered wood cost – approximately C$70/$m^3$
- Transportation cost – the most variable cost item
    - Transportation costs are approximately 30% of the wood delivered price
    - Trucks are empty more than 50% of the trip time
- Lack of communication and coordination

To address these inefficiencies, Audy,D'Amours and Rousseau, (2007) have suggested the following solutions:

- Road transportation performance evaluation
- Multimodal transportation
- Transfer and satellite yards
- Backhauling
- Truck scheduling

3.2.1 Road Transportation Performance

Road transportation dominates forest operations; thus, inadequate transport management techniques can be detrimental to the entire wood supply chain. In his research, Michaelsen (2010), evaluated road transportation performance and concluded that its performance is influenced by:

- Equipment
    - Trucks performance

    - Loaders (loading time)
- Hauling distances
    - Road network
    - Cycle times
- Drivers
    - Driving techniques
    - Resistance to change
- Operation management
    - Dispatching and scheduling
    - Loading/unloading time
    - Backhauling

3.2.2 Multimodal Transportation

Multimodal transportation can be defined as the handling of goods under a single contract through the use of different transportation modes (rail, road and water). A study conducted at Alpac through FPInnovations indicates that a proper allocation of timber transportation modes (road and rail) can significantly improve the efficiency of the supply chain compared to relying on one mode of transport, (Michaelsen, 2010). Appropriate transport allocation can reduce road maintenance costs, and savings on transportation costs can be realized. Multimodal transportation has other collateral benefits. For example, it is estimated that 500,000 m^3/year transported through rail could reduce carbon emission by 5,100 tonnes/year (Michaelsen, 2010).

3.2.3 Transfer Satellite Yards

Within a supply chain perspective, transfer satellite yards can be defined as the application of global positioning system technologies to transfer data/communications within the resources used in that supply chain. The application of satellite technologies helps to improve communication within the resources used in the entire supply chain. John Deere has introduced software known as Timbermatic to enhance transfer of satellite yards within the supply chain process (John Deer, 2010).

3.2.3.1 Timbermatic on Harvesters/Processors

According to John Deere, "timbermatic is a PC-based system, which integrates the control of the harvester head, the measuring of timber, bucking, the control system of the basic machine and the harvester head into an effective harvesting tool". Through the use of GPS, it is feasible to locate daily production, concentration of tonnage produced (tonnage harvested) and harvesting routes. This information can be saved automatically in the production and stem profile file. Timbermatic works as a two-way system when communicating with the outside world. First, it allows the equipment operator to receive and send production information and second, it allows managers to update machine settings and harvesting instructions. According to John Deere, through the use of this software, harvesters can transfer required information to forwarders concerning the quantity and location of timber volumes; therefore, idle time and bottlenecks in the harvesting system are reduced.

3.2.3.2 Timbermatic on Forwarders

Timbermatic, according to John Deere, enables “recording and reporting” of the production of forwarders through its *“Intelligent Weight Scale System”*. The reporting system is similar to the case discussed above on harvesters. The forwarder is fitted with a grapple “weight scale system”, which enables load weight measurements, (John Deere, 2010). This system results in timber inventory estimations being close to reality, thereby scheduling of transport could be efficient and cost viable.

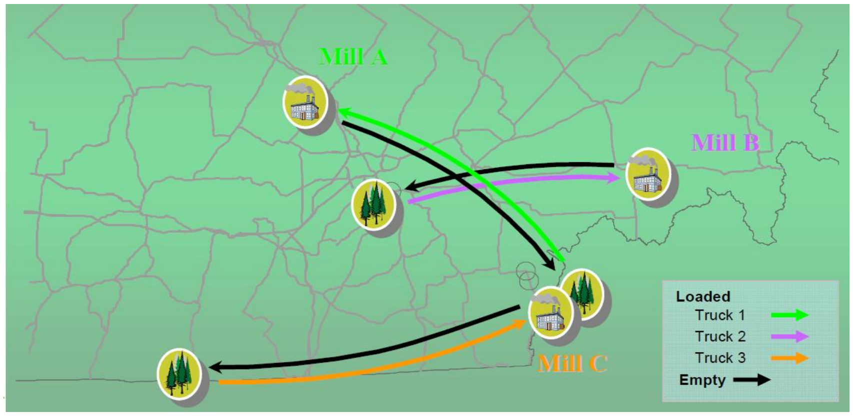
In their study, Ericksson and Ronnqvist, (2003) added that satellite yards can improve the efficiency of the supply chain by availing opportunities such as:

- Maximizing payloads
- Better timber recovery
- Backhauling opportunities
- Low inventory costs

3.2.4 Backhauling

The cost of timber transport has increased partly due to the fact that trucks travel half of their trips empty. Through the use of operations research, backhauling opportunities can be maximized. Backhauling can be more practically feasible in a forestry setting where there are adequate markets/customers that rely on the supply chain (sawmills, pulp mills and other industries), and there are a variety in demands for species and grade between markets.

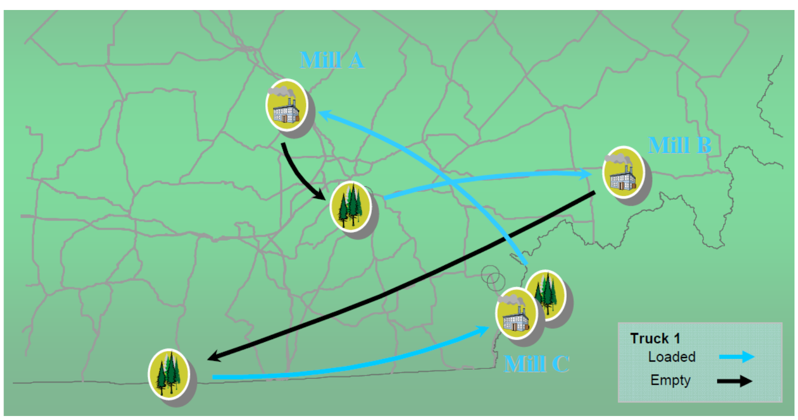
Figure 4: Traditional transport operations (No backhauling)



Michaelsen (2010)

Figure 4 shows a scenario where without proper planning, backhaul opportunities are ignored; therefore, operating costs increase.

Figure 5: Planning enhanced transport operations (backhauling)



Michaelsen (2010)

Figure 5 shows backhauling opportunities in an integrated supply chain. Better fleet management, cooperation between customers as well as the use of multiple trailers can lower transportation costs.

4 Integrating the Supply and Value Chain Optimization

This section will focus on selected advancements in the forest sector aiming at integrating the entire supply and value chain. Through the use of heuristics models aided by operations research, the following models are used extensively within the forest sector:

- Virtual Transportation Manager (VTM)
- PLANEX
- OPTICORT
- ASICAM

4.1 Virtual Transportation Manager

Developed and tested by FPInnovations, VTM is software for truck scheduling. It focuses on the optimization of transportation logistics on regional basis using web-based technologies. This software integrates different databases such as:

- Transportation demand – based on timber volumes and products (inventory size)
- Transport supply – type of truck and trailer need
- Clients – mills and harvesting periods

Precise route planning by VTM has yielded numerous advantages to the supply chain (FPInnovation, 2009):

- Implement a solution for supply chain management
- Manage transportation capacities
- Favour multimodal transportation
- Facilitate accounting

- Control fibre freshness (Just In Time concept)
- Reduce fuel consumption and transportation costs
- Increase revenue per truck and backhauling
- Reduce waiting time

4.2 PLANEX

This is a decision making system that was developed to support harvest planning on a tactical to strategic planning perspective (Andalaft, Guignard, Mangendzo and Weintraub, 2003). The system relies on GPS data to analyze timber volumes, topography height levels and geographic features. The user (forester) provides essential information concerning the productivity of the harvesting machinery, road building and transportation costs. The software then selects the best location or shortest path to connecting roads or timber landings. The advantages of PLANEX on a harvesting operation are as follows:

- Fewer roads built therefore less environmental impacts due to reduced earth excavation
- Improved productivity of harvesting equipments
- Monetary savings can be achieved

4.3 OPTICORT

This is a linear programming (LP) model designed for stand level planning. It supports decision making on how to produce many different products as defined by tree length and diameter. The basic stand/compartment level questions addressed by this linear programming model are (LeBel and Frayret, 2007):

- Which compartments are to be logged in each period
- What bucking instructions/patterns are to be used in each stand.
- What volumes of different products are to be sent to each market to satisfy specific demands for length and diameter therefore minimizing downgrading of high value logs and restrict excessive logging.
- Which harvesting equipments are required to harvest the stands
- And what quantities of tucks are required to transport timber.

PLANEX and OPTCORT are similar systems; however, PLANEX is applicable in long-term planning where as OPTICORT was designed for short-term/operative planning. The information provided by PLANEX on harvesting cost and productivity is an input to the short-term OPTICORT harvesting model. The interaction/relation between these two models can be summarized as:

- PLANEX feeds cost and productivity information, whilst OPTCORT supports decision on which stands to harvest.
- PLANEX indicates locations of machinery relative to harvestable stands but does not indicate the timing of the operation, whereas OPTCORT indicates when to use skidders, harvesters and yarders in each respective stand as well as indicating any limitations on availability of each type of equipment.

On harvesting operations (operative planning), one can infer that OPTCORT is an effective management tool for equipment availability, utilization, amended task and performance.

4.4 ASICAM

This a heuristics driven simulation model designed for truck scheduling. As an operative planning model, ASICAM has the following inputs, (D'Amours and Rousseau, 2007):

- Demand for each product, at each destination, with priorities for the next day
- Next day availability of stock for each product at each origin
- Scheduled production of each product at each origin for the next day
- Loading and unloading capacities at origin and destination
- The fleet of trucks available (not in maintenance) by type of truck, which determines load capacity and type of log trucks as well as operating conditions
- Time and costs for loading at origin and unloading at destination: loaded travel from origins to destinations, and unloaded travel back to origins

This model has been efficient, practical, and close to simulating reality. Developed for Chilean forestry firms, ASICAM has been reported to be largely used in Brazilian and South African firms. Andalaft,Guignard, Mangendzo and Weintraub, (2003) note the software's success has resulted in winning the South African Logistics Prize of 1996, where an estimated 15% savings in transportation costs has been achieved through its implementation. By incorporating GIS into the model, real time measurements have been achieved and communication among harvesting equipments (trucks, loaders, harvesters and forwarders) and transport scheduling centre has improved, (Garcia, 1990).

The results/outputs should therefore enhance planning within operative planning time frames such as:

- The quantity of trucks and loaders needed for the next
- Allocation of products to different destinations
- Precise route schedule for each truck and loader such that the productivity of each unit can be maximized

4.4.1 ASICAM versus Supply Chain Optimization

The system compels managers to keep a much tighter control on stocks in the forest therefore:

- Improving timber inventory estimates as well as reducing timber theft
- Improving the efficiency of a company's potential to meet customer demands therefore maintaining a steadier sequence of raw material

Through simulating the transportation system, the firm can efficiently schedule the right quantity of equipment (loaders and trucks) needed for the following day. Furthermore, through the information obtained from the programme, timber production level can be matched with the dimension of fleet needed for transportation, and therefore, maintaining a steadier timber supply

5 Sawmilling

Sawmilling plays a significant role in the supply and value chain optimization. Decisions on the value adding on every log, determine the profitability or efficiency of the entire supply chain. This section will address the challenges facing sawmilling optimization chain, as well as focus on the latest trends in improving the value chain.

Despite improved silvilculture regimes, wood is still anisotropic in nature. Timber defects (mechanical and biological) are inevitable due to the long- term rotations associated with forest management. A sawmill's main objective is optimizing the manufacture of wood at the minimum cost possible, but still be adding value on the end product. The challenges in value adding that sawmills often encounter include the following, (Song and Usenius, 2007):

- Species type
- Log diameters (piece size volume)
- Log quality (density, knots, ring width, early wood vs. latewood)
- Lumber recovery/m^3 of round wood supplied
- Logs/round wood prices

With many variables, sawmilling firms need to plan and implement efficient strategies to maximize lumber production (improved recovery), minimize production costs and maintain a sound supply chain. Song and Usenius (2007) have suggested the following strategies, through the use of optimization software, to optimize lumber recovery from sawlogs:

- Modelling of saw logs and timber stems
- Simulation and optimization algorithms for wood conversion chains
- Modelling of sawn products
- Visualization of wood entities such as stems logs and sawn products

6 Conclusion

Harvest scheduling, optimization and timber transport models are important tools for increasing the efficiency of forest supply chains. There is a wide variety of models currently available in the market with various strengths, limitations, weaknesses and complexities. Forest planners and managers should invest in models that are simple, less complex and easy to implement. Although there is a growing need to integrate forest supply chains, the more integrated the supply chain, the more complex are the optimization techniques. Timber rotation lengths in forestry create an inevitable scenario where strategic decisions become a constraint on tactical planning process and tactical decisions becoming a constraint on operational planning process. Forest planners should not be entirely dependent on optimization models, but rather use them as guidelines for complex optimization processes.

However, the integration of forest supply chain and the industrial supply chain (pulp and paper and sawmills) remains the main objective. Achieving this objective may result in cost savings, especially for a vertically integrated business unit (where the business is responsible for the entire supply chain: timber harvesting and timber transport to the company's saw/pulp mills). Operative planning in each segment of the supply chain should aim for its optimization and cost savings, and therefore giving the entire supply chain a competitive advantage (economical viability). A holistic link (transfer of information) between strategic, tactical and operative planning models is essential in optimizing the entire forest supply chain. It is of significant importance that strategic planning makes future estimates based on the current operational issues/constraints.

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