Simulation of Lumber Production Planning using Software Agents: a Case Study

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Abstract

The objective of this study is the evaluation of pull and push strategies in lumber production planning using a Quebec sawmill as case study. An Advanced Planning and Scheduling System (APS), based on a distributed software architecture, simulates the main operations planning and production processes of the sawmill (sourcing, sawing, drying, finishing, warehousing and delivery) representing them as autonomous software agents. Push and pull strategies are simulated using different penetration positions of the demand information decoupling point over the value chain. To set experiments, configurations are defined by two controllable factors, namely: the decoupling point position and the level of contracts for a product family. Following, a set of scenarios are generated by two uncontrollable factors: the quality of supply and market prices differential for products under contracts. These configurations and scenarios leads to a mixed levels experimental design with 54 runs. Three performance indicators: orders fill rate, work in process, and potential monetary throughput (PMT); are calculated for every production plan generated by the APS. Results show a direct relation between the orders fill rate and the positioning of the decoupling point, pull strategy configuration, for the three levels of demand on products under contract. Accordingly, at every demand level, production plans under pull strategies generate improvements of 100% compared with equivalent plans under push strategy. This service level performance improvement has a financial cost of about 7% of the PMT which should be compensated externally with better contract conditions or internally by lowering costs of inventory management. This trade-off seems to be a direct consequence of the divergent nature of lumber production. After all, in a business context that privileges service and where customers are willing to pay for, the use of this kind of demand driven strategies in production planning represents a source of competitive advantage.

Key words: Production planning, software agents, simulation

1. Introduction

The forest products industry is an important business sector in Quebec, Canada. It plays a central role in its economy, providing over 115.000 direct employments and contributing about 4% of its Gross Domestic Product (QFIC, 2005). Despite its importance, the lumber industry is facing serious difficulties. Timber has become scarce in quantity and quality in public forests, especially in eastern Canada. Furthermore, the combination of longer hauling distances and higher gas price result in constantly increasing supply costs due to higher transportation cost. Moreover, the increased concurrence in the US market, due to the emergence of low cost fiber producers, has also affected Quebec's lumber industry directly and indirectly because of its business relationship with the pulp and paper industry. Finally, the Canadian lumber industry is facing strong protectionism measures in the US market, as well as a strong Canadian dollar that impairs exports in general. To confront these issues, lumber producers have focused on cost reduction and potential market value recovery (i.e., price-based optimization with 3D scanning and curve sawing). The use of such push-oriented strategies also finds justification in a highly standardized and commoditized North American softwood lumber market. On the one hand, Quebec sawmills have become highly productive machines, in spite of the small diameter of the available logs (Bédard, 2002; Lévesque 2005). On the other hand, they have become inflexible to adapt to changing market needs. Even though these make-to-stock strategies served the industry rather well when market prices were higher and competition inexistent, new market conditions are reshaping the way lumber is demanded. Value-added wood based industries, such as engineered wood products and prefabricated houses have been experiencing a sustained development for a few years and ask for more collaborative relationships with lumber producers. Instead of ordering large volume of commodity, engineered wood producers expect high quality products on demand, because they do not hold large inventory of raw material. A similar kind of pressure is emerging from the home center industry. Vendor-Managed Inventory (VMI) is becoming extensively used, forcing lumber producers to learn how to manage consigned inventories and replenish their customers with the right quantities of the right product at the right time. Contracts that enforce the delivery of certain volumes of products are also more frequently used with large retailers. Even if these contracts are profitable, they put pressure on lumber producers as they must pay important penalties, or even may lose their contract, if stores become out-of-stock.

Quebec lumber production strategy is still mainly driven by potential value recovery and market prices. The adoption of client-centric strategies is a difficult task for lumber producers who strongly believe that cost reduction is still the main driver in the lumber business. Although low production cost remains a barrier to access the lumber market, it becomes more and more necessary for lumber producers to adopt new strategies to improve their ability to meet market needs.

This paper provides an exploratory analysis of the introduction of demand-driven (pulled by demand information) strategies in the lumber production process. In order to do this, a series of simulation experiments that exploit an agent-based advanced planning system has been carried out. The objective is to provide managerial insights concerning the design of a mix marketing strategy (i.e., contract and/or spot market) that is closely related to the production and procurement specificities of softwood sawmills.

2. Production Planning and Control in the Lumber Industry

The lumber industry is characterized by production control principles specific to process industries. Fransoo (1993) proposes a definition of production control in this context that emphasizes profit maximization rather than cost minimization. Indeed, the author explains that a process production system is more likely to influence the profitability of the company because it is the bottleneck that defines the company's capacity to satisfy customers demand. Crama *et al.* (2001) go further and explain that the characteristics of process industries, such as the availability of raw materials, the simultaneous production of several products, and the use of expensive equipments (which is not necessarily the case in the lumber industry), limits the flexibility of production control so that demand satisfaction cannot be enforced. Consequently, it is here necessary to allocate capacity to customer demand in order to maximize profit.

Similarly, the Quebec lumber industry is first constrained by supply availability. It is controlled, to some extent, to meet orders allocated to mills and market conditions perceived by the sales force. Although, production planning seems to be triggered by market needs, planning and control is in practice not geared up with advanced planning tools that can simultaneously consider both actual market orders and a forecast of aggregated market needs. Orders are usually allocated by corporate sales offices to mills according to their ability to produce certain types of products and according to their relative proximity to the customers. In turn, these orders influence production planning in a myopic way. In other words, the mills' production planner decides the mix of log types to transform daily, and sometimes (i.e., from once a week to once every 6 month), adjust the price list in the log sawing optimizer in order to influence output mix. It is indeed largely believed in the industry that the variability of the sawmilling process is too unpredictable to be triggered by orders or demand forecast information. However, a large part of this variability is due to poor raw material characterization and mills' inability to control divergence. Thus, the most important task of the mills' planner is to forecast output product mix and volumes based on supply availability and to communicate these production forecasts to the sales force in order to push products (i.e., forecasted available-to-promise and on-hand inventory) to the market. De Toni *et al.* (1998) classify this type of production control approach as a process with a look-back rather than look-ahead criterion, which means that it is less responsive to market fluctuations. Furthermore, these practices are greatly encouraged by the performance measurement system metrics commonly used in the industry and indirectly validated by government policies. In such a system, metrics are mainly concerned with lumber recovery factors (i.e., volume of lumber produced per unit volume of raw material) and productivity indicators. Consequently, it is usual for sawmills production planners not to pay attention to customer's satisfaction key performance indicators (KPI). Inventory costs are also often neglected and inventory buffers build-up to push products to the market hiding organizational inefficiencies.

With pure price-based production control systems, the only two possible ways to influence the output is to control the mix of input logs and to adjust the price list that is fed directly into the production control optimizers. In other words, the same production control decisions apply simultaneously to all input logs and products. Consequently, the adjustment of the price list to force the production of a certain type of lumber will automatically push the flow of other co-products. This production control strategy limits the company's ability to commit with customer to deliver specific product types. Contracts are thus usually based on the mill's historical production data used to identify the reasonable volume that can be promised and delivered on time. This strategy tends to increase inventory levels due to limited control of output mix. The remaining products with less rotation are then pushed to market at a generally lower price.

3. Decoupling Point Strategies

Push and pull are two production strategies used to trigger production decisions whether at the planning or execution levels. On the one hand, push refers to the production of items according to upstream signals from input products flow, such as material release or demand forecast information. On the other hand, pull refers to the release of production orders/authorization triggered by downstream signals, such as sales orders or kanbans. Both push and pull strategies offers advantages depending on the operational environment in which they are deployed (Olhager, 2003). The pull logic implies market information flowing and driving decisions upstream the supply chain in order to improve operations coordination. This strategy contributes to reducing the inefficiencies generated by information asymmetry, such as the bullwhip effect.

Hopp and Sperman (2004) highlight that no system operates under pure push or pull strategies (i. e., moving materials according to only one pure logic). In fact, the question is where to establish the best push/pull interface (i.e., decoupling point) in the supply chain. In a multi-stage production process, it is possible to apply simultaneously both logics in order to reduce inventory and meet market response expectations. This leads to the positioning of a decoupling point within the production process. Several authors have studied this problem (Lampbel and Mintzberg, 1996; Garg and Tang, 1997; Adan and Wal, 1998; Olhager, 2003; Gupta and Benjafaar, 2004). The operations upstream from the decoupling point are planned and controlled in order to push products to the next stage (i.e., make-to-stock, MTS). Downstream from this point, operations are planned and controlled in order to pull products from the previous stage, except for the first operations that uses material from a buffer inventory (i.e., make-to-order, MTO; or assemble-to-order, ATO). The positioning of the decoupling point is strategically equivalent to minimizing inventory holding costs subject to response time constraints. On the one hand, the closer the decoupling point to the market, the shorter the response time and the higher the inventory levels. Production is not differentiated, in this case, to match market needs. On the other hand, the further the decoupling point is set from the market, the longer the response time and the lower the inventory levels. This approach allows producers to customize production to match customer needs.

In a divergent production process, co-products are simultaneously produced, which makes it impossible to plan and control the production system with a single strategy. Some products are indeed automatically pushed through and offered. Here, production managers must balance the production capacity used to satisfy demand and the production capacity used to process co-products in order to avoid building-up work-in-process inventories. This is particularly the case in the lumber industry. In order to address this issue, Maness and Norton (2002) propose a production planning model that allows setting a sales target for products as well as inventory and penalty costs for over or under achieving the sales targets. Such a model allows finding a trade-off between inventory cost and customer satisfaction. However, the lumber production process model is aggregated. The details of sawing, drying and finishing are omitted and only general yields are considered. Differently, Todoroki and Rönnqvist (2002) propose an optimization model that considers demand information to control production execution. Here, the sawing of each log is optimized in order to maximize the volume or the value produced, taking into account the volume of each lumber grade that remains to be produced to meet demand (i.e., the difference between previous production and demand). This approach only takes into account the detailed sawing process. Consequently, none of these approaches can be used to model a variety of production planning strategies with various decoupling point positions.
The experimentation platform used in this study models the operations planning of each production stages separately. Consequently, it is possible to configure this platform in order to model different strategies and compare their respective potential to meet demand. In the context of the lumber industry, the tested strategies are outlined in Figure 1.

4. Experimentation Platform

The general modeling architecture used to carry out this study was designed to model a typical softwood sawmill. The main software components include three types of agents. Downstream the supply chain, the Deliver agent is responsible for managing the relationships with customers through the exchange of demand information.

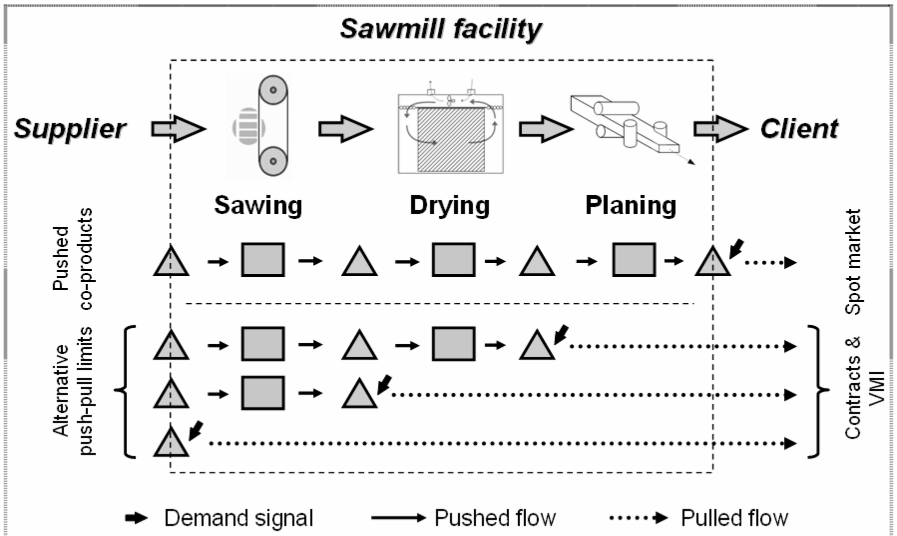

Figure 1: Tested decoupling point positions

Upstream the supply chain, the Source agent is responsible for managing the procurement of logs. Next, the central part of the application is a series of three Make agents responsible for operations planning and for the coordination of their decision-making activities. These Make agents are respectively responsible for the planning of sawing, drying and finishing (i.e., planing and sorting) operations. Similarly, another Make agent referred to as the Warehouse agent, responsible for making products available to customers, was used. Each agent was designed with specialized optimization tools described in Frayret et al. (2008) and in Gaudreault et al., (2006).

To simulate the lumber supply chain planning process, agents can propagate upstream and downstream information concerning demand and supply decisions. Through the propagation of this information, it is possible to configure various planning strategies by changing the point up to where demand information flows. For instance, if no demand information is passed from the Deliver agent to the Make agents, then production will be made-to-stock with the goal of maximizing the potential value recovery at each stage of production. On the contrary, if demand information is passed up to the Make agent responsible for sawing, then production is made-to-order by minimizing tardiness (i.e., late customer deliveries) at each stage of production. Therefore, the experimentation platform was configured in order to model various planning strategies from push to pull as is depicted in Figure 2. The doted arrows represent information going upstream through the transmission of planned needs from one agent to the other. Bold arrows indicate the downstream transmission of supply plans. Demand plans (respectively supply plans) are composed of order quantities (respectively supply quantities) for products needs (respectively products availabilities) at certain dates. The numbers on the arrow indicate the sequence of the planning protocol activities.

In order to plan their respective operations, each Make agent is geared up with advanced planning tools. The details of these models are outside the scope of this paper. Consequently, they have been voluntary omitted for the sake of clarity. The interested reader is referred to Frayret et al. (2008) and

Gaudreault et al., (2006) for more information. In the context of this study, only planning decisions were simulated. In other words, the simulation of the execution of operations was not carried out.

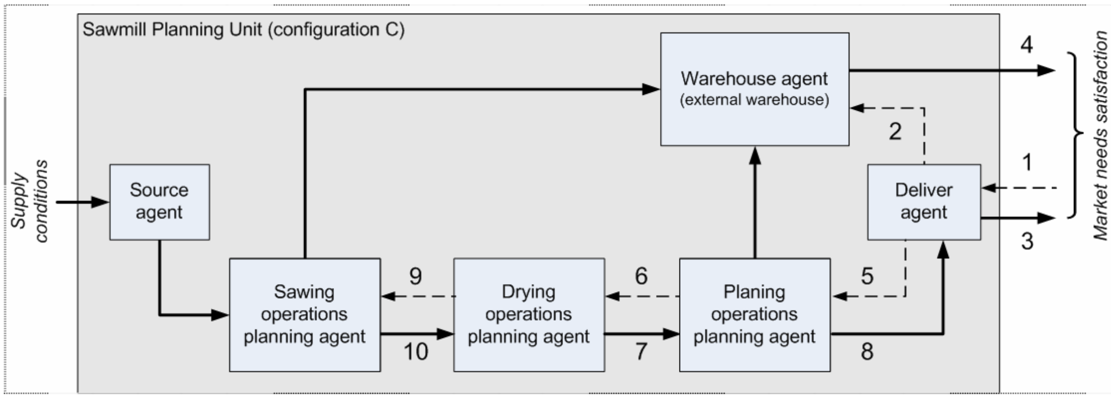

Figure 2: Modeling of the decoupling point strategies

5. Sawmill Case Study Modeling

The sawmill case study is similar to the real stud oriented sawmill in terms of capacity and production processes. Its annual lumber production can rise up to 120 Million Board Feet (MMbf) or 283,000 m3, from spruce, pine and fir (SPF), although spruce represents more than 60% of its total raw logs inputs. The overall planning process was specifically adjusted and designed to model the tested planning strategies. For instance, in the real sawmill, there is no log classification, and all logs are sawed in a bulk process. The production system and processes of this sawmill were modeled with Optitek® from Forintek. Optitek aims at simulating the yields of any configuration of sawmill in order to evaluate a new design or modifications of a lumber production system. It also simulates the optimization process of the production controllers that optimize log breakdown. The production processes and yields respectively modeled and calculated with Optitek were then used to configure the FORAC experimentation platform.

Data from a random sample of 600 3D scans of real logs and Optitek were used to model the real sawmill and its typical procurement. Next, using Optitek, the sawing of each log was simulated using actual and manipulated price lists in order to obtain the production yields of each output product. This approach also allowed us to define log classes based on output mix distribution similarities. For kiln drying, several feasible loading patterns were developed for each thickness of lumber from actual kiln drying operations. A loading pattern may include various lengths of lumber, but thickness must be the same for all pieces of lumber. Air drying, planing and sorting operations were modeled similarly. All configurations were then translated into a XML file and fed into the platform. Table 1 presents the general elements of the case study configurations.

A mixed level design approach was used for the experiment. This kind of design, yet simple, is well suited for combining factors that can be controlled through structured decision-making processes (such as the decoupling point position and the level of capacity committed to contracts) and noise factors that can only be controlled within the experiment (such as supply type and market prices). Table 2 describes these factors and their various levels as they were set in the simulation experiments. In these configurations, the level of capacity allocated to contracts is included in the definition of a configuration in order to study the effect of production/sales commitments on performance. This level is expressed as the percentage of the maximum production capacity (i.e., total volume of production over the planning horizon) of the product sold in these contracts.

6. Performance Measurement Framework

The first complementary measure introduced concerns the daily average inventory of work-in-process (i.e., DAWIP). It is an indicator that evaluates material flow streamlines and an indirect representation of work-in-process (WIP) inventory costs. In the context of this study, it is

	Structure	**Assumptions**
Logs	• m^3 of bulk raw logs 4.8 m (16') long. Logs in 7 classes.	The randomly generated sample is used in each configuration.
Sawing	• 1 sawing line. • 47 sawing patterns. • fixed sawing speed.	Sawdust and chips produced are sent to the warehouse.
Green Lumber	• 30 products based on dimensions.	Only 2×3, 2×4, 2×6 and 2×8 in their five different lengths will go through drying. Small boards, 1×3 and 1×4 in their five lengths are transferred to warehouse as is.
Drying	• 2 kiln dryers of 576 m^3 plus 8 air drying locations. • 237 alternative loading patterns for kiln drying, plus the same number for air drying.	One fixed time duration for all loading patters regardless of green lumber dimensions.
Dry lumber	• 20 products based on dimensions	2×3, 2×4, 2×6 and 2×8 in their five different lengths will go through planing and sorting.
Finishing	• One planing and sorting line • Fixed input/output relationship based on actual recovery yield.	Changeover of thickness during a shift is penalized.
Planed Lumber	• 60 products according to dimension and grading.	From these 60 products demand is placed on five of them, namely 2×4 12 RL.
Operation conditions	• Sawing and finishing have operates 16 hours per day. Drying operates 24/7 for the sixty days planning horizon.	No downtime. Demand is visible from time zero.

Table 1: Case study general characteristics

Factor	**Description**	**Levels**	
Decoupling point position (Planning configuration)	The point upstream in the lumber supply chain up to where demand information is incorporated in production planning decisions	3	Between deliver and finishing:
			Between drying and sawing:
			Between sawing and source:
Level of contract (demand configuration)	The percentage of the maximum capacity for producing 2×4 12 R/L allocated to contracts	3	60 % of the max. capacity
			80 % of the capacity
			100 % of the capacity
Supply type (Scenario)	The main type of logs procured (surrogate for supply quality)	2	SMALL: higher distribution of small logs
			NORMAL: Typical dist.
Market prices	Price lists with differences for 2×4 12	3	-10 %: The products have lost value

(Scenario)	R/L with respect to Random Lengths® average price for 2004		0: Regular prices
			+10 %: The products have a better price than average

Table 2: Configuration and scenario elements

measured using the operation plans of each agent. The second measure is a classic in supply chain management: the weighted fill rate (WFR). It is calculated once for each simulated production plan as the percentage of demanded quantities planned to be delivered on time over the planning horizon, weighted by the total demanded quantity The third measure, proposes to asses the throughput value generally used in practice. However, instead of measuring throughput in terms of volume of lumber produced per shift, we are rather interested in the potential monetary throughput (PMT) over the entire planning horizon. This allows us to compare the potential revenue of the overall planned production in each simulation using referential lumber market prices. Finally, we have not directly analyzed the recovery factor in the study, because supply quality is an uncontrollable external factor, which implies that for each given supply type procurement costs are similar for every tested configuration. As a result, the PMT provides indirectly a rather good idea of the performance of the system in terms of raw material transformation.

7. Logistic Performance

First, WFR improves as the decoupling point is set upstream in the lumber production process. The ANOVA shows that this factor explains more than 40% of WFR variation alone and 96% when it is coupled with the contract level factor. Although this is intuitive, it indicates that lumber co-production can be controlled to a certain extent in order to match a specific demand pattern. Moreover, it also shows that the further upstream demand information is propagated, the more accurate the control of production and, thus, the better the customer service. In particular, Figure 3 confirms the importance of controlling the sawing process, which sets the dimension (i.e., width and thickness) of the lumber to be produced, in order to satisfy contracts. Additionally, for a given level of contracts, the coefficient of variation of the WFR decreases as the decoupling point goes upstream. In other words, positioning the decoupling point upstream in the supply chain tends to decrease the negative effect and incertitude produced by other contextual factors.

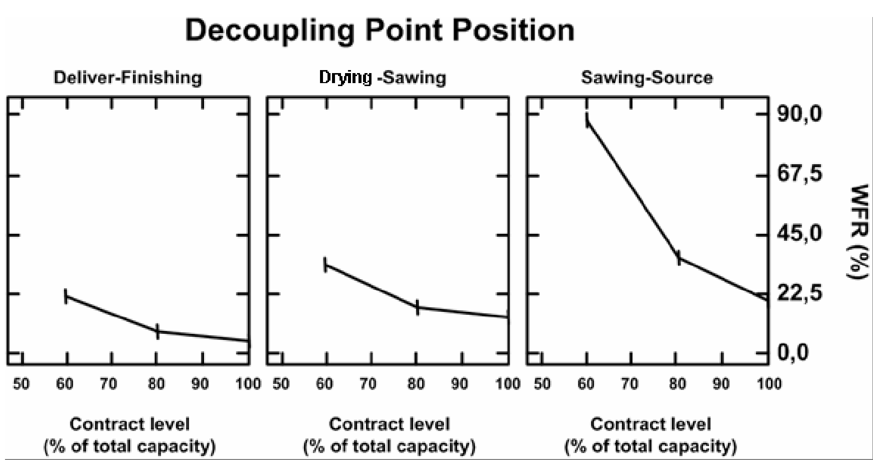

Figure 3: Weighted Fill Rate performance

Second, concerning *DAWIP*, the resulting planned levels of WIP are reduced when the decoupling point is set upstream the sawing process. Demand-driven planning strategies thus seem to improve inventory levels in the context of a divergent process industry. However, the results are not conclusive when the decoupling point is set between drying and sawing. This may be explained by the nature of the objective function of the drying agent, which is to minimize tardiness without regard to green lumber inventory. Consequently, inventory builds up because the sawing agent pushes whatever

products have a good market value. This effect disappears when the sawing agent also minimizes tardiness (i.e., plan to produce on time whatever the drying agent needs).

8. Financial Performance

Improved service level and lower inventories are obtained by adding constraints to the production planning process and by changing the objective function to reduce tardiness. Consequently, one can expect lower PMT levels compared with a pure push strategy that maximizes potential value recovery from every single log. This decrease of the PMT is captured in Figure 4.

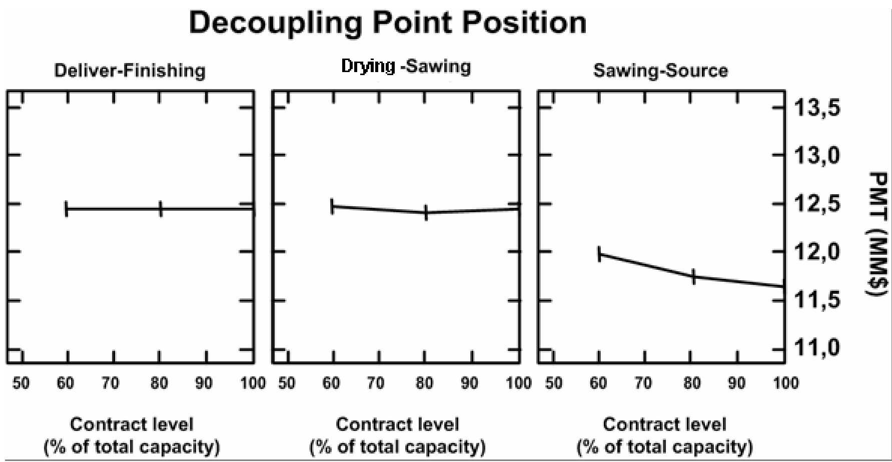

Figure 4: Potential Monetary Throughput (PMT)

In order to compensate for this loss of potential sales revenue, a higher sales price is generally applied in the industry using a premium added to the market price. This premium represents the price to be paid for the service of committing production capacity and minimizing supply risk for the customer. Table 3 summarizes the average losses for the pull strategy (the pure push strategy being the reference for calculations) and for each contract level. An additional interesting finding indicates that an optimal limit to the contract level should exist for every configuration, which includes the log supply availability and quality. Consequently, increasing the contract level does not necessarily improve profitability. For instance, in the context of this study, the 80% and 100% contract levels require a larger premium in order to compensate for a larger loss of potential value recovery and risks of unfulfilling contracts. Over committing thus creates in this context more constraints on the production system than it generates revenues. Further study should thus be carried out in order to investigate more precisely this point in order to help lumber producers define the contract level that is most appropriate for their facility.

Contract level	Average Potential monetary Throughput ($)	Loss ($)	Loss (%)	Premium (%)
Pure push strategy				
0%	$ 12 433 143	$0	0%	0%

Pure pull strategy (Configuration C)				
60%	$11 987 220	$ 445 924	3,59%	7,75%
80%	$11 756 677	$ 676 467	5,44%	8,99%
100%	$11 637 634	$ 795 509	6,40%	8,54%

Table 3: Loss and premium calculations for 60 days of production

Conclusion

This paper proposes an evaluation of various production strategies to introduce demand information within the production planning process of a typical lumber production system. This exploratory study is done through simulation using several configurations of an advanced planning systems developed by the FOR@C Consortium. The main conclusions drawn from this study confirm the positive impact of the pull strategy to improve customer satisfaction and reduce overall inventory. However, due to the divergent nature of lumber production, this improvement impairs the ability of the production system to generate value based on market prices. Indeed, forcing the system to minimize tardiness creates a pressure on the production system that limits its ability to maximize value recovery, which is generally the case in lumber production systems. Consequently, improved service level must be paid by customers through a premium which value can be evaluated through this kind of simulation. Future work includes the evaluation of the trade-off between the premium value and the contract level in a context of profit maximization. Another interesting insight suggests that in order to introduce customer demand in the planning process of lumber production, a particular effort must be done on the planning of sawing operations. Hence, sawing, which is generally the most upstream transformation process in sawmills, seems to control the logistic performance of the entire production systems.

Finally, from a methodological point of view, this study demonstrates the capability of agent-based technology to provide the means to analyze specific industrial contexts and support decision makers to configure their production systems.

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