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DECISION-MAKING FRAMEWORK FOR TACTICAL PLANNING TAKING INTO ACCOUNT MARKET OPPORTUNITIES (NEW PRODUCTS AND NEW SUPPLIERS) IN A CO-PRODUCTION CONTEXT

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ABSTRACT: *In North-America, the lumber industry almost solely produces commodity products (i.e. products with standard dimensions and properties). Yet some customers also want products with very specific characteristics. The current situation in softwood lumber manufacturing does not enable the sawmills to know how the introduction of a new product will affect quantities for the other products they are also producing (i.e. they do not know how the introduction of a new product will affect the global “mix of products” of the company). This is due to some characteristics of the lumber manufacturing process (divergent processes, co-production, automation). We propose a decision-making framework for tactical planning in order to take into account the demand for specific products never produced by the company. This framework connects a log breakdown simulator and a tactical planning model. Through an industry-inspired case study we developed, we show the potential and the relevance of the approach.*

KEYWORDS: *Lumber industry, simulation, tactical planning, optimisation, co-production, divergent process.*

1 INTRODUCTION

The North American softwood lumber industry produces mainly commodity products with standard dimensions and characteristics (e.g. 2 inches x 3 inches x 8 feet, grade 3) which means that products of any company are interchangeable with those of their competitors. Moreover, the potential market of each company can be considered as limitless as every product made in each sawmill can be sold on this huge market. However, prices change all year round.

Softwood lumber sawmills have another particularity. From one unit of raw material (log), the sawmill produces several different finished products (divergent process) at the same time (co-production). Companies are trying to maximize their profits by using equipment which optimizes the production value in real time without taking into account orders and without human intervention. The equipment analyzes each log and then cut it in a way that will produce the *mix of products* that will generate the highest possible value.

In this particular situation, when a sawmill receives a demand for a product with specific dimensions and/or characteristics (a customer's specific request), parameters of the machinery have to be modified in order to “allow” the equipment to produce this product. However, it is unclear for the company what quantity of that product will be obtained (given the fact that the deci-

sions of how to cut each log is taken in real-time by the hardware based on the expected value of each product, with no consideration for demand). Moreover, it is difficult to predict how it will affect the rest of the production and subsequently the overall profit. Finally, if we change the raw material supplied (e.g. dimensions of consumed logs), it will be difficult to evaluate its consequences on the obtained mix of products and profits.

The aim of this research is to propose a decision-making framework which enables to tackle these problems. The framework proposes the use of simulation to evaluate what would be the impacts of several modifications of the equipment parameters and the impacts of new supplied raw material on the mix of products obtained. Simulation results feed a tactical planning model which enables to determine which orders should be accepted, the equipment parameters to use and the raw material to use at each period.

The remainder of this paper is organized as follows. Section 2 deals with some basic concepts concerning the lumber industry (sawmill operations, tactical Sales and Operations Planning). Then, section 3 introduces the decision-making framework. Finally, we apply the framework through an industry-inspired case study to show the relevance of our approach (section 4).

2 PRELIMINARY CONCEPTS

2.1 The lumber industry

In forests, trees are felled down. Logs (corresponding to felled trees that have been limbed and cut to length) are taken to a lumber mill log yard. Logs are usually grouped together regarding to their log “classes” (e.g. dimensions, quality, source, variety of wood, etc...). Logs wait in the yard before being transformed in several lumbers (sawing). Next, those lumbers can be dried, and then they can be planed (Figure 1).

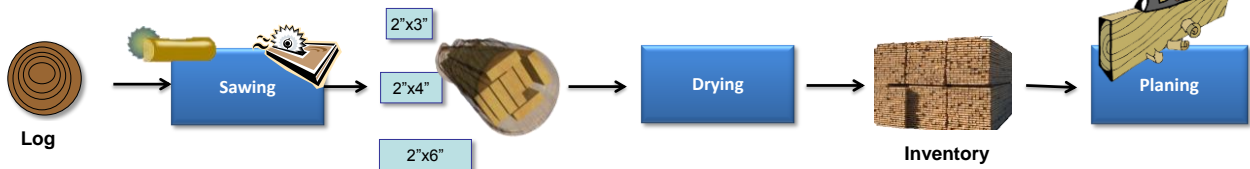


Figure 1: Wood transformation process in a sawmill

2.1.1 Sawing process

Since North American lumber products are normalized (they are classified by dimensions, length and grades according to the NLGA¹ standard grading rules) there is a limited number of different products that can be produced.

Logs are converted according to a push system in order to produce the range of products with the highest possible market value using a fully automated process (Cid Yáñez *et al.*, 2009). Each log generates many products at the same time (it is a divergent process with co-production). At the physical level, when a log is processed by the sawing unit, an optimizer² decides which cutting pattern will be used in order to maximize the profitability. The goal of the optimizer is to maximize the value of the log and minimize the material losses. Each log will be automatically sawn following the recommendations of the optimizer. The decision concerning the cutting pattern is done individually for each log. The decision is not influenced by actual customer orders. For this reason, and because it is impossible to produce a single particular product without getting some other products at the same time (co-production), it is difficult to plan production according to customer orders (Crama *et al.*, 2001).

However, logs in the yard are usually stored according to their “class”. Each class corresponds to logs which have similar characteristics. Based on past production data, sawmills are able to estimate the quantities of each product that a log class can produce (Gaudreault, 2009), as shown in Figure 2. By deciding which quantities of each log class will be sawn on each period, we then have “some” control over the production quantities of the different finished products we should obtained.

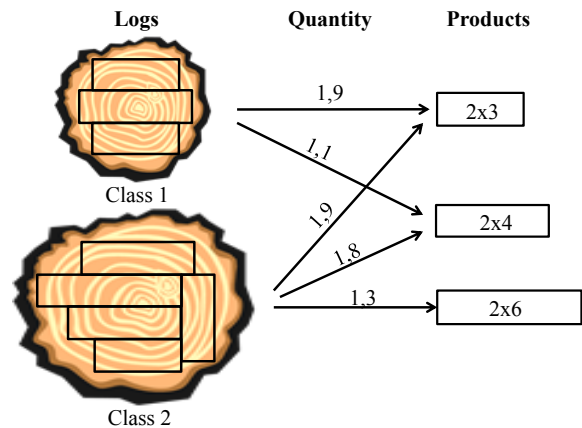


Figure 2 : Example of a production matrix, adapted from Gaudreault *et al.* (2010)

2.1.2 Other stages of the wood transformation: Drying and wood finishing

Once the log has been transformed into several lumbers, lumbers will be dried in a kiln. Drying is mandatory for lumber that will be used by the construction industry (this is the case for most of the North American lumber). It increases dimensional stability, reduces biological decay and reduces transportation costs (Yan *et al.*, 2001).

Once dried, lumber will be planed. That will give to the lumber its final standard dimensions. It will also suppress some small defects caused by the drying operation or handling (Doucet and Côté, 2009). A lumber can be also planed without having been dried before. Wood finishing (i.e. planing) process is conceptually similar to the sawing process (one lumber gives several finished products as outputs).

Finally, each lumber will be classified regarding to his physical defects. It can as well be trimmed i.e. sawn

¹ NLGA stands for National Lumber Grades Authority and is the organization responsible for lumber grading rules and standards in Canada

² Software integrated to the hardware

transversally to the length in order to get several lumbers with better quality. From one type of product coming to the wood finishing unit area we get several types of products after wood finishing (see example in Table 1). Consequently, co-production phenomenon is very present all along the wood transformation process.

Grade	Length			
	96 “	92 ^{5/8} “	88 “	72 “
Premium	11,71%	4,93%	-	-
No 2	35,70%	14,15%	10,68%	6,81%
No 3	6,81%	-	-	-
Economy	4,49%	-	2,68%	1,61%
Kiln wet	0,50%	-	-	-

Table 1: Example of lumber distribution after wood finishing a single type of dry lumber (2”x3” 8 feet)

2.2 Tactical planning and optimisation models

In standard manufacturing situation, it is considered that there is three different planning levels: strategic, tactical and operational (Genin *et al.*, 2007). Sales and Operations Planning (S&OP) is a tactical level decision process. S&OP joins together sales, marketing, procurement, development, finance and production around a set of plans which are considering aggregated products families (Vollmann *et al.*, 1984). It enables to establish a balance between inventories, forecasted production and finance. Here, the main objectives is to determine, in an integrated way : (1) the raw material to use, (2) the optimal mix of products to make, (3) the transformation process to use, (4) the whole set of contracts/market opportunities that the sawmill should take. Planning horizon is generally of one year (twelve periods of one month or 52 periods of one week). Planning takes sales, production, supplies and distribution constraints into account. So, for example, planning takes into account production lead time, transfer lead time between sawmills and distribution centers, production capacities with the objective of maximizing profits. It allows sawmill to foresee the production of its different units, to size resources (humans/machines) if needed and inventories.

In order to establish a tactical plan for a North American sawmill, the particularities/physical constraints of the plant have to be taken into account. For example, the decision about how to cut the logs is made in real time by the hardware. So, it is illusory to suppose that this decision can be made by the tactical planning model. However, the tactical planning model can be used in order to decide on which parameters will be given to the hardware, and the quantities of each log class that will feed the sawing unit at each period.

In order to do this, we have however to be able to feed the tactical planning model so that it can predict what will be the equipment production according to the pa-

rameters and the given raw material (i.e. the different outputs got according to the inputs considering the transformation processes). We can get the major part of those data based on past production data. They can, as an example, be extracted from the manufacturing execution system of the company (in this paper, we won't explain in detail data extraction process).

Among those authors who have worked on the specific problem of softwood lumber production planning, Maness and Adams (1993) have proposed a mixed programming model that simultaneously determines the optimal bucking and sawing policies based on demand and final product price (integration of stem bucking and log sawing). This model was later modified to handle several periods (Maness and Norton, 2002). These works focus on the identification of new cutting patterns/policies.

Taking a more global view of the supply chain, Singer and Donoso (2007) presented a model for optimizing planning decisions in the sawmill industry. They modeled a simplified internal supply chain, including two transformation stages and two inventory stages. The objective was to demonstrate how collaboration can benefit the partners, by transferring timbers and using the competitive advantages of each.

More recently, Marier *et al.* (2014) developed a mathematical model allowing to make the Sales and Operations Planning of one (or more) sawmills. They considered the three units of sawmills (sawing, drying and wood finishing) and their capacity constraints. This tactical production planning model enables also to consider yearly price fluctuation of sawmill finished products and several raw material sources. The model is able to modulate production and inventory levels and they show that this can increase significantly sales revenue without changing the capacities.

2.3 Current tactical planning approaches limits

In the North American commodity products context, it happens that clients express needs for high volumes of a really specific product (specific dimensions or grade). In our co-production context, it is difficult to forecast the quantities of the co-products that will be obtained if we allow the automated machinery to produce the new product: no historical data are available concerning the “new” process needed to obtain this new product. Therefore, it is impossible to use a classic tactical planning model to decide if the new market opportunity should be captured, as we do have the production matrixes (quantities of each product obtained if this equipment is setup with some new parameters). This gives real uncertainty regarding the profitability of the new product. The new product can seem at first very profitable, but the impact on other products quantities may bring a loss of profits. To summarize, it is very difficult for the company to comply with a specific need of a client and it is even

more difficult to know if it will be profitable for the company to produce this new product.

Moreover, if logs from a new supply source had never been processed by the sawmill, it is difficult to know the mix of products given by this new raw material as well as the benefits and losses that it can bring. Consequently, it is nowadays a quite delicate issue to change sawmill suppliers, to decide which log classes to buy, or even the way logs are classified.

We have here questions that the industry is today not able to answer with existing tactical planning approaches. Consequently, sawmills uses expensive approaches like trial and error.

3 PRESENTATION OF THE DECISION-MAKING FRAMEWORK

We propose a framework which allows making tactical planning in a situation when transformation process data do not exist (either because the plant never had the opportunity to transform a particular raw material or because a specific finished product has never been made). The proposed framework makes it possible to determine in an integrated way the raw material to use, the optimal mix of products to make (and the corresponding equipment parameters) and the set of available contracts/market opportunities that the sawmill should capture.

3.1 Basic components of the framework

The framework is based on the tactical planning tool developed by the FORAC Research Consortium (Marier *et al.*, 2014).

In order to compensate the lack of information regarding the possible new products, we simulate the sawing process with the Optitek™ simulator in order to get missing data. Optitek gives us the possibility to check what will be the mix of products obtained by a mill for each machine configuration/parameter. Optitek was developed by the FPInnovations research center (Goulet, 2006). It can simulate the sawing of a log (represented by a 3D scan) by a plant modeled with great details (machines, configurations, etc.)

If equipment configuration or log supply changes, then the finished products resulting from the simulation changes as well. Those data will be used to feed the tactical optimization model.

Optitek has been the base of several research projects like Goulet (2007), Tong and Zhang (2006) or Liu *et al.* (2007). Optitek is as well used by manufacturers.

3.2 Concept and model

In order to run a simulation (Figure 3), we first need to model the plant within Optitek (a), to know the different raw materials that the company could buy (b) and the different machine configurations that can be used (c). Simulation allows us to get the characteristics and the quantity of finished products (d). Simulation enables us to get some information about transformation (d) (i.e. characteristics and quantity of finished products) as well as the time spent to transform each of the logs into lumbers for each scenario/combination valid of b and c defined.

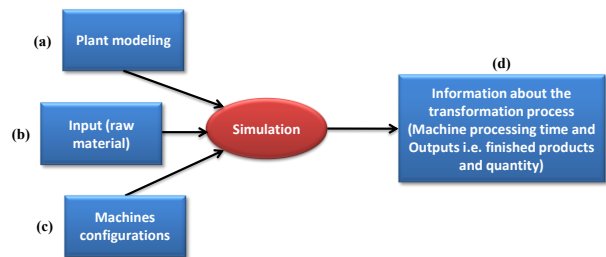


Figure 3: Using simulation to recreate sawmilling process

This simulation enables us to obtain, for the new products/parameters/supply, data similar to what we extract from the manufacturing execution system for the already used process (e).

We get then the whole set of data (d) needed to make the tactical planning model working (Figure 4).

Then, the optimization model is able to establish which scenario (or which combination of scenarios) is the most profitable for the company (Figure 5). Formally, input data for the planning model of Marier *et al.* (2014) which are obtained from the simulation results and from historical data are the following: consumption (volume) of each log class b which can be sawn in one time unit according to the sawing configuration y ($vc_{b,y}$), the volume of product p that we got after sawing one volume unit of log class b according to the sawing configuration y ($vt_{p,b,y}$), the volume of product p which can be dried in one time unit according to the kiln (for drying process) configuration z ($vt_{p,b,z}$), the volume of product p which can be planed in one time unit according to the wood finishing configuration x ($vr_{p,x}$), the volume of product p obtained after wood finishing operation for the wood finishing configuration x ($vo_{p,x}$).

In order to run the model, it is as well necessary to have information (f) about the volumes of the different log classes available for replenishment. We need to take into account the quantity available for each log class at the period t (va_t) as well as the procurement costs (ca_t).

Tactical planning takes as well into account available capacity (g) for each period t at the sawing unit, drying unit and wood finishing unit (dt_t , ds_t , dr_t). The maximal

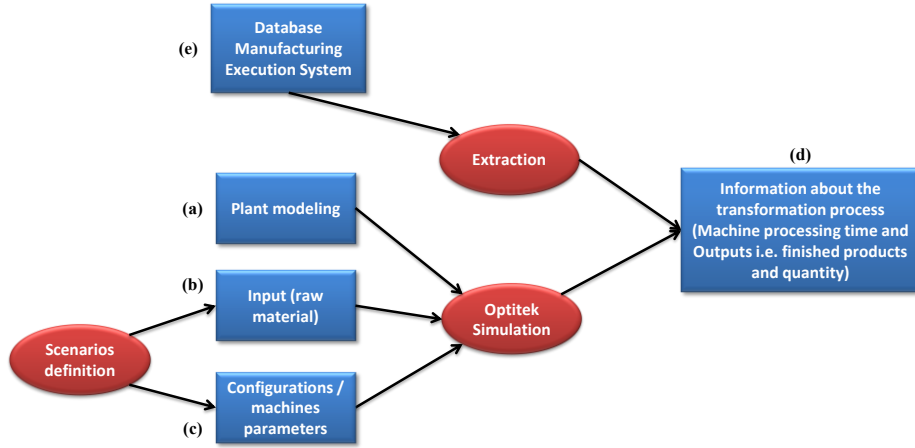


Figure 4: Integrating simulation with the Optitek software in order to know information about the transformation process needed for tactical planning

inventory of each product p that can be stored at period t ($i_{p,t}$) and the maximal inventory of each log class b that can be stored in the log yard at period t ($i_{b,t}$) is important for tactical planning.

It is necessary to have some information about the market (h) in order to decide which products should be sold, when and at what price. We use the expected selling price of product p at period t ($pv_{p,t}$), the minimum quantity of product p to sell at period t ($qm_{p,t}$) corresponding to agreements already signed and the maximum quantity of product p which could be sold at period t ($qm_{p,t}$) on the market (really important for new particular products).

This allows us to prepare an optimal multi-period tactical plan (i) considering all the parameters listed before. Thus, we can get the volume of log class b sawn at period t ($VT_{b,t}$), the volume of product p planed at period t ($VR_{p,t}$), the volume of product p obtained after sawing operation at period t ($VS_{p,t}$), the volume of product p dried at period t ($VO_{p,t}$), the volume of product p obtained after wood finishing operation at period t ($VV_{p,t}$), the volume of sales of product p at period t ($VF_{p,t}$), inventory of product p at period t ($IF_{p,t}$), inventory of log b at period t ($IF_{b,t}$), the incomes regarding the sales of product p at period t ($R_{p,t}$) and so the global incomes at period t

(R_t). Moreover, this enables us to determine costs linked to each of those transformations : sawing costs at period t (CT_t), drying costs at period t (CS_t), wood finishing costs at period t (CR_t), inventory costs at period t (CI_t) and supply costs for log class b at period t ($CA_{b,t}$) and consequently the total supply costs at period t (CA_t).

In order to know if an agreement should be signed with a client or not, we have to check if the model sells the new product p i.e. if the decision variable $VV_{p,t}$ is equal to 0 for the periods t when the sawmill should give the product to the customer.

The multi-period plan enables to maximize global profit i.e. incomes minus costs for the entire planning horizon. Let T be the number of periods within the planning horizon, the objective function to maximize is then:

$$\text{Max} \sum_t^T (R_t - (CT_t + CS_t + CR_t + CI_t + CA_t))$$

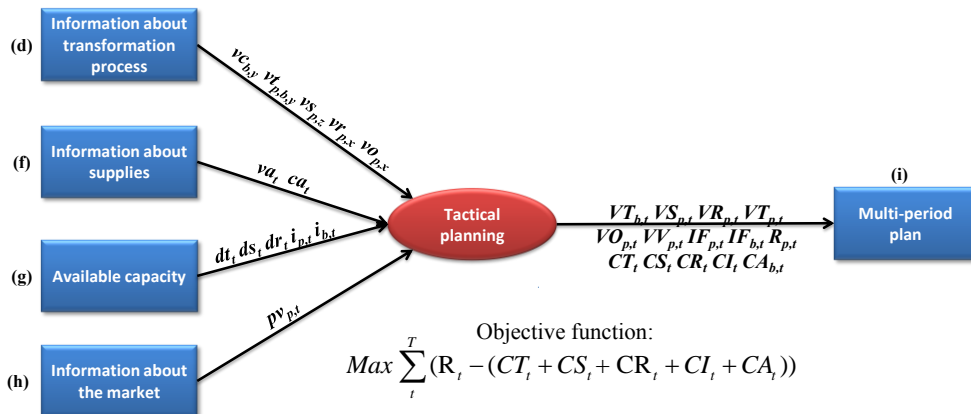


Figure 5: Outputs and inputs of the tactical planning model

4 PROOF OF CONCEPT

The case study in this section is fictional. It was developed as a proof of concept together with our industrial partners. Parameters and characteristics used in this model were given by field experts. We suppose a lumber mill normally producing standard NLGA products (commodity products). A customer would like to sign an agreement for a product with specific characteristics that the mill has never produced before. The lumber company would like to know if it would be profitable for them to produce this particular product. They also would like to know what will be the impact on the rest of the mix of products.

4.1 Experiment and data presentation

Figure 6 shows the standard mix of products obtained by the sawmill when transforming 100 m³ of logs. The company can sell rough green, rough dry, planed green or planed and dried products.

The lumber 2x4 12 feet can be either planed without having been dried before or dried and then planed. The terms G1, G2 and G3 mean respectively Grade 1, Grade 2 and Grade 3. It is quality levels (Grade 1 is the best quality).

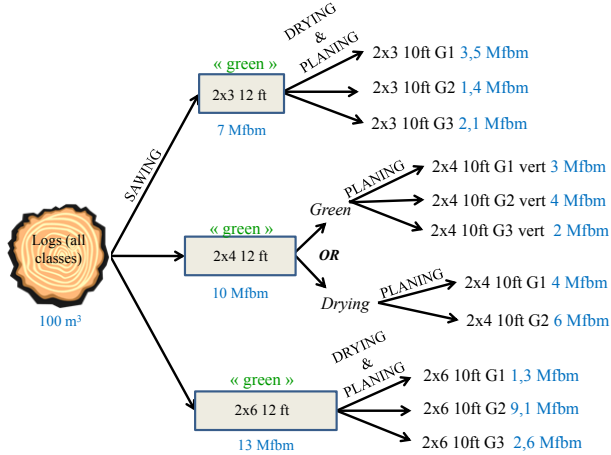


Figure 6: Basic mix of products

The Table 2 shows the price list for the products:

State	Dimension	Length	Grade	Selling price (\$/Mfbm)
Rough green	2x3	12 ft		500
Rough green	2x4	12 ft		325
Rough green	2x6	12 ft		350
Rough dry	2x3	12 ft		400
Rough dry	2x4	12 ft		425
Rough dry	2x6	12 ft		450
Planed dry	2x3	10 ft	G1	550
Planed dry	2x3	10 ft	G2	550
Planed dry	2x3	10 ft	G3	550
Planed dry	2x4	10 ft	G1	550
Planed dry	2x4	10 ft	G2	500
Planed dry	2x6	10 ft	G1	610
Planed dry	2x6	10 ft	G2	600
Planed dry	2x6	10 ft	G3	590
Planed green	2x4	10 ft	G1	500
Planed green	2x4	10 ft	G2	495
Planed green	2x4	10 ft	G3	490

Table 2 : Prices used for the planning

We assume that a new product (2x3 8 ¼ grade “super”) is needed by a customer for a long term agreement. The company has never produced before this product. After a discussion with the customer, we established that this particular product could be sold at 900\$/Mfbm. It is more expensive than the other products because it has been defined for a particular contract for a particular customer. As it is not a commodity product, there is minimum and maximum quantity as well as a calendar to observe. Allowing our equipment to produce this product (by giving them new configuration parameters) will lead to variations about the quantity of other products which will be made at the same time.

In practice, it could be possible to find out the new mix of products by performing a test in the plant (which is time consuming and expensive). So, an alternative is to use Optitek in order to simulate the sawing of the logs under the new operating parameters and to find out about the new mix of products.

Changes on the mix of products are shown on Figure 7. While in the basic mix of products, there were only one transformation possibility for the product 2x3 12ft (i.e. to 2x3 10ft grade 1, 2 and 3), it is possible when adding the new product to transform the 2x3 12ft either in 2x3 10ft

grade 1, 2 and 3 (i.e. as well as for the basic mix of products) or in 2x3 10ft grade 1 et en 2x3 8^{1/4}ft Super.

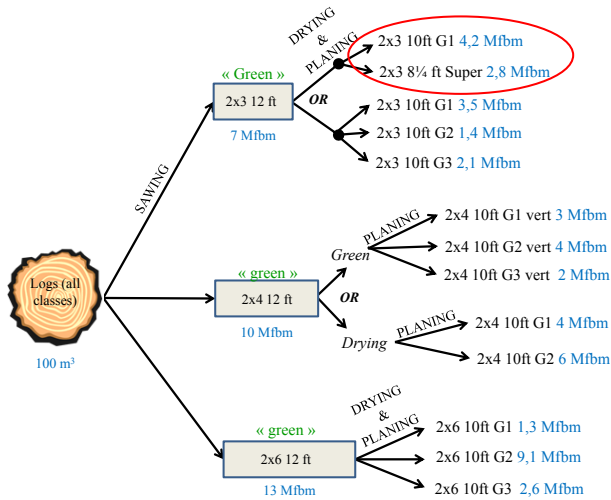


Figure 7: New mix of products for the product 2x3 12ft enabling producing the new product (2x3 8^{1/4}ft Super)

In order to check the profitability of the new product, we have done two different tactical planning optimizations. Two different sets of parameters have been used for operating our plant. In first place, we have used basic parameters corresponding to the normal sawmill production. Then, we have added the new product (and so the parameters related to it) to the basic parameters.

Using the tactical planning model, we were able to create a 12-month sales and production plan for both scenarios. These plans take into account all the parameters and decision variables shown in section 3.2. They maximize the global benefits in both scenarios (i.e. decides which products to sell green vs dried, rough vs planed according to capacity limitations, etc.). Log supply is considered infinite (there is always available raw material). The

market (of commodity products) is also considered as infinite (everything which is produced can be sold).

However, for each period we have a maximal capacity for each unit: 160 hours for sawing process and wood finishing process, 720h for 300 Mfbm for drying process³.

By adding to the basic parameters the parameters related to the new product, the optimization model won't make a tactical plan which would be less profitable than with only the basic parameters because it is the same basic parameters to which we have added more possibilities. Indeed, if selling the new product is not globally profitable for each period when it needs to be sold, then the tactical planning model won't choose to produce the new product. However, performing the optimization with both sets of parameters allows us to compare and analyze both scenarios in order to look at the influence of the new product production (which can be equivalent to a long term agreement) on the mix of products.

4.2 Influence of new products and result analyses

By adding a product other products which were not profitable to produce before, become profitable. Adding a new product changes completely the entire production process and the whole set of products available for sale at each period. Indeed, as the Figure 8 shows, no rough dry lumber were available for sale with basic parameters. However, with the parameters related to the new product, 14% of the sold volume is rough dry products. So, the final optimal mix of products is completely different. In this experiment, the sales of the new product (2x3 8^{1/4}ft "Super") bring the company 1.4% more profits than the profits made without producing this new product (revenues increase of 443 542\$ and costs increase of 2 705\$). It would have been really interesting for the company to accept this order.

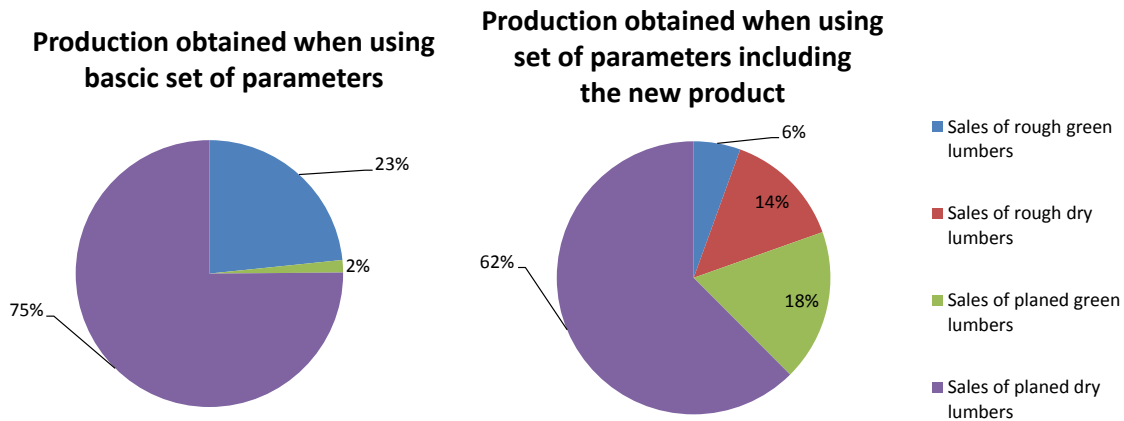


Figure 8: Planning results: proportion of sold products resulting from the optimization with the basic set of parameters on one hand and with the same set of parameters to which we add parameters which enables the production of the new product on the other hand.

³ Board foot is the unit of volume measurement used in North America; Mfbm = thousand foot board measure

In a more detailed level (Figure 9), we note that the most sold product with the basic parameters (2x6 10ft G2) is still the most sold product when we introduce a new product. Concerning the rest of the products, as we said, adding the 2x4 8^{1/4}ft grade “Super” totally changes the mix of products and this shows the importance of the planning. Indeed, in order to know if accepting a long or mid-term agreement with a client for a new particular product will be profitable to the company, we should carefully verify if this agreement won't result in losses due to the changes in the final mix of products.

slow and very long to proceed to these simulations. If all of those scenarios must be simulated before launching the optimization model, the planner may get his plan too late (particularly in the case of a market opportunity). In a real situation, only a certain number of scenarios would be simulated. In our future work, we intent to propose a mechanism to prioritize which scenarios should be simulated first.

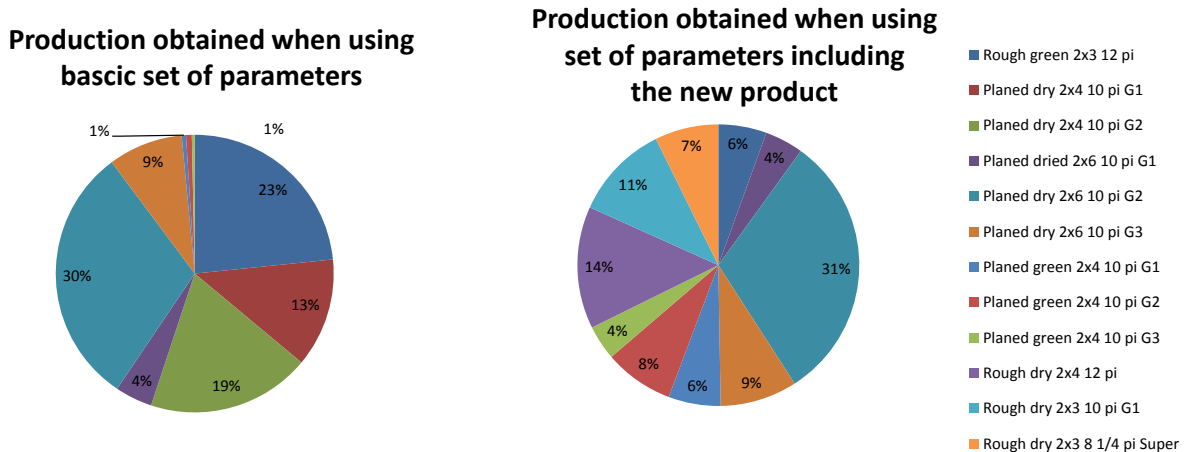


Figure 9: Mix of products resulting from the optimization with the basic set of parameters on one hand and with the same set of parameters to which we add parameters which enables the production of the new product on the other hand.

5 CONCLUSION

The proposed framework combines simulation (with Optitek) and a tactical planning tool in order to take into account new products (or new raw material sources) for the Sales and Operations planning. The simulation enables to find the new mix of products resulting from the integration of a new product to the normal company mix of products. The tactical planning tool considers the new mix of products to create a multi-period tactical plan.

Thanks to the framework established, we are able to check whether accepting a mid-term contract for a specific product is profitable or not. The framework could also allow us to find both the best price for each client and the raw material the most suitable for our production and for the sawmill profitability. Our experiment highlights that adding a new product highly influences the changes in the mix of products. Indeed, some products are sold even though they were not produced in the case only considering standard products. Benefits have also increased thanks to the new product.

For this paper, a simple case has been studied to show the relevance of the proposed framework. In real practice, a huge number of simulations should be made with Optitek to feed the tactical planning model because we have a large number of alternative machine configurations. The time for each simulation means that it will be

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