La comptabilité par activités appliquée aux scieries pour la planification de production et la valorisation des produits

Mémoire

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Résumé

Si la comptabilité par activité (CPA) a été très largement développée dans l'industrie manufacturière, son application à l'industrie de première transformation du bois l'est beaucoup moins. La première partie de ce mémoire est consacrée à une revue de littérature dans laquelle nous montrons pourquoi les méthodes de comptabilité traditionnelles ne fournissent pas les informations nécessaires à la prise de décision et plus spécifiquement dans le cas d'une production mettant en œuvre des processus divergents. Nous y présentons également les outils qui permettent de déterminer un plan de production sur un horizon de temps donné. L'article qui fait l'objet de la deuxième section de ce mémoire, présente une méthode de CPA appliquée à une scierie ainsi qu'un outil de planification de production basé sur la résolution d'un modèle mathématique. Enfin, dans une troisième partie, nous présentons le développement d'une CPA axée sur la valorisation des extrants pour le département de rabotage d'une scierie nord-américaine.

Abstract

If Activity Bases Costing (ABC) has been widely developed for manufacturing industries, its application for wood first transformation industries has not. The first part of this thesis is dedicated to a literature review in which we show why traditional accounting methods do not provide accurate information to support supply chain planning, especially in a production line which involves divergent processes. We also present the paradigms which enable to determine a production plan on a given time horizon. The paper in the second section presents an ABC method applied to a sawmill which provides the required data to a production planning tool based on a mathematical model resolution. In the third and last part, we introduce an ABC method development focused on the valuation of the outputs of the planing department of a North-American sawmill.

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Abbreviations and acronyms

ABC (CPA): Activity-based costing (Comptabilité par activités)

GT: Game theory

MSR: Machine stress rating

NRV: Net value realization

TA: Traditional accounting

TDABC: Time-driven Activity-based costing

TOC: Theory of Constraints

RABC: Report activity-based costing

RIV: Resource Integer Variables

VBA: Visual Basic for Application (Microsoft)

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Foreword

This study has been directed by Mikael Rönnqvist, Professor, Department of Mechanical Engineering Université Laval, and Sophie D'Amours, Vice-Rector, Research and Innovation, Université Laval and supervised by Marc-André Carle, Adjunct Professor, Université Laval. It was written by myself, Damien Chauvin, at the end of my Master in Mechanical Engineering with a major in Industrial Engineering at Université Laval.

The literature review of the thesis and its summing up in the article, the paper methodology, and the paper results section has been executed by myself. Based on my requirements, my professors and the FORAC professional researcher team helped me for the development and the implementation of the production planning tool presented in the section four of the paper. It is based on an existing mathematical model developed in the FORAC Consortium to which new constraints and variables has been added to meet the needs of my study. Both the paper application case and the case study presented in the chapter three has been conducted by myself in accordance with the directions given by my professors. I collected the data of the application case in the literature and in the data base of the Research Consortium FORAC. Those of the case study come from the industrial partner. The activity-based costing tool for product valuation presented in the case study has been entirely designed and implemented by myself using data to the property of Maibec Inc.

The paper has not been submitted for publication yet. My professors and I plan to do it at the beginning of the year 2015.

The Conference proceeding presented in the annex section has been published during the Conférence Internationale de Génie Industriel 2013 which took place in La Rochelle (France) on June 2013. It has been written by myself except the introduction by Marc-André Carle.

Introduction

I. Context

The very rich biodiversity on the Earth makes the extraction of a desired material from natural resources generally very difficult. Many natural resources industries are dealing with coproduction issues because this resource does not give a unique material but a basket of products, some of which having a high value whereas some others have to be disposed of. In all the cases, extracting and transforming a natural resource in order to add value to it imply financial expenses.

Because natural resources must be exploited in an ethical and responsible way, it is important to know how to manage all the supply chain to fulfill smartly the customer demand, reduce inventories and operational costs in order to be sustainable and to make money (Goldratt 2008). To do so, political, economic, social, environmental and technical factors have to be analyzed and understood in order to be able to integrate them into the decision making processes. The criterion we are interested in for the current study is the economical and the technical ones.

Linking expenses and production operations is not an easy task (Kaplan and Cooper 1987). It requires knowing accurately what has to be done to meet the need of the client from raw material supply to the delivery to the customer. Activity-based costing is an innovative managerial accounting method which enable to trace most of financial expenses to the products by express all the value added or non-value added actions – called activities – executed needed to obtain a product. These activities can be as easily traced to the expenses as to the products. This way we can compute quite accurately how it costs to produce an output and by extension knowing the benefit of a given product. However contrary to manufacturing production in which a final product is an assembly of several inputs, in a context of coproduction it is difficult and expensive to be able to trace an output to a specific input either to specific activities (Tsai 1996).

The first transformation forest industry is one kind of the field in which coproduction comes into play in North America. Before the 2008 crisis, whatever was the product produced, it used to meet a customer demand. The market was thriving and the demand very high. Today, industries cannot sell the products they produce anymore. They rather have to produce what can be sold. They need to move from a pushed production flow to a pulled one.

II. Key concepts

This section is dedicated to a review of different concepts on which we built our problematic. We present the specific field in which we are interested: industries whose production involves divergent processes. Particularly, we lay emphasis on the sawmilling industry which is the particular application field which serves our demonstrations. We consequently present the characteristics of the sawmilling supply chain and the issues raised by the management of it.

II.1. Divergent processes

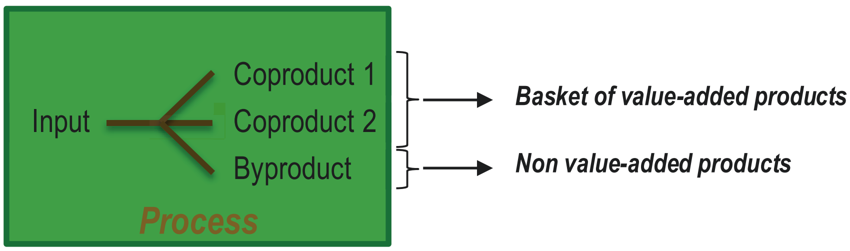

Figure 1 Divergent process

Divergent process, or joint production process, is the term used to qualify an operation in which several products are obtained from one or several raw materials (Tsai 1996). As illustrated in Figure 1, the term "process" is used to define the combination of an input and the recipe which turns this input into a basket of products – which are commonly called joint- or co-products. Petrochemistry, forestry, food industry or dismantling industry are confronted with this kind of production. Numerous issues are raised about costs computation – operational costs and their allocation among products –, in-progress products traceability – because of splitting points – or operations yielding optimization. The source of these issues is mainly the nature of divergent processes, in which several alternative baskets of products can be obtained from a single input or raw material. Indeed, among the set of products obtained, just a few are wanted and can even be produced from different processes. Most of the time, some of them can be considered as non-value products and are then qualified as by-products.

II.2. Sawmilling industry

Canadian forest industry is a highly complex industrial field which faces new ways of production. Sawmills are nodes of a large supply chain composed by numerous actors. Some of these are forest harvesters, pulpmills, manufacturers, distributors or external customers (D'Amours et al. 2006). Those actors are not necessarily part of the same company and their interests may also differ. If the goal has been to maximize the volume of lumber produced from forest logs in the past, today economic globalized environment force companies to change this way of thinking. Customer requirements are now more complex to fulfill. Companies also investigate more and more ways to move from a push mode production to a pull one by trying to set long-term agreements with their clients (Gaudreault et al. 2010). Let us briefly present the main operations and specificities of a sawmill; those operations are depicted in the Figure 2. Log from a timber assortment, defined by its species, dimensions, and grade, is the most valuable part of a stem harvested from a stand in the forest. Once loaded on a truck, logs are transported to a sawmill (Nurminen, Korpunen, and Uusitalo 2009). Depending on the sawmill policy, logs are sorted according to their species and dimensions and stored in the log yard. Then, the value chain of a sawmill can be divided into three main production units (Gaudreault et al. 2010).

The first one is the production line, which transforms a log into green lumber by first debarking then sawing the log. These are two divergent operations: from the debarking opreation barks and debarked logs are obtained and from a debarked log at the sawing line, chips, sawdust and several types of lumber are produced. The sawing operation characteristics are well known, and are described in (Rappold 2006). Lumber is sorted by section and species and generally stacked in bundles for the next operation in the production line: drying.

The second production unit is the drying operation which aims at decreasing the moisture rate of lumber to meet some mechanical requirements. Air drying – natural – or kiln drying – industrial – are the two technologies available (Gaudreault et al. 2011). Because species and dimensions of lumber are very heterogeneous from a bundle to another, drying time can vary a lot, especially in North America or Northern Europe where outside temperatures fluctuate significantly depending on the season. Drying time is consequently one parameter which varies a lot between different bundles.

The third production unit follows the drying and is dedicated to the finishing and the sorting of lumbers. Lumbers bundles are destacked, planed using specific tools according to the required finishing aspect, then sorted according to their moisture rate, their mechanical characteristics and their external appearance (Korpunen, Mochan, and Uusitalo 2010). Most of the time they are trimmed to meet the required combination of length and grade (Gaudreault et al. 2011). At the end of finishing, the lumber is given its final quality grade, which is printed on its surface. Once again, this operation is highly divergent because it is possible to get up to 10 grades and length combinations from a single bundle. Moreover, a lot of by-products are generally obtained – like trimmer residues, and wood shavings. Sometime, a surface treatment is applied, like a varnish or a water-repellent. The last operation of this production line is packaging which consists in stacking lumbers then wrapping them to be easily transported to the customer.

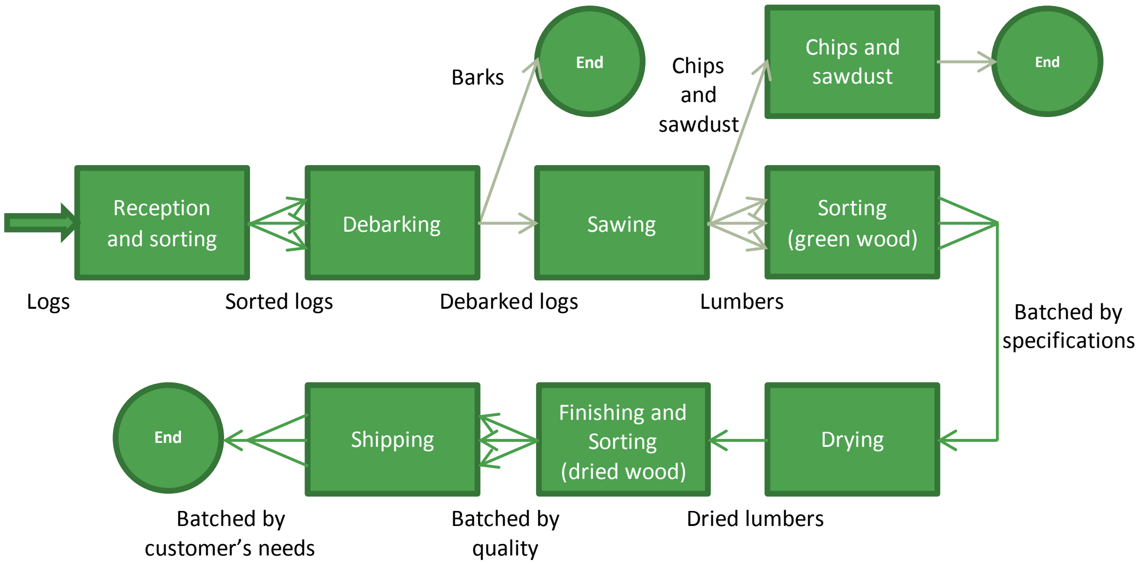

Figure 2 Operations in a sawmill

II.3. Concept of supply chain planning

To run a company, supply chain planning decisions must be taken at different planning levels. Depending on the field and the complexity of the company, the time horizon and the level of detail needed, criterions are numerous and can be dealing with a lot of various issues. In this paper, we focus on decisions that have a direct impact on the company's profitability. Mainly, we will answer the question: what will we produce, when, from what inputs and to satisfy which customer demand in order to maximize the company's profit? To support decisions, a lot of parameters must be found, set and analyzed which represents by itself an important phase.

For the purpose of this study, decisions and their parameters will be defined as follow:

- Customer portfolio: which customer's demand will we satisfy? Parameters of customer portfolio will be composed by the quantity of each product demanded for each customer at which price for each day of a given horizon.
- Supplier portfolio: from which supplier will we buy raw materials or inputs needed to manufacture products? Same as customer portfolio, parameters of supplier portfolio will be composed by the quantity of each input required for manufacturing products ordered by customers.

- Product portfolio: which products are valuable to produce and which ones will not be produced? The parameters of decisions linked with the products are the most complex to define because we are facing issues of process definition. We will have to define recipes which include machining or operation times, handling times and input consumptions. Unfortunately, these recipes may vary a lot because of heterogeneous material. But decisions are taken both at the operational and tactical level and will have an impact on the strategic level, a good level of details is very important.
- Production structure: which equipment to use, how many shifts to schedule, how many employees to hire? As for product portfolio, the production structure must be modeled at an accurate level of details to catch specificities of the company. Each process or alternative process will be defined with its constraints about capacities, costs and linked to other processes.

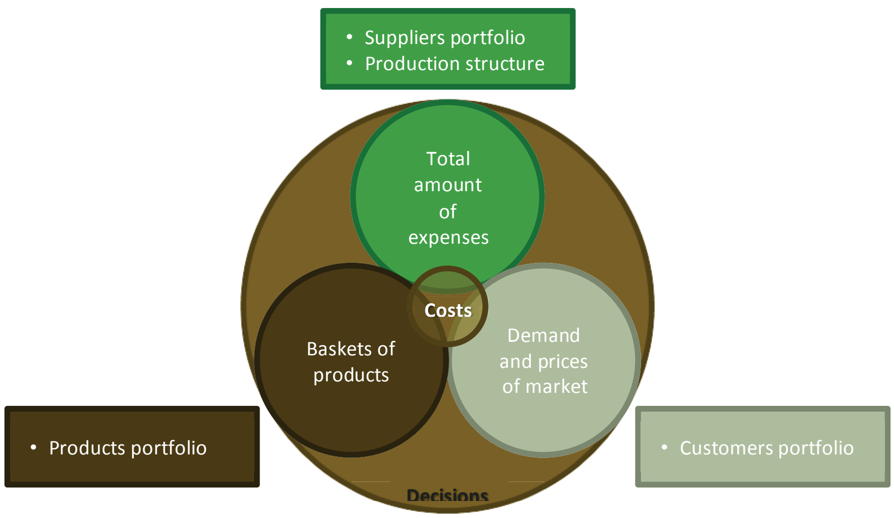

Figure 3 Supply chain planning decisions

As shown on the Figure 3, because answers to these questions depend on each other, they must be dealt with simultaneously. Some tools must be developed for setting up these parameters as for finding a good or optimal set of decisions.

II.4. Planning and scheduling operations

Because of the high complexity of the sawmill operations, obtaining a good, feasible production plan is a very difficult task. In order to account for all the specificities of a plant or a supply-chain, several methods have been developed which break the planning and scheduling operation into several distributed decision structures. Three main paradigms can be employed to solve planning issues (Frayret et al. 2008).

The first one is based on hierarchical production planning (Hax and Meal 1973) which structures the supply chain decision-making process in several level of decisions: the product assignments to the supply chain plants; the planning operations and finally scheduling operations. Advanced Planning and Scheduling (APS) systems (Stadtler 2005) disaggregate these steps by introducing a time scope which starts with long term – strategic network planning and demand forecasts – then mid-term – tactical or master planning – to finish with short term – production planning, scheduling, material requirements, distribution planning, transport planning and demand satisfaction. As depicted on the Figure 4, they so cover procurement, production, distribution and sales. Each upstream module takes a set of decisions which constraints the downstream ones.

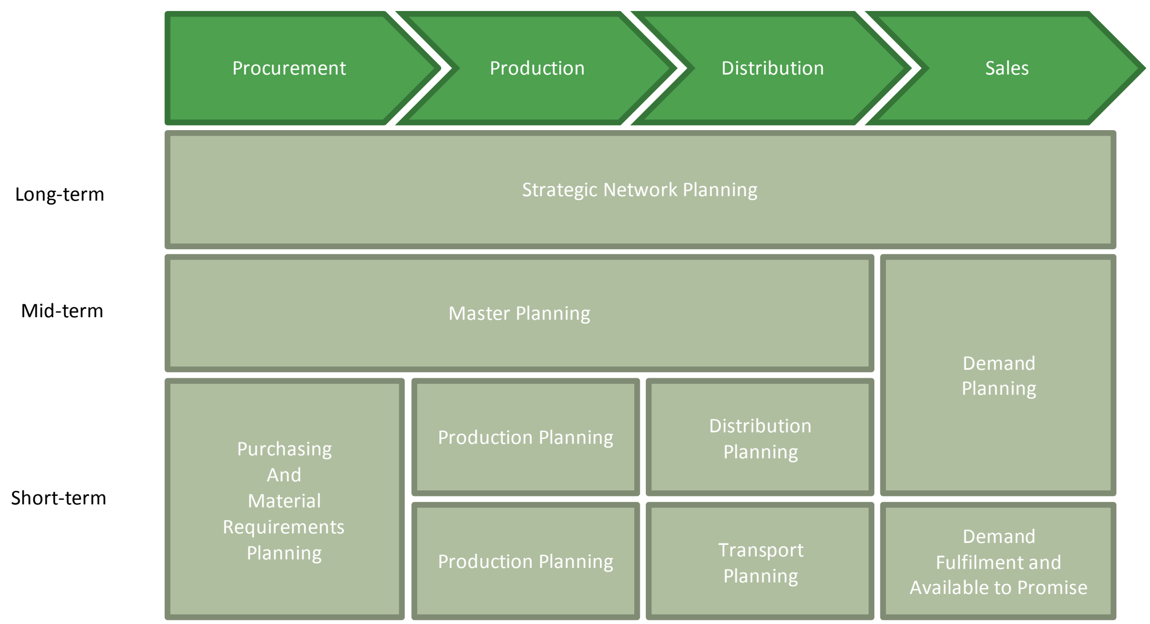

Figure 4 Software modules covering the supply chain planning matrix (Stadtler 2005)

The second tool family can be divided into two classes, agent-based manufacturing and agent-based supply-chain management. Each agent is given a task to contribute to the achievement of a global purpose which means that they take their own decisions independently but by taking into account others' requirements (Frayret et al. 2008). For application to sawmills, reader can refer to (Frayret et al. 2008; Gaudreault et al. 2010).

The third way to solve those complex problems for the whole value chain is the use of an integrated model, formulated as a Mixed Integer Programming or a Constraint programming model (Gaudreault et al. 2011). The goal is to generate the production planning and the scheduling at the same time but at a more aggregated level of details, like tactical level.

Ⅲ.Thesis structure

The purpose of this study is to show how activity-based costing can be adapted to sawmilling industries to serve the supply chain management, especially at the operational level production planning. We chose to build the thesis on three parts: a literature review, a paper and a case study.

In a first part based on a literature review, we will demonstrate why traditional accounting method cannot provide accurate and relevant cost information to decision makers and why activity-based costing can be a powerful tool to meet their needs.

The second part is a paper in which we will present the supply chain decision-making process that rules the management of a sawmill. It is based on the two uses that can be made of an activity-based costing method, production costs and pricing cost computation that serve production planning and sales respectively. We will see that both are intrinsically dependent from each other. We warn the reader that the article is self-sufficient. That is why some parts in the literature review of the article will be redundant with some of the thesis literature review.

The third part of this thesis is a case study which has been realized in collaboration with an industrial partner. We first present the operations of the planing department in which the study had been lead. Then, we introduce the traditional accounting method decision makers use to run the production and the limits of this method. Based on the operations and the resources structure, we propose an activity-based costing method for the planing department and we show the way it can be used to compute production and pricing costs. The reader can refer to this section throughout the thesis as a numerical example of the concepts introduced.

Literature Review

Because most of the inherent decisions follow from financial considerations, the main purpose of the following literature review is to demonstrate why companies cannot dig relevant information out data from traditional accounting method. A possible alternative to overcome this lack of information which has been widely used in manufacturing industries is the implementation of activity-based costing method. Unfortunately, we see that the adaptation of this method to joint-production operations are small in number and the few of them dedicated to sawmill do not serve the purpose of production planning.

I. From traditional accounting to Activity-based costing

I.1. Product and pricing Costs

Since economical criterion may be the one on which all decisions are made, costing is one of the most important steps to support the supply chain management. Despite this statement, we realize that the costing process is sometimes overlooked. There are two purposes for costing: pricing and supply chain planning.

The first purpose emphasizes on the margin – revenue minus costs – what we can make when selling products. That is why it is intrinsically linked to the price of a product. Contrary to most manufacturing processes, joint-production implies that separate products come from the same raw material (Tsai 1996). Whatever the accounting method used, it is obvious that an issue is at stake if we aim at sharing the incurred costs to the joint products at the split point: from zero to hundred percent, an infinity of cost sharing possibilities exists. We can define the pricing cost as the part of all resources incurred to obtain this product that is allocated to this product.

The second purpose must reflect the resources consumption. It is the one which supports supply chain planning decisions. It can be divided into two parts. Firstly, the resources that are expended to manufacture the product which is obtained from an accounting method. Secondly, an optional and arbitrary positive or negative weighting part which reflects the strategy of the managers. It is an incentive or a penalizing cost.

I.2. Shortcomings of traditional accounting methods

A resource, material or immaterial, which implies or not an expense, is what a company requires to meet a customer's need. Ground location, machines, materials or employees: the size, the number or the quantity of a resource has to be determined accurately to maximize the profit of a company. During the late 1980's, it has been demonstrated that financial traditional accounting (TA) methods could lead to wrong decisions (Kaplan and Cooper 1987). Both full- and variable-costs systems may fall short to provide enough valuable information on a product's cost. TA usually distinguishes two kinds of resources when they refer to their behavior. On the one hand, variable resources are consumed proportionally to the quantity produced. On the other hand, fixed resources are usually named overhead. Unfortunately, the boundary between fixed and variable resources is never clearly established. Alternatively, we can divide resources into two categories: direct or indirect resources in that they can find a relation or not with a product respectively. Finding the appropriate share of indirect resources between products is often arbitrary and can lead to distortions whose result wrong decisions (Kaplan and Cooper 1987).

In a variable-costs system, like marginal costing, only variable costs are assumed relevant for costing. This approach results in two types of problems. The first one is the assumption that decisions are made on short-time horizon, whereas most of products decisions have implications on long-term horizon. As demonstrated in the paper (Kaplan and Cooper 1987), a resource can be fixed considering a given time horizon but variable for a shorter one. For optimization purpose, the planning horizon is the one covered by the mathematical model. For other purposes, we can introduce several levels of horizon (Kaplan and Cooper 1998:chap. 6).The second reason is the increasing amount of fixed-costs in factories. In a fully automated production line, fixed costs are higher than variable resources like material, energy or manual operations. Those accounting systems were justified in a context of low-competition and stable market for companies with a large part of manual-production lines.

Full-costs systems, whose the two-phase method is one of the most widespread, are also problematic for allocating variable and fixed costs to products (Kaplan and Cooper 1987). This method consists in a first stage in allocation of resources to cost centers which refer to service, maintenance or production departments. If first stage allocation base differ from a cost center to another, in the second stage, sharing of cost center among products are often only function of direct labor hours. Once again, in a fully automated factory in which a single employee works at the same time on several production-lines for supervise, control or setup operations, the products costs cannot be accurate. Even by adding new repartition bases, problem is not solved. Indeed, most of the time costs do not raise proportionally to the quantity of product but with the complexity or the diversity of them. Due to these repartition bases, those systems over-allocate support costs to high-volume products. In this way, high-volume products appear more expensive to produce than low-volume products (Goldratt 2008). Moreover, those systems generally do not take into account any variable cost, or just during budgeting.

All of these statements remain true in the lumber industry in which data are very hard to collect, mostly because of heterogeneous materials and products and divergent processes. Nowadays, companies can improve their production due to computer databases. However, costs calculation is still very basic. Sawmills in North-America are often sixty years old that have produced according to a push production flow. In the 1980's, a method is proposed to set a cost on products according to the volume proportion (White 1980). Production cost is so obtained by dividing the total amount of expenses – from which the log cost is subtracted – by the annual volume of lumbers produced. This way any distinction can be made between products because cost is the same for all products.

A more accurate method has been proposed in the early 1990's by Howard (1993) which takes into account variable and fixed costs incurred at each operation of the production line. Costs are allocated to inputs at each operation according to the operation-time – function of a given dimension of the wood piece – or the volume – if the operation time is impossible to determine for a piece of wood. While cost production per log is quite accurate, the part of the cost considered as fixed is very large as Metzger (Metzger 1993) concluded after having compared fixed cost from TA to those from other accounting method on a given time horizon as we will see in the following section.

I.3. Origin of the Activity-based costing method

Activity-based costing (ABC) appeared in the 1980s. Based on insights of Kaplan (Kaplan 1990), several big companies intended to implement new accounting methods, providing radically different information compared with traditional – financial – ones. This method which cannot substitute for financial accounting, has for purpose to avoid the arbitrary choice often made to decide if a resource is variable or fixed. Because time horizon is linked to a view of the firm which is basically most subjective, ABC considers the variability of a resource according to the hierarchical level of the activity it is associated with. In this way, a resource is incurred in the realization of a product each time an activity is performed. The distinction between variable and fixed resources disappears in favor of the level of the activity.

An ABC is a method that could be similar to a two stage allocation in that resources are first allocated to activities according to a resource cost driver and then activities are traced to products thanks to an activity cost driver (Kaplan and Cooper 1998). instead of considering that resources are committed to produce, ABC supposes that producing implies expenses (Kaplan and Cooper 1991). In other words, performance of an activity triggers an expense. Usually, four levels of activity are defined (Kaplan and Cooper 1991; Lere 2000):

- Unit-level activities are related to resources that vary proportionally to the quantity produced. They are similar to variable costs.

  Examples: Machining, material or consumables costs, some energy costs etc.
- Batch-level activities correspond to resources linked to the realization of a batch of products. They will change depending on the number of batches whatever the number of products in a batch.

  Examples: Setup operations, scheduling, material movements etc.
- Product-level activities refer to activities which performance will affect all batches of products manufactured. They can be easily traced to an individual product.

  Examples: Special testing or tooling, product design, update of a product specification etc.
- Facility-level: can be compared to fixed costs – overhead – in TA methods. It is about all costs incurred to open the factory, independently of the use made of it. Those costs refer to the capacity of the factory and cannot be traced to individual products.

  Examples: building costs, management staff, catering or security service, heating and lighting etc.

If we can find some common activities from an ABC to another, their formulation and the resources traced to them are always intrinsically linked to the specificities of the structure whose they depend. Managers can decide whether an activity must include a given operation or resource or not. The reader can refer to the Case Study section to find activities examples. Cooper and Kaplan (Cooper and Kaplan 1991) warn ABC users by explaining that ABC had been created to give managers an aggregated view of relations between production and resources because these are too complex to be studied one by one when a decision must be taken. *An ABC model serves to direct managers' attention to where more detailed analysis will likely yield the highest payoffs.*

One of the first use of ABC was for resources management. Cooper and Kaplan (Cooper and Kaplan 1991) defined more accurately the link between the resources and activities which are related to them.

A very important statement is that once established, an activity or resource cost driver does not vary. A resource is supplied to provide a given practical usage capacity for one or several activities. Cost of unused capacity must not be loaded on cost drivers: a change in capacity usage does not change the cost of performing an activity. In other words, unused capacity should not be confused with traditional volume variance which is an aggregated financial information calculated on budgeted production generally used for inventory estimate which vary with the number of units produced. Cooper and Kaplan explain that this ABC view can be useful for pricing, product mix, optimizing resources usage, improving profits and adapting resource supply to resource demand.

In 1996, Salafatinos (Salafatinos 1996) question this statement by introducing an ABC incremental analysis. The paper presents a way to deal with the use of capacity. As Cooper and Kaplan (Cooper and Kaplan 1991), Salafatinos (Salafatinos 1996) argues that *ABC systems were designed to measure the cost of using resources, not the cost of supplying them*. This means that it is not because the resource demand increases that the resource supply will increase too and even less the cost of using it. The authors are only interested in the interaction between activities and their resources, so the way products will consume activities is not at stake here. He distinguishes between two kinds of resources. The pushed resources are the ones which are paid before being used and they can be modeled by a stepwise function. Consequently, it will always remain a gap between the usage and the supply of this resource. The pulled resources on the contrary will be dragged by the demand and because they are paid in function of the usage, they can be modeled with a linear function. This concept leads to considering the resource cost driver as the link between resource supply and resource demand when a decision is taken, first by analyzing changes on cost drivers – number of purchase orders, or setups for example, then by deducing which activities will be impacted by those changes, and finally determine the cost supply function for each of the resources linked to the identified activities. If the proposed method models quite accurately increases in resource supply, it does not consider the cost of reducing it. Indeed, the cost of reducing the supply of a resource can be different from the one for increasing it.

Metzger (Metzger 1993) shows the usefulness of ABC by giving an example in which he compares a traditional volume-based allocation with several allocation bases, to an ABC with volume-, batch- and facility-level activities. By using this allocation scheme, the "irrelevant" cost part – fixed costs – which is equal to 1.425 million in the TA method is reduced – by the introduction of batch-level activities – to 175,000 with the ABC method. The second conclusion is that the most profitable of the three multi-parts products in competition is not the same with both methods.

I.4. Implementation of Activity-Based Costing methods

A major issue companies are facing is the total reengineering of their accounting method and even more the introduction of new costs interpretation methods. Deherripon (Deherripon 1996) establishes a method to move from a TA to an ABC method. The aim of his study is to redefine the supply chain planning decision structure of the company. After identifying customers, products and responsibilities of the decision-maker, the basic functions and their industrial performance indicators are developed. Activities which gather basic functions, and the associated cost drivers will be determined. About 10 activities will be used. The core of the method is to link activities to resources. Basic functions will be developed into several sub-functions, easily linkable to resources. According to persons in charge of departments, resources will be allocated to functions. In this method, cost allocation to products is not at stake, the method focuses only on resources management.

Over the years, because of the democratization of the method, the method to integrate an ABC in the supply chain management is standardized. Kaplan and Cooper (Kaplan and Cooper 1998) propose a 4 stages method to set up such a method in a company. First, developing the activity dictionary which counts from twenty to hundred or more activities depending on the complexity of the firm. The authors claim that activities whose amount of associated resources is less than five percent of the total should be ignored. On the other hands, activities may be aggregated if they have the same resource cost driver, but in order to identify differences in activities performances and resources procurements cost driver may be different.

Once the dictionary is completed, the organization has to trace resources to activities. Because some resources are common to several activities and vice versa, surveys among employees can be a good way to identify which activity requires the most of resources. To get an overview of activities, managers have to associate attributes to activities: degree of short-term variability, links to operations, person in charge, distinction value- or non-value-adding etc. The most important and essential attribute is the activity-level we described above.

If the two first steps are sufficient for operations and activities improvement, when activities and their costs had been defined, products, services and customers must be linked to them.

The goal of the final step is to set a cost driver for each activity which will measures the consumption by products of activities. As we explained, cost drivers are very important to identify improvements that could be done on products, processes or activities. Activities triggered by a same event can be associated with the same cost driver. We can sort cost drivers according to their types: transaction cost driver refers to a countable driver, duration to the time spent to perform the activity and intensity to the level of complexity of the activity.

In 2000, Lere (Lere 2000) shows that ABC can be a powerful tool for pricing. By using an example, he compares the uses of a traditional allocation and an ABC one. He focuses then on the influence of orders characteristics on the order products prices. He demonstrates that knowledge about batch-, product- and facility-level activities can help managers to identify potential improvements. For instance, the application case highlights how a reduction of the batch-size influences the price.

A new method called Time-Driven ABC (TDABC) (Kaplan and Anderson 2003) has been developed because some criticized several aspects of ABC systems:

- They require a lot of data and can be very expensive and difficult to maintain and update;
- Capacity on which cost drivers are based does not correspond to used capacity;
- Accuracy of cost drivers can be sometime subjective.

TDABC assumes that capacities, instead of being based on multiple units of measure are driven by the time capacity. In this way, if the performance of an activity varies from one time to the next, then the cost incurred varies too. The implementation of this method is far easier because all activities have the same cost driver. This kind of method is better in large or for multiple-location companies because of the high number of them that are common to several sites.

Since, ABC has been widely used to support different decisions. Pierce and Brown (Pierce and Brown 2006) made a state of the art of ABC. They interested themselves in what does make an ABC or a TA system a success or a failure. They gathered a lot of surveys and studies to support their analysis. The first statement is that both methods are used similarly but for different purposes – there are nineteen of them. Authors compute Kendall's Tau-b, a value to evaluate correlation between usage and success and it appears that ABC success perception is higher when used than TA.

Charles and Hansen (Charles and Hansen 2008b) raise the issue about the trust to give to one or another costing system. They also use game theory (GT) concepts as an *independent representation of the true product cost* to compare a TA system and an ABC one. GT can give an insight of what would be an accurate non-arbitrary cost sharing between products when a firm produces several products which imply overhead sharing. The core concept states that *any joint cost allocation scheme, therefore, should be designed to render unprofitable suboptimal decisions, on the divisional level, by either independent divisions or any potential subcoalitions of divisions* (Hamlen, Hamlen, and Tschirhart 1977). They consider the problem of the allocation of overhead only: in other words, all levels of activities except unit-level activities. Charles and Hansen prove that contrary to TA, ABC assignments are always imputations – all amount of expenses are allocated – and members of the core – cost allocated to a product is less or equal to the cost incurred to produce it alone. They introduce a threshold value of product diversity which enables to know if TA assignments satisfy imputations and core conditions or not.

II. ABC and sawmills

II.1. Application of ABC to divergent processes

Not a lot of application of ABC to joint production has been made. Hartley (Hartley 1971) demonstrates that joint production processes raise some issues in the supply chain management. He presents a linear programming model divided into five cases whose the objective is to decide which quantity of each co-product has to be sold just after the divergent process or further processed beyond the divergent process. From one to the other he adds a new constraint, first on capacity, then on demand, on the proportion of each co-products obtained at the split point and finally on the possibility to recycling the waste of one of the final process as input for the first one. The author demonstrates that it is not necessary to know contribution on profit of a single product.

Based on this work and those of Turney (Turney 2005), Brimson (Brimson 1997), Cooper and Kaplan, Tsai (Tsai 1996) adapts ABC for joint production processes. Cost objects can be matched with final products in traditional manufacturing production because the final product is an assembly of several others (Boisvert 1998). In a divergent production line, because once obtained at the split point co-products can be processed in various processes – an input and a recipe – those processes will take part in the method. Instead of tracing resources to activities and then activities to products, resources will be sorted according to their relation to processes. Direct resources – those used for production like labor, material, machine hours – will be allocated to processes whereas indirect resources – related to support operation like scheduling, moving material or setup – will be associated with activities. Processes will use direct resources and trigger activities. The allocation of direct resources and activities costs of a process will be shared by outputs arbitrarily, using volume, weight or another factor of repartition. Like Hartley, Tsai considers that co-products can be sold just after the split point or processed further. The Figure 5 sums up the concept of the method.

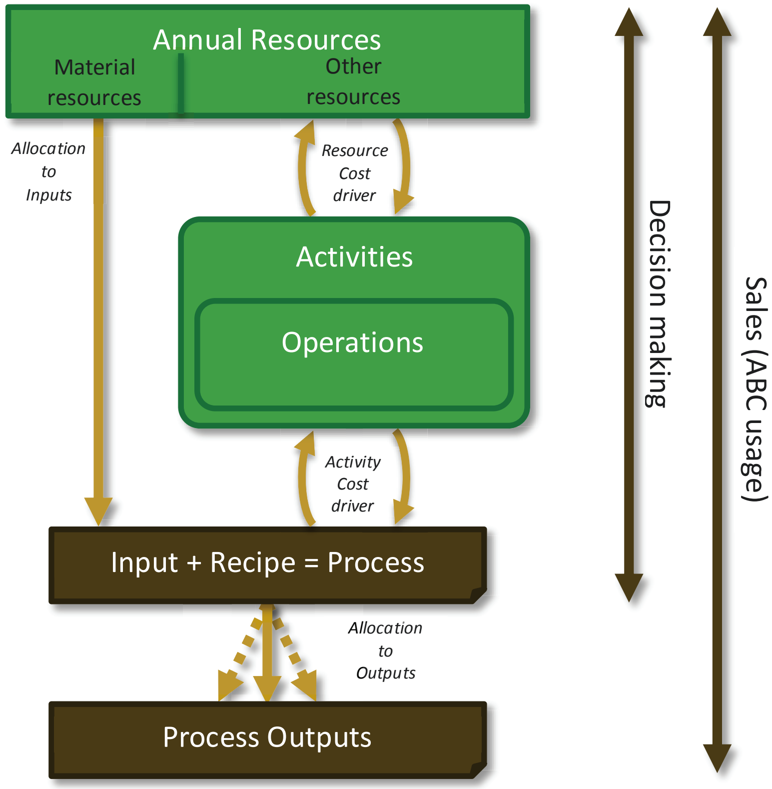

Figure 5 ABC applied to divergent production

In 2007, Tsai (Tsai and Lai 2007) further extends the method to integrate it into a mixed-integer programming decision model which determines the use of extra capacity and to investigate outsourcing opportunities at the strategic level. As Hartley, Tsai concludes that it is not relevant and not necessary to allocate costs of a process to its outputs to take that kind of decisions. He introduces the different levels of activities detailed above with the exception of the facility-level activities which will be divided into process-level activities – a fixed cost step-wise function for a given process that varies with the number of machine hours – and facilities-level activities the remaining common fixed cost habitually defined. As for process-level activities, outsourcing opportunities are modeled by a stepwise function which varies with the outsourced quantity. Labor, related to unit-level activities, is considered linear. Beyond a given number of hours, night shifts or overtime are necessary which lead to a variation of slope in the labor cost function. Thanks to a numerical example, Tsai show how these parameters can influence the product-mix and the profit. First, he computes the solution obtained by considering only the available capacity. Second, he adds the expansion capacity variables and finally the outsourcing opportunities. Most profitable situation is of course the one which offers more opportunities, the third one. As a conclusion, Tsai explains that this kind of decisions must be taken only with an as accurate accounting method as ABC with a special attention to the process-level activities the most important specificity of a divergent production system.

Same year, Tsai (Tsai, Lai, and Chang 2007) introduced an algorithm to solve a mix-product problem following the theory of constraint (TOC). This method was developed by Goldratt during the 1990's (Goldratt 1990). It assesses that only variable resources – material resources essentially, which purely vary with the quantity of processed unit – can be considered as relevant for supply chain management. Labor or overhead are assumed to be sunk costs. The TOC is a method which aims at maximizing throughputs under the constraints of bottlenecks of the firm. A five-step protocol (Goldratt 2008) (p.307) is stated:

1. Identify the production system's constraint(s).
2. Decide how to exploit the system's constraint(s).
3. Subordinate everything else to the above decision.
4. Elevate the system's constraint(s).
5. If, in the previous steps, a constraint has been broken, go back to Step 1.

To enlarge the method to divergent production systems, Tsai considers resources priority ratio which lead to build a sequential approach of bottlenecks analysis to reach optimal product-mix. By using a numerical example, Tsai shows that a LP model gives the same – optimal – solution.

Based on the 2007 papers (Tsai, Lai, and Chang 2007; Tsai and Lai 2007), Tsai (Tsai et al. 2008) presents three other mixed integer programming models based on the TOC, on ABC and on ABC with consideration of discretionary and non-discretionary capacities. Same as in the previous article, facility- and product-level activities have been removed to the benefit of process-level activities. The three models have a common part in the objective function and in the constraints at the difference that for the TOC one, constraints on process- and batch-level activities do not appear because cost related to those activities are considered as fixed, in other words already incurred. If the TOC model can be compared to a management system in which decision makers have a total lack of control over labor, with an ABC one in contrast, they have a complete control over it. To qualify it, the third model introduces new variables and parameters in the model to force the model to use at least a given part of the capacity – a balanced control over labor – while giving the opportunity to raise it at the three levels of activities. The conclusion drawn is that TOC model is better for short term decisions, when resources have already been acquired because it enables to obtain the higher profit. ABC is so better for long-term decisions, when resource has to be determined. Kee and Schmidt (Kee and Schmidt

2000) come to the same conclusion with the comparison of these three models applied to a manufacturing industry.

In order to catch influence of price and demand variations, Tsai enhanced his model (Tsai et al. 2009). As for the previous paper, he introduces three models which are TOC, ABC and ABC with control power on resources. The article presents the three stages of the analysis. First, the optimal product-mix is determined, same way as the 2008 article (Tsai et al. 2008). Then the model is solved again but with the addition of a new product. In the last part, and under some assumptions – for example, the competitor's prices do not change – new product price is lower and demanded quantity is increased according to an arc elasticity of demand equation. This equation is driven by a parameter which translates the influence of the variation of one of the value on the other. Authors conclude that depending of the potential increase of the demand, profit will not necessarily increase.

II.2. Application of ABC to sawmilling industries

If ABC has been widely applied to manufacturing industries, we saw in the above section that adaptation to divergent production was less common. Nevertheless, some researcher developed methods for the sawmilling industry. One of the first paper written on this field is from Wessels and Vermaas (Wessels and Vermaas 1998). The method is based on production operations more than activities. Each operation can be seen as a unit-level activity for which a cost driver is defined. Rather than introducing activities to allocate indirect overheads from services departments, authors use the reciprocal allocation method to share their costs between production centers. Production centers costs are then associated to operations. Cost drivers are chosen in order to catch specificities of the operation. The cost of some of them are also split into several parts and allocated to products according different cost-drivers. To face with the sawing process divergence, a simulation software is used to determine the sawing patterns from which principal products are obtained. Products are then aggregated in different classes depending on their section and their length. Two lengths classes are defined to simplify the problem and logs costs are allocated to their products according to volume proportion. Due to log and products heterogeneity, ABC implementation and sustaining are very expensive and time-consuming.

Because of the necessity to be able to trace products all along the production line, Rappold (Rappold 2006) developed a discrete event simulation model to analyze impacts of ABC compared with TA. The author begins with the assumption that raw material costs represent between two-thirds and threequarters of total expenses of sawmills. Contrary to Wessels and Vermaas (1998), Rappold focuses his study on debarking and sawing processes but at a very high detailed level. Different kind of saws – headrig, edger, trimmer etc. – are modeled. Direct costs consist only in direct labor and raw materials costs. Direct labor costs of a given operator for a given machine center are allocated to a product according to the volume processed proportion. Same way, raw material costs are traced from a log to its products thanks to the volume proportion. Overheads are shared according to global volume proportion. The TA method proposed is quite the same at the difference that allocations are done at an aggregated level. Total cost of a given operator is incurred to a product depending on the total volume proportion. Raw materials are not allocated to products function of the link between a log and its products: the total raw material cost is incurred to products according to the volume proportion. As a conclusion, the author states that under TA high grade products profit is overestimated and low grade products profit is underestimated. Because it is very hard and expensive to trace products to log, a third approach for raw material costs allocation is introduced called lumber yield method. The goal of this method is to estimate products volumes obtained from a given class of log. The method to estimate yields is described in Mayer and Wiedenbeck works (Mayer and Wiedenbeck 2005). Moreover, thanks to the simulation model, Rappold identifies that under ABC, log grade has a significant impact on the products costs for a large volume production sawmill whereas log diameter is the factor which influences the most the production cost in a medium volume production sawmill.

Since 2009, two very detailed studies about application of ABC for the forest industry have been published. The first one, by Nurminen (Nurminen, Korpunen, and Uusitalo 2009), is for harvesting cut-to-length timber harvesting and trucking. Each operation is disaggregated into several steps characterized by a resource consumption ratio. Two main activities are defined which are on the one hand Cutting and Forest Transport and on the other hand Trucking. The cutting cost for instance, is function of travelling time within a stand, positioning-cut time, felling time, delimbing and cross-cutting time etc. Each cost represents a portion of the total capacity cost enable for a given activity which includes all resources needed to perform this activity. Most variables and parameters are calculated from model functions. One of the parameters is very interesting: authors introduce a gross-effective time coefficient which increases the effective time by a few percent to take into account delays or idle time and to be this way in accordance with long productivity levels.

A part of the paper is dedicated to a numerical example of an application to the ABC method at stake. Some operation times are defined by model equations which depend on other variables. For instance, time consumption for delimbing and cross-cutting is a linear function of the log volume. Results show how timber or pulp assortments consume resources very differently because of operation time and trucking distances they require.

The discussion section raises a very important question which is not at stake in all other articles though it is an issue intrinsically linked to every divergent process. "*Since they are from the same* [input]*, should all of* [outputs] *have the same costs since the whole input is utilized anyway?* […] *It seems clear that if an* [output] *has unique special characteristics that are found only in small quantities of* [input]*, it is right to allocate all costs to that product".* The problem is actually not to compute the costs incurred to realize a divergent process, the question is to know which part of this cost will be allocated to each product jointly obtained.

The second article written by Korpunen et al. (Korpunen, Mochan, and Uusitalo 2010) is the most relevant to the present study because it focuses on the application of an ABC in a sawmill. According to the authors, an ABC system has to meet four conditions to be considered efficient. The first, technical soundness, is related to the degree of reliability of the ABC results. It insures that resources are correctly linked to the products, in other word that cost drivers and their measurement are well designed. The second, management usefulness, is to be sure that the system can support supply chain management with relevant information. The third, behavior acceptability, is about the necessity to involve employees to contribute to the improvement of the system. The last one, economic feasibility, deals with the necessity to implement a system which is profitable: it must not cost more than it enables to save.

The proposed ABC method is based on Kaplan and Anderson's work (Kaplan and Anderson 2003) on TDABC which aims at using only time-based cost drivers. This way, resources capacities are all viewed as temporal availability. To build their demonstration, they use a virtual sawmill which we will use for the current study. The large-scale sawmill described is very similar to those found in Finland. The sawmill is composed by eight departments which are: Log reception and pre-sorting; Debarking; Sawing; Green sorting; Drying; Quality sorting; Expedition and Chips and Sawdust processing. No distinction is made for unit-, batch- or other activity-levels. We can decompose the cost computation into three different steps. First step is dedicated to the computation of global annual cost of each resource common or not to several departments. Machinery or energy expenses are directly associated to the department they refer to and others are traced to operations according to a resource cost driver (Kaplan and Cooper 1998) like basal area, usage percentage or proportion of employee for ground constructions, loader and vehicles and administration staff and infrastructures respectively. Second step consists in defining cost drivers which can be viewed as the cost incurred to transform a single input into its outputs, in other words: processes. Except for the Expedition operation for which a volume cost driver had been chose, all cost drivers are based on time consumption in accordance with TDABC. The time spent to transform an input is determined by a dimension, the volume or other characteristics of the input. The third and last step is dedicated to the allocation of inputs costs on the outputs obtained from them. Two approaches are presented, the first one is the log view and consists in splitting the total log processing cost into its outputs on a volume base which leads to allocate cost of quality sorting operation to barks, chips and sawdust which is inaccurate. The second approach is more realistic and aims at allocating separately a volume based proportion of each process to the outputs. For instance, log sawing cost will be allocated to Sawdust, Chips and lumbers according to the volume of each obtained.

To illustrate the method, the authors give a numerical application. Reliable financial and technical data provided for this application case come from interviews of a Finland scots pine sawmill managers or official public market information. For comparison they apply a TA volume-based method for cost computation and it appears that because cost per cubic meter is the same for all the logs, any difference appear between log diameter or log length classes. To lay emphasis on the usefulness of ABC system, two sawing patterns set are presented and we also can see how the cost changes and we can conclude that longer and higher the diameter of the log is less the cost is.

II.3. Using ABC for supply chain management

If ABC has been used successfully for supporting supply chain management, it is only for the strategic and tactical levels. Indeed, when they provide data that are used as parameters in decisions support tools it is always for mid- or long-term horizon and mostly to determine the needed resource capacity and the product-mix. We will see that for operational level decisions, which correspond to a short-term horizon, costs have to be seen a very different way because they can severely distort the reality and lead to wrong decisions.

In the following section, we show that ABC can serve two different purposes to support the supply chain management: the production planning and the products valuation. In both cases the goal is to establish links between resources and products throughout the production operation. The first one requires to be able to know how much resources have to be incurred to produce a basket of outputs from a particular input according to a specific process whereas the second one is interested in knowing the amount of these resources that should be associated with each of these outputs. The connection between the two of them is the production planning which brings in itself a high level of complexity, especially in the context of the divergent production in the sawmilling industry.

Paper

I. Abstracts

I.1. Abstract

ABC has been widely applied to manufacturing industries. Nevertheless, its extension to joint-production companies is much rarer and do not serve operational level supply chain management. Purpose of the current study is to investigate how ABC can be applied to support decision making in a North-American sawmill. Two specific uses of ABC are distinguished. On the one hand, it enables the production costs computation which are the most relevant parameters to support the supply chain planning at the operational level. A mixed integer programming mathematical model fed by these costs and its dedicated resolution method are presented to establish an operational production planning. On the other hand, the focus is on the computation of the products pricing costs used for the only purpose of sales.

I.2. Résumé

La CPA a été largement appliquée aux industries manufacturières. Cependant, son extension aux industries mettant en œuvre des processus divergents est beaucoup plus rare et elle n'est pas utilisée pour la prise de décisions concernant la planification de la chaine d'approvisionnement au niveau opérationnel. La présente étude a pour but de voir dans quelles mesures la CPA peut être appliquée pour supporter la prise de décision dans une scierie nord-américaine. Deux utilisations distinctes de la CPA sont présentées. En premier lieu, elle permet le calcul des coûts de production qui sont les paramètres les plus pertinents pour supporter la planification de la chaine d'approvisionnement au niveau opérationnel. Un modèle mathématique basé sur la programmation en nombres entiers utilisant ces coûts de production et sa méthode de résolution particulière sont présentés pour dresser un plan de production de niveau opérationnel. Une seconde utilisation de la CPA est également étudiée et porte sur le calcul des coûts des produits qui permettent la valorisation de ces-derniers dans le cadre spécifique de la vente.

II. Introduction

In an economical context which is competitive and global, the management of the value chain of a company must lead to maximize the value added creation for customers. Research of efficiency and productivity implies a good knowledge of the relevant costs.

The use of the costs from financial accounting systems – known as general or traditional accounting (TA) – for decision-making in value chain optimization involves several risks and disadvantages. In particular, general costs allocation mechanisms from general accounting prove to be unsuitable to set the unit costs needed for decision-making (Kaplan and Cooper 1987).

Nowadays, one of the most pioneering method which enables to compute the production costs of all the outputs of a company is probably the activity-based costing (ABC). It links the fabrication operation specifications of an operation input to the expenses involved to carry out this operation. It enables to know accurately what amount of resources must be committed to obtain a set of both coproducts and byproducts.

This study focuses on the relevancy of production costs computed from an ABC to support supply chain planning in the specific context of divergent production line in the sawmilling industry. We are interested in determining a long term aggregated operational production plan. Indeed, costs from ABC are based on resources subject or not to capacities, mostly acquired for a middle or long term horizon (Kaplan and Cooper 1991). Numerous planning models have been developed for different supply chain management systems (Carlsson et al. 2009) which are all based on cost data. In this paper, we propose our own production planning mathematical model and its solving method.

This paper starts by presenting, the sawmilling industry and the different issues related to the use of costs in supply chain planning particularly in North America, based on the relevant literature. We will demonstrate why traditional accounting may provide inadequate information to managers and how an ABC system can help to solve most of the issues. Secondly, we present the methodology which aims at providing accurate and relevant cost information to support supply chain management. This methodology is based on the two uses of an ABC method: computation of production costs and pricing costs. We present the steps which have to be followed to adequately support supply chain decision-making process from strategic to operational level to produce and sell products in the context of divergent processes. Because the supply chain decision-making process implies the consideration of an important number of data and variables to establish a production planning, we introduce in a third section a tool based on a mathematical model resolution. We will review the different parameters taken into account, then the solution method as well as some details on the implementation. The fourth section will be dedicated to the presentation and discussion of an application case built on data from literature and industrial data.

III. Context

III.1. Application field

III.1.a. Sawmilling industry

Sawmills are nodes of the wood value chain. Part of the first transformation industry (D'Amours et al. 2006), it breaks down several species of logs harvested in the forest into its barks, chips, sawdust and numerous lumbers of different qualities and dimensions. Lumbers for building purposes or for further second transformation; chips for paper mills; and barks which do not represent any interest except for cogeneration or rare value added products, sawmills products serve a large panel of many and varied customers. If the goal has been to maximize the volume of lumber produced from forest logs in the past, today economic globalized environment forces companies to change this way of thinking. Customers' requirements are now more complex to fulfill. Companies also investigate more and more ways to move from a push production to a pull one by trying to set long-term agreements with their clients (Gaudreault et al., 2010).

The main issue sawmills are confronted with is that to obtained a demanded high value added product, a lot of byproducts and non-demanded products must be produced jointly because of divergent processes. From the debarking operation, barks and debarked logs are obtained and from a debarked log at the sawing operation, chips, sawdust and several lumbers are produced. The sawing operations characteristics are well described in the literature by Rappold 2006.

This raises numerous issues about costs computation – operational costs and their sharing among products –, in-progress products traceability – because of splitting points – or operations yielding optimization which complicate the production planning establishment.

III.1.b. Planning and scheduling operations

Run the company by making the best possible net operating margin is the goal we want to achieve here. A lot of supply chain planning decisions can impact this outcome. That is why we will focus only on the ones relating to the way resources are used to produce. Because planning and scheduling operations constitute a difficult task, three main paradigms have been developed to support their realization.

The first family is based on hierarchical production planning (Hax and Meal 1973) which structures the supply chain management in several levels of decisions: the product assignments to the supply chain plants; the planning operations and finally scheduling operations. Advanced planning and scheduling (APS) (Stadtler 2005) systems aim at solving the problem hierarchically and sequentially by disaggregating the decision-making process into several steps on long-, mid- and short-term horizon. Each upstream module takes a set of decisions which constraints the downstream ones.

The second one is referring to agent-based systems. Each agent is given a task to contribute to the achievement of a global purpose which means that they take their own decisions independently but by taking into account others' requirements (Frayret et al., 2008). For application to sawmills, readers can refer to Frayret et al., 2008 and Gaudreault et al., 2010.

The tool we present here is part of the last third family whose the goal is to generate the production planning and the scheduling at the same time by solving the whole problem formulated as a Mixed Integer Programming or a Constraint programming model (Gaudreault et al., 2011).

III.2. From traditional accounting to ABC

III.2.a. Shortcomings of traditional accounting methods

During the late 1980's, it has been demonstrated that traditional financial accounting methods could lead to wrong decisions (Kaplan and Cooper 1987). Both full- and variable-costs systems fail to provide valuable information on a product cost.

In a variable-costs system, like marginal costing, only variable costs are assumed relevant for costing. There are two main reasons which explain the inaccuracy of this kind of method. The first one is the assumption that decisions are made on short-time horizon, whereas most of products decisions have implications on long-term horizon. The second reason is the increasing amount of fixed-costs in factories: in a fully automated production line, fixed costs are higher than variable resources like material, energy or manual operations. Those accounting systems were justified in a context of low-competition and stable market for companies with a large part of manual-production lines because resources associated with a cost center like service, maintenance or production departments are shared by products only function of direct labor hours. Unfortunately, most of the time costs do not raise proportionally to the quantity of product but with the complexity or the diversity of them. In this way, high-volume products appear more expensive to produce than low-volume products.

All of these statements remain true in the lumber industry in which data are very hard to collect, mostly because of heterogeneous materials and products and divergent processes. Nowadays, companies can improve their production due to computer databases. However, costs calculation is still very basic. Sawmills in North-America are often sixty years old that have produced according to a push production flow. In the 80's, a method is proposed to set a cost on products according to the volume proportion (White 1980). Production cost is so obtained by dividing the total amount of expenses – from which the log cost is subtracted – by the annual volume of lumbers produced. This way any distinction can be made between products because cost is the same for all products. In the best case, financial budget is established for each operation or at least for each production department – sawing, drying and finishing.

A more accurate method has been proposed in the early 1990's by Howard (1993) which takes into account variable and fixed costs incurred at each operation of the production line. Only variable costs are allocated to inputs at each operation according to the operation-time – function of a given dimension of the wood piece – or the volume – if the operation time is impossible to determine for a piece of wood. While variable cost production per log is quite accurate, the part of the cost considered as fixed can be very large as Metzger (Metzger 1993) concluded after having compared fixed cost from TA to those from ABC on a given time horizon. In a sawmill in which machines are amortized such that the labor represents the largest part of the resources, the impact is not significant whereas in an automated recent sawmill fixed costs represent the most important part of the resources (Kaplan and Cooper 1987).

III.2.b. ABC applied to sawmilling industry

Not a lot of application of ABC to joint production has been made. One of the first one is Hartley (Hartley 1971), who points out by using a linear programming model how coproduction make the supply chain planning in a divergent production line more complex. The objective is to determine if products are sold or if production continues beyond the split point. The author also demonstrates that it is not necessary to know contribution on profit of a single product. This issue is taken over by Tsai (Tsai 1996) who adds the costs parameters of an ABC method in the constraints of the mathematical model. Ten years later, Tsai (Tsai and Lai 2007; Tsai et al. 2008; Tsai et al. 2009) extends his study to issues of outsourcing; control on resources and price and demand variations.

Studies that are specifically dedicated to apply ABC to sawmilling industries are very rare and do not consider its integration to the supply chain management. The main purpose considered is the way to allocate resources associated with operations to processes or products. Wessels and Vermaas (Wessels and Vermaas 1998) developed a method for a sawmill whose the considered operations are the logyard storage, sawing, bundling for drying, kiln drying and quality sorting. The principle is similar to the one introduced by Howard (Howard 1993) in that the method is more based on production operations than activities. Contrary to Howard, Wessels and Vermaas share fixed costs between production centers which are associated to operations. In this case, an operation can be seen as a unit-level activity for which a cost driver is defined. A more detailed ABC method is proposed by (Korpunen, Mochan, and Uusitalo 2010). Once again, the ABC method is based only on sawmill operations but the computation is more detailed.

None of these studies focuses on analyzing the impact of the inputs ABC costs allocation to final products nor the use of ABC costs for planning and scheduling.

IV. Methodology

IV.1. ABC basics

Through the literature review, we can assume that for joint production, ABC methods can be classified in two categories. The first category is more suitable for feeding supply chain planning support tools related to strategic and tactical decisions like product mix, resource capacity determination or outsourcing evaluation. These kinds of methods has been developed by Hartley (Hartley 1971) then Tsai (Tsai 1996; Tsai et al. 2008) and serve the production cost determination: in other words, the way resources are committed in the production. Any allocation to products is necessary. We will refer to this kind of method by ABC.

Methods of the second category have been developed to be used in deterministic context for pricing cost computation. The goal is to allocate all the resources to the company's outputs to compute the margins – the difference between the income and the resources allocated to the product. The resources sizing is not at stake here because the method is applied to draw up a report on a past production period. The goal is to trace resources to products rather than understand how these resources are used. Let us call this method report ABC (RABC).

In this paper we will use both methods. The first one will be adapted to provide useful information for a multi-periods production planning which will be close to an operational one. The second method would be applied once the production plan had been established to determine costs of products at each period of the plan.

IV.2. Analytics and supply chain planning

An ABC system is always unique and closely linked to the structure of a firm. That is why an analysis of the firm and its environment must be done to understand its mechanism, its policies, the market and its range of actions.

IV.2.a. Demand and supply

In North America, it is possible to distinguish two kinds of sawmills. Sawmills which are a member of a larger company and independent sawmills.

For the first category, sawmill's suppliers and customers may be the upstream and the downstream unit respectively in the value chain. Demand and supply – or just one of them – are so driven by the company's interests and value-added outputs are so not especially the sawmill ones. That is why decisions to fulfill or not a demand is not at stake if the sawmill's output consumer is a second transformation firm of the company. Same way, supply and harvesting planning are set simultaneously in accordance with sawmill's needs and forest opportunities if the harvester is the upstream member of the company's network. In those contexts, when a company do not use any appropriate management accounting method, a major difficulty is to evaluate the value of products that are virtually bought or sell to the other members.

If the sawmill is an independent entity, its own interest has to be considered. Methods to plan supply and demand differ between companies but each of them have to integrate important degree of uncertainty and variation. Demand forecasts are so often done manually every month and periodically revised, based on manager's experience, market surveys or historical data. To guarantee a sufficient level of raw materials all over the year, and because forest is not an infinite resource – log mix is not always optimal – sawmills try to establish long-term contracts with their suppliers (Gaudreault et al. 2010).

IV.2.b. Sawmill features

Sawmilling context is very specific and difficult to model for several reason. The first one is the inputs heterogeneity: if all of the products almost follow the same path in the production chain, because of the joint production most of them are obtained from a different log. Because of nods positions and defects, two identical logs compared with species and external dimension will be sawed according to different sawing patterns and lumbers obtained will be given different quality grade and length combinations (Wéry et al. 2012a). Thanks to technology and field expertise, we are even though able to sort log and accurately associate sawing patterns with logs.

The second reason is the production time variability among processes on the one hand and for a given recipe at a given process through the year on the other hand especially in North America. For instance, drying time – from three to seven days in a kiln – is about 7000 times as higher as sawing time – of the order of few minutes. Added to this, because of outside temperature variation and the high humidity rate of wood, some of process times evolve consistently throughout the year. Balance the production line is so a daily challenge.

The third reason is in relation with the previous one and contribute to the balancing of the production line. Indeed, contrary to the others, lumbers are dried by batch. A buffer stock is so necessary upstream the drying operation. Specificities of this operation will be described further. Even if other operations can transform inputs one by one, managers have to deal with the machines setups because of specific tools, adjustments or cleanings needed when inputs characteristics change.

IV.3. Decision levels

IV.3.a. Strategic and tactical decisions

In this section we will not try to draw an exhaustive list of decisions that can be made by managers. Moreover, each sawmill has its own situation, interests and policies so a decision is good only in a particular context. Strategic decisions can be seen as long term decisions. In this article we focus on the links that can be traced between those decisions and costs or prices. Decisions related to the resources management, storage policies or customers prioritization for example can be taken into account when price and cost setting and analysis are made. The challenge is to catch manager's unquantifiable directives like risk or preferences. For instance, if two products are sold at the same price, and produced the same way at the same cost, we can differentiate them by adjusting their cost.

IV.3.b. Operational decisions

Operational decisions refer to short term horizon. Through this study it will concerns decisions taken to build a production planning. We can sum it up with the question: what will we produce, when, how much, from which input to meet which customer's need? All the decisions will be taken in order to maximize the profit by satisfying capacities, which means that costs will be the main support for the production planning setting.

IV.4. Supply chain decision-making process

IV.4.a. Production costs

The most important step in the supply chain decision-making process is to determine production costs. Those costs have two main objectives that is why a cost can be broken down into two parts set independently. On the one hand, costs are the link between a resource and the quantifiable entity which consumes it. On the other hand, as we saw in the previous section, costs must be a mathematical translation of the manager's policies.

The first part is a non-zero value which is established thanks to a reliable managerial accounting method, like ABC in this study. This part of the cost is used by managers to discriminate the products relative to each other in order to make supply chain planning decisions. At this point, the goal is not to sell the product, the production cost must enable to know the fair amount of resources that have to be dedicated to obtain a given quantity of a given costs object. Especially in a joint production context, a capital point is that those costs cannot always be traced to final product. When an activity is triggered by a process, the associated production cost cannot be traced to the process outputs. Even for a non-divergent process, the allocation of facility-level activities costs to the product is impossible in a non-arbitrary way. They have to be considered as the amount incurred globally to obtain a set of products, no product can be assigned a particular contribution.

The second part of the cost is an optional value. Positive or negative, this weighting coefficient is set so that the cost object can appear more or less profitable to the mathematical model. The way to compute this weighting coefficient depends on the strategic decision we want to respect. The goal is not to force the model to produce a given product because in this case, the lower bound of the demand constraint just has to be equal to the demand instead of zero. The goal is more to guide the model for him to take decisions that are not financial. For example, a reducer coefficient can be used to constraint the model to perform an activity to produce a flagship which is actually not a profitable product but which enables the sawmill to enter a new market. It can also be a product whose production has to stop because of environmental, political or social decisions. As Goldratt (Goldratt 2008) explains very well, the ultimate goal is always to make money, that is why a lot of decisions has to be translated in term of costs.

IV.4.b. Decision-making process

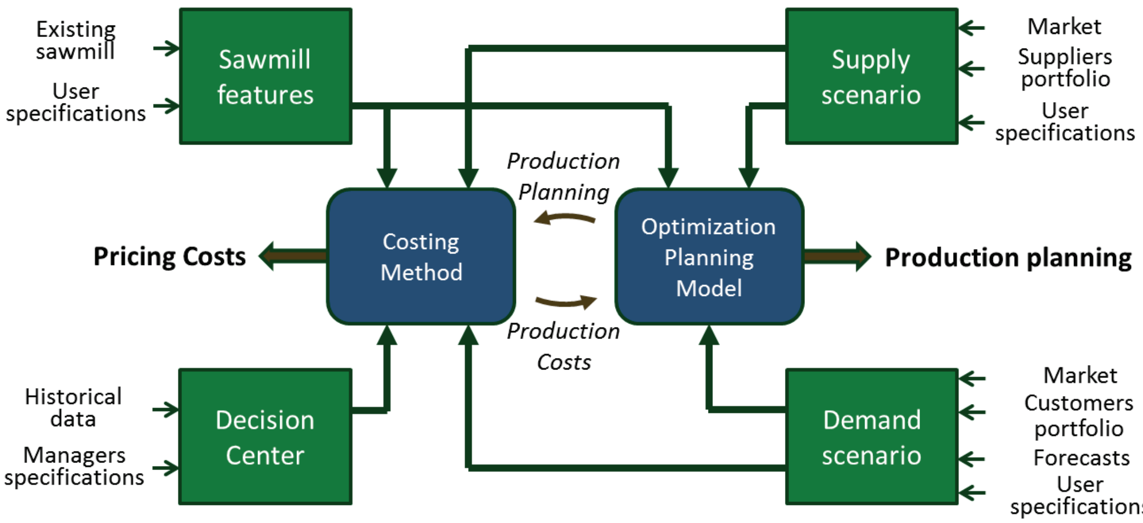

Figure 6 Decision-making process

Figure 6 is a model of the supply chain decision-making process structure. Each block is totally independent but a modification made on one of them has an impact on all the others. Both the decision center and the set of sawmill features are on the base of the structure. Indeed, costing method must provide a set of parameters which are reflect the resource consumption – thanks to the ABC – and managers' policies and tactical or strategic decisions. Those costs will be used to link customers demand to supplier's raw materials use. Adding to the sawmill features which provide data on processes like availability, capacities or operational times, they will provide relevant information to an optimization planning tool to determine an operational production planning. Once this one will have been performed and knowing raw material price, we will be able to allocate the part of production costs computed from ABC to the different products to compute margin and trade products: the pricing costs.

IV.4.c. Pricing costs

There is a second purpose for which costs are needed: product pricing. The purpose of this article is not to propose a method to solve this very particular financial issue, we just present the outlines that have to be respected. Our goal is to focus on the main differences between the production cost and the pricing cost.

IV.4.c.i. Concept

If the production cost can be useful for managers to *evaluate* the margin that can be made on a product, it cannot be used by sellers to *compute* the margin made at the sale. A production cost pulls a resource in the sense that more an activity is performed more the amount of resource raises. A pricing cost in contrast can be viewed as a push flow from a resource to a product because the goal is to allocate the whole amount of resources incurred in the production planning application. Those costs have for principal characteristic to not be unique and a given product pricing cost is intrinsically dependent of all the others.

There is no obvious method which enables to determine what cost part has to be allocated to a product or another. Typically, volume, weight, commercial value or any arbitrary proportional coefficient is used to share those untraceable costs. But this subjectivity can be source of misunderstandings. In a more practical expression, it is not possible to know how much a given product costs, we just know how much it has to be spent to obtain it. There is no objective way to set a product cost to 2$, the only thing known is that it has to be spent 10,000$ to obtain it. Give this product for free is possible as far as all of its co-products are sold for at least 10,000$.

Whatever the allocation chosen, it is strongly linked to the interests of the decision maker. If a social or environmental criterion is at stake instead of an economic one as we consider here, the rules will change to be in accordance with the sharing fairness.

IV.4.c.ii. Sharing rule example

As an example to illustrate the concept of pricing cost, let us consider a sharing to set the pricing cost according to the revenue in order to support sales decisions after the end of the budget and planning horizon. To be acceptable – right to the eyes of the seller and his client – the allocation should be done throughout the production for each activity performed: the resources committed to transform an input into a set of outputs thanks to each activity has to be shared by all the outputs considering three rules:

- A product must not incur a cost which it is not responsible for;
- A product must not incur an amount of costs higher than the revenue it generate;
- A set of coproducts must incur all the expenses associated with their creation.

The first step to compute pricing costs in this case is to apply the RABC. The RABC allocation structure is the same as the ABC system because we keep the links between resources, activities and inputs. The first levels of allocation are identical: we use the same resource cost drivers to trace resources to activities. The only change is for activity cost drivers which are conserved but updated to include unused resource capacities.

However, we are facing with two important issues for the next step. On the one hand, a batch-, product- or facility-level activity cost has to be shared by products in the batch, all the concerned products or by all the products of the facility respectively. On the other hand, the cost allocated to an input – a process – must be divided between the outputs. Consequently, even if the divergent process production cost allocated to an output is 0 – the cost is supported by the other coproducts and byproducts obtained from this process – if the cost of operations realized on this output to obtain a product beyond the split point are higher than the revenue then the margin – revenue minus the costs – for this product will be negative.

IV.4.c.iii. Unprofitable operations identification

This last point rises the issue of the identification by the model of the unprofitable operations. A model as the one we use does not enable to identify if a part of the production line is not profitable. Indeed, without RIVs, the model is looking for a solution which is globally profitable which means that when a basket of final products is obtained, it is the global revenue regarding the global production cost which is used to evaluate if these products are produced or not. This concept of sharing can also be transposed to the share of an activity subject to resources capacity between its processes: activity cost drivers of these activities are not used anymore: each process take a part of the resources function of its ability to generate a revenue.

V. Production planning tool

V.1. Mathematical model

V.1.a. Mathematical model overview

The mathematical model defined in this section, is based on the one presented by Jerbi et al. (Jerbi et al. 2012) whose the goal is to determine a multi-periods operational production planning by maximizing the company's profit under a set of flow and capacity constraints. The objective function is composed by the sum of all the sales revenues generated by the quantity of product p sold by business unit u at period t from which the sum of all the costs is subtracted. Costs linked to the quantity of process w performed in business unit u and ending at period t and those linked to the flow of product p on link e period t – like handling or transportation. Parameters of the objective function and constraints are described in the Table 1.

$$\underset{D_{tup},Y_{tuw},F_{tep}}{maximize}\left(\sum_{t\in T}\left(\sum_{u\in U}\left(\sum_{p\in P|d_{tup}>0}\rho_{tup}.D_{tup}-\sum_{w\in W_{tu}}c_{tw}.Y_{tuw}\right)-\sum_{e\in E}\left(\sum_{p\in P}c_{tep}^{f}.F_{tep}\right)\right)\right) \quad \textbf{(1)}$$

T	: Number of periods.
U	: The set of business units.
K	: The set of types of capacity (machine capacity, limits of stocks).
W	: The set of processes (machines, inventories).
$W_{tu} \subset W$	: The set of processes that can be performed in business unit u at period t.
P	: The set of products.
E	: The set of links between business units.
$\delta_u^+ \subset E$	: The set of incoming links.
$\delta_u^- \subset E$	: The set of outgoing links.
q_{tku}	: Capacity of type $k \in K$ of the business unit u at period t. (k is always time in this model)
f_{tep}^l	: Minimal flow of product p passing through the link e at period t.
f_{tep}^u	: Maximal flow of product p passing through the link e at period t.
f_{et}^u	: Maximal flow of all products p passing through the link e at period t.
c_{tw}	: Cost of process w if begins at period t.
c_{tep}^f	: Transportation cost of product p on the link e at period t.
l_{tep}	: Delay of transportation of product p on the link e at period t.
s_{tw}^r	: Delay of production of product p at period t.
s_{tw}	: Delay of production of product p period t round up to the number of period if higher than a period.
α_{pw}	: Quantity of product p required by the process w.
γ_{pw}	: Quantity of product p made by the process w.
λ_{kuw}	: Quantity of units of capacity type $k \in K$ of the business unit u consumed by the process w.
d_{tup}	: Demand for product p at business unit u at period t.
ρ_{tup}	: Sale value of product p at business unit u at period t.
β_{tup}	: External supply of product p at business unit u at period t.

Table 1 Mathematical Model parameters

V.1.b. Constraints definition

First, a set of flow constraints insures processes working. Each of them defines for each of the processes at every period of the time horizon in what proportion material are bought, sold, consumed, produced, shipped or received from or to upstream or downstream processes respectively. If most of the processes involve continuous variables, some of them, like drying, are defined by integer variables. The following equations are so introduced:

$$\beta_{tup} - D_{tup} - \sum_{w \in W_{tu}} \alpha_{pw}.Y_{tuw} + \sum_{t_1 \in T}\left(\sum_{w \in W_{tu} | t_1 + s_{tw} = t} \gamma_{pw}.Y_{t_1uw}\right) + \sum_{e \in \delta_u^+}\left(\sum_{t_2 \in T | t_2 + l_{et_2p} = t} F_{t_2ep}\right) - \sum_{e \in \delta_u^-} F_{tep} = 0, \forall t \in T, u \in U, p \in P. \quad (2)$$

$$D_{tup} \leq d_{tup}, \forall t \in T, u \in U, p \in P. \quad (3)$$

Other constraints limit the way materials or products can move from a process to another or to a storage location at each period. Because of handling technologies, quantities and moving times are defined for each material or product that can move from a location to another. It is possible to set an inferior and a superior quantity limit for each product in addition to a maximal global quantity limit on the total quantity transported from a location to another. This is modeled by the following equations:

$$\sum_{p \in P} F_{tep} \leq f_{te}^u, \forall t \in T, e \in E \quad (4)$$

$$f_{tep}^l \leq F_{tep} \leq f_{tep}^u, \forall t \in T, e \in E, p \in P \quad (5)$$

Second, because time and resources are limited, capacity constraints insure that the use of processes does not exceed the period duration or the resource availability which can be a volume or a number of pieces or batches. These processed quantities are modeled by continuous or integer decision variables. To avoid symmetries issues, we use tow strategies to model multiple units operations, like kiln drying. The first one is the addition of a priority rule constraint which prevent the use of a process if the previous one is not available. In this case the following equation must be used:

$$\sum_{t_1 \in T}\left(\sum_{w \in W_{t_1u_{n+1}} | s_{wt_1}^r \geq 1} q_{t_1ku_{n+1}}.Y_{t_1u_{n+1}w}\right) + \sum_{w \in W_{tu_{n+1}} | s_{wt}^r < 1} \lambda_{ku_{n+1}w}.Y_{tu_{n+1}w} - \sum_{t_1 \in T}\left(\sum_{w \in W_{t_1u_n} \left| \substack{t_1 + s_{t_1w} > t \\ t_1 < t \\ u_n = u_{n+1}} \right.} q_{t_1ku_n}.Y_{t_1u_nw}\right) - \sum_{w \in W_{tu_n} \left| \substack{s_w < 1 \\ u_n = u_{n+1}} \right.} \lambda_{ku_nw}.Y_{tu_nw} \leq 0 \forall t \in T, u \in U, k \in K, p \in P. \quad (6)$$

The second strategy consists in introducing a macro-operation whose capacity is equal to the sum of all the others. It is the second one we decided to implement. Usually, several products with the same sections but different lengths can be batched together. To simplify the problem we assume that at most one kind of product – same species, same section and same length – can be batched. These flow constraints are ruled by the following equation:

$$\sum_{t_1 \in T}\left(\sum_{w \in W_{t_1 u} \left| \substack{t_1 + s_{tw} > t \\ t_1 \le t \\ s^r_{wt_1} \ge 1} \right.} \lambda_{tku}.Y_{t_1 uw}\right) + \sum_{w \in W_{tu} | s^r_{wt} < 1} \lambda_{tku}.Y_{tuw} \le q_{tku}, \forall t \in T, u \in U, k \in K. \qquad \textbf{\textit{(7)}}$$

At last, a set of constraint imposes that variables remain positive all the time:

$$D, F, Y \ge 0 \qquad \textbf{\textit{(8)}}$$

V.2. Parameters

Before mathematical model generation, the user has to define all of the parameters which will be integrated in the objective function and the constraints. As shown in Figure 6, sawmill features, demand and supply scenarios and decision center can be built on several sources.

V.2.a. Time horizon

The degree of accuracy of an operational production planning depends, among other, on the time horizon which can be described by two parameters. The first one is the number of days covered by the production planning. We will refer to it by the time horizon. The second parameter is the day subdivisions, which are called periods. Some of the process operation times, like drying duration, are higher than a period. For these, in order to simplify the model, we made the assumption that they were rounded up to the period time. The sharpness of the production planning will be consequently dependent of this subdivision.

V.2.b. Sawmill features

In a previous section, we pointed out the different challenging issues we are facing with sawmill modeling. In order to reach an acceptable level of flexibility and accuracy, we made some assumptions.

To take into account inputs heterogeneity, each operation is characterized, at each period by a set of processes. A process, defined independently for each of the input, is the combination of a production cost, an operation time and a list of outputs proportions which are obtained from this input.
All production costs and operation times are expressed in quantity unit – like volume or number of batches – and whatever the number of day subdivision, they can only change once a day. To overcome the lack of data, we introduced a functionality which enables to compute operation times and production costs for each days of the time horizon from monthly values. The method is based on Bouchard and Montreuil (Bouchard and Montreuil 2011) approach. It aims at smoothing the slope variation due to the monthly seasonal factor. Instead of having a gap from the last day of a month to the first of the following one, the seasonal factor evolves gradually and linearly during a given proportion of the beginning or the end of each month. It does not change the sum of daily values during the month but just their daily distribution.

V.2.c. Supply and demand scenarios

We saw that supply and demand policies were very different from a sawmill to another especially because of the sawmill position in the value chain. So we chose to design a very flexible model, to be able to model various scenarios. The supply scenario will be set up in the same manner as the operation time and the production costs. Meanwhile, the demand scenario can be generated based on four parameters: an annual trend which represents the global growth or decreasing of sawmill demand; a monthly seasonal factor to respect demand variation from a month to another; a daily seasonal factor because some days can be unworked or have a higher demand; a random daily variation to have a more realistic scenario.
Each raw material and each product will be defined by a daily supply and demand scenario respectively. The user can decide if the quantity available or demanded is divided up to each period or proposed as a whole at the beginning or at the end of a day respectively.
Because of joint production, some of the sawmill products are obtained in a very little quantity and it takes a long time to reach a sufficient stock level. If the product is rare, so is the demand and it may therefore occurred while the product is not available. To solve this problem, sawmills postpone the delivery of an order. We modeled it by a backorder. If a demand cannot be satisfied at the period it occurs, it will be sold when the product quantity will be available within a limited number of days. If not, the order is lost. The selling price will always be the lowest one of the period between the order day

and the selling day. If the price is already the lowest, a discount will be made on the initial price. No penalties occur if an order is not completed because the goal is to identify the most profitable products. Backorders must so be seen as a way to enable the model to not miss a sale opportunity.

V.3. Solution method

V.3.a. Issues and assumptions

The challenging issue of the sawmill ABC model is batch- and product-level activities which requires the use of binary or integer variables in the model which drastically complicates the solving. In our situation, these activities are linked to the operations themselves that is why it is inaccurate to approximate them by a linearization. To reach an acceptable level of realism, we limited the flexibility of the system by considering a given layout of the sawmill (Tsai and Lai 2007; Tsai et al. 2008) which leads to avoid most of this two kinds of activities.

The remaining problem is the drying operation which deals only with batches of a very high number of units – reader can refer to the below sections for further information about this operation. Two issues are raising: the very long operation time which covers several periods and the batches consideration. As explained before, the first one requires a high number of periods and the second the use of integer variables.

V.3.b. The 3-phase method

No commercial algorithm – Gurobi or Cplex – can find a satisfying solution in a reasonable time to the aforementioned model, considering that a one-month planning horizon is the shortest acceptable horizon considering the drying time of lumbers. To find an acceptable solution, we developed a heuristic which is divided into three steps as shown on the Figure 7.

The first step consists in solving the linear relaxation of the problem. All integer variables are relaxed which means that batch constraints are ignored. The optimal solution to this relaxation is reached in a few minutes and corresponds to the optimal supply plan. In this relaxed model, drying operation time is respected but the nature of batch processes is not.

In the second step, all the continuous variables upstream of the drying operation are fixed, but the integrality of the variables representing kiln drying batch decisions must be respected. This model is then solved with a mixed-integer programming solver, albeit with a time limit. Solving this sub-model takes significantly longer than solving the model used in step 1 – from some minutes to several hours.

The last step is to re-solve the original model while fixing the (integer) kiln drying decision variables to the values found in the solution from step 2. While the kilns are not required to be filled at maximum capacity, the batch constraints are respected. The solution obtained from this model is then returned to the user.

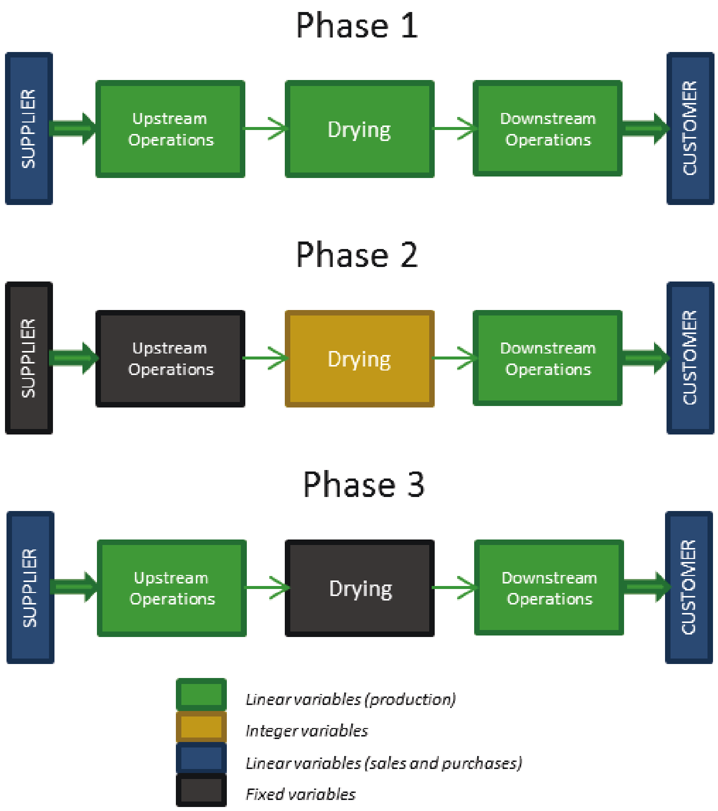

Figure 7 The 3-phases method

V.4. Implementation

To realize the aggregated operational production planning, we adapted the mathematical model embedded in the software platform LogiLab which enables to optimize a forest value-chain network from wood harvesting to customer by maximizing profit made on several periods at tactical level (Jerbi et al. 2012).

LogiLab had been created so that the user deals with a lot of flexibility for the conception and the use of the mathematical model. Initially, the software was created for tactical operation planning of a forest network in which a business unit is a forest, a papermill as well as a sawmill. Then, a period corresponded to a week for a total of fifty-two periods – a year. We can easily make an analogy with the forest network and the sawmill. This way an operation like debarking or sawing, can be considered as a business unit and an eight hours shift as a week.

VI. Application case

VI.1. Operations description

The sawmill modeled – illustrated by the Figure 8 – in this study is composed by several independents operations which transform a log brought to a supplier into barks, chips, sawdust and several dried lumbers sold to customers. This value chain can be divided into three main production units (Gaudreault et al. 2010) which are sawing, drying and finishing. In the current study, we subdivided the sawing operation into debarking, sawing and sorting operations. On the other hand, we did not consider the planing operation that can be integrated to finishing operations. Reader can refer to Korpunen (Korpunen, Mochan, and Uusitalo 2010) for other details on those assumptions.

We assume that each process is available 5 days per week and 8 hours per day. Because of its long operation times, the drying operation is working the whole week in continuous. We chose a planning time horizon of 6 months, from January to June with a day subdivision of 8 hours – whether 3 periods per day. The sawmill is designed to produce 270 000 cubic meters of lumbers in a year from 300 000 cubic meters of raw logs. Each working day, the raw material quantity which can be bought is available at the beginning of the day – during the first period – and the demanded lumbers and by-products quantity at the end of the day – on the third one. Each one of the 28 products, obtained from 16 different logs, is characterized by its own seasonal factors which make fluctuate simultaneously its price and the ordered quantity.

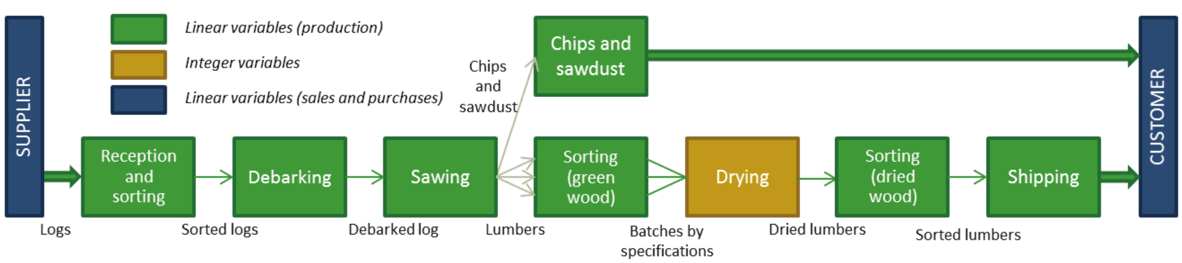

Figure 8 The sawmill operations

VI.1.a. From sorting to green sorting operation

The first unit begins with sorting logs from trucks according to their external dimensions – like diameter, length or taper – and their quality thanks to a visual or an x-ray scanning test. Suppliers offering volumes of raw materials, the decision variables of this operation are based on volumes. The operation time – from 13.7 to 24.0 seconds per cubic meters – depends on the log length only and does not change during the year.

Once sorted and stored in the logyard, the log is debarked. In accordance with the upstream operation, this one is also modeled by volume decisions variables. Because of the climate, operation times – from 17.2 to 30.0 seconds per cubic meters – are function of the length and the outside temperature. To simplify, we assume a linear process speed variation of twenty percent around its average value between the coldest and the hottest month. With the exception of a case, we do not consider the barks treatment further the debarking operation.

After being debarked, the log is sawn. Thanks to different technologies – like x-rays or acoustic testing – and products raw material requirements, the best sawing pattern is determined by an optimizer. Here again, we chose continuous volume decision variables. Operation times – from 20.5 to 36.2 seconds per cubic meters – variations are defined the same way as the debarking operation. Because a mathematical model optimization is based on deterministic parameters, each log is associated with a unique sawing pattern which states the proportion of each lumber and chips and sawdust obtained from it.

Chips and sawdust are conveyed to packaging space before being sold to customers. We assume that all logs give the same kind of chips and sawdust, no distinction is made between the species. The operation is designed to treat about 92 000 cubic meters of by-product which is equivalent to a 74.5 seconds per cubic meters operation time.

Before being batched and stored to wait for the drying, lumbers are sorted according to their dimensions – length and section – and their quality. Generally, lumbers can be trimmed if the end has defaults but in our case, a given input is always transformed into the same unique output and all inputs are processed in the same operation time. As for previous operations, volume decision variables are used and the operation time is 74.5 seconds per cubic meter.

VI.1.b. Drying operation

Drying operation is the most difficult to model. It consists in reducing the wood moisture rate to improve mechanical characteristics. In the reality, each batch is composed by different products with similar characteristics. We assume here that they are homogeneous to a unique product. Technologies are also highly variable, and several of those can be used together to dry a given batch. For example, most of the time the drying time in kiln is proportionally reduced function of the time that a batch spent outside for natural air drying. In our model, all the drying is made in kilns – tunnels and chamber technologies. This way, operation time is fixed for a given batch at a given day. As for Debarking and sawing operations, drying operation is highly dependent on the outside temperature. Operation time – from 40 to 116 hours per batch – can consequently double from December to July. As we mention in the previous sections, integer decisions variables are used to model this operation: each time, a given volume of product is required to launch a batch. If bundles dimensions and the number of bundles in a batch do not change from a product to another, the number, and so the volume, of product in a bundle – because of lumbers stacking – change.

VI.1.c. From quality sorting to packing

After a batch is took out from a kiln, bundles are destacked and each lumber is tested visually by an operator in addition to an optional x-ray scan and depending on customer requirement, a moisture rate or a bending mechanical test can be executed. As for green sorting operation, a lumber can be trimmed to obtain another required product. Quality sorting will be model the same way as green sorting.

Just after being sorted, lumbers are stacked and optionally wrapped according to customers' orders requirements. This volume-based operation is sized to process about 285 000 cubic meters of lumber which is equivalent to a 24.1 second per cubic meters.

VI.1.d. Storage

To give the model enough flexibility in its production strategy, we assume that infinite volumes of products can be stored between operations. In practice, it appears that the maximum stored volume between two operations is around three thousand cubic meters for all products, inputs or outputs.

VI.2. ABC method

VI.2.a. Methodology

VI.2.a.i. Components of an activity

As illustrated on Figure 5 activities represent the way resources are committed to enable production. An activity can be seen as the association of three elements. The first one is the function – expressed by a proposition starting with a verb in the infinitive – which is performed for a single unit, for a batch, for a process or for the entire sawmill. A batch-level activity is performed for a batch, whatever the number of units in the batch, a process-level activity is executed once whatever the number of time the process is executed and a facility-level activity is performed once for the entire firm during the time horizon. The second element is the resources cost drivers which enable to allocate resources to the activities. When several activities share the same resource, the resource cost driver is common to all these activities. The last element is the activity cost driver which define the resources consumption of a cost object – a product, a batch of products, a process or a facility – when an activity is performed. It is a rate which determines which amount of the activity resources is incurred to the cost object, function of one of this cost object specifications: the production cost.

VI.2.a.ii. Cost objects

In a traditional manufacturing process where the product is obtained from an assembly of several components, a unique output of an operation incurs alone its own costs. Consequently, it is possible to consider that the final product or service is the trigger of all the activities which contributed to its realization. On the other hand, when an activity is associated with a divergent process which implies the production of multiple outputs from a single input, this simplifying assumption is no longer valid. The cost object to consider is no longer the final output but the combination of an input and a recipe: the process itself (Tsai 1996) which can be different for each activity. The only situation in which the cost object and the output can be merged for a divergent process is when the outputs are taken as one: the products basket. The interest of doing so is very limited because this products basket input is often itself a component of another products basket.

VI.2.a.iii. Resources capacity

Most of the time, an activity is subject to a capacity because resources cannot be acquired proportionally of the use made of the activity. For example, if a worker is hired to perform an activity, whatever the level of this activity he will not execute it once, neither an infinite number of times. That is why when an activity is defined, so is its capacity (Kaplan and Cooper 1998:chap. 7). As described by Kaplan, Cooper and Goldratt (Kaplan and Cooper 1998:chap. 7; Goldratt 2008), a decrease in the demand must not be interpreted as a growth of the cost of the activity: once sized, the cost per activity cost driver unit is set and do not change with the use variation of the activity. A death spiral would occurs because more the cost rises, more the demand decreases and vice versa.

For instance, let us consider a batch-level activity which would be the set up of the sawing operation machine. The two resource cost drivers are the proportion of time spent by a worker to perform this activity on the one hand and the proportion of machine hours dedicated to this activity on the other hand. Those resource cost drivers are set at 75% for the worker and 20% for the machine hours. The activity cost driver is the setup time which is particular to each batch. Considering a worker paid 30$ per hour and a sawing machine which costs 60$ per hour, if the available capacity for the activity is 20 hours it represents an amount of 690$. The cost of performing a setup is so 34.5$ per hour that only 16 hours are used or 20.

VI.2.a.iv. Activity intensity levels

In some cases, for a given activity, two cost objects will consume the same amount of activity cost driver but one of them will do so at a higher level of complexity: an additional resource quantity will be required. One way to capture this discrimination among cost objects is to introduce different intensity levels in the activity (Kaplan and Cooper 1998:chap. 6). Each level is associated with its own activity cost driver value which is computed based on its amount of the activity resources and – if required – its amount of the activity capacity.

VI.2.b. Activities

VI.2.b.i. Assumptions

There is an infinity of ABC methods that can be implemented in a company. None is better than another, each of them corresponds to a vision of the company at the moment it has been developed and for a given purpose. Depend on the details level needed, the number of activities, resource sizing, activity or resources cost drivers will change. Because the main tool for which the ABC method is designed here is a mathematical model, which is deterministic, some concessions must be done. Recall some important assumptions:

- The sawmill is designed to produce a given maximum volume of products. Machineries, buildings, labor etc. have been sized. We do not consider the possibility to buy or sell a machine, neither hire or dismiss an employee;
- All activities are based on time or other dimensions which imply that if two cost objects trigger an activity by consuming the same quantity of activity cost driver, they use the same amount of the activity resources capacity. No intensity factors are used;
- We do not envisage to introduce new products, the products portfolio cannot be changed: it is only possible to choose to produce or not one of the products;

- Suppliers and customers portfolios are known and represent all the opportunities to buy raw material or to sell products respectively.

VI.2.b.ii. Consequences

This section highlights the issue raised in the previous sections: the distortion created by activities subject to resources capacities when the processes or products costs are obtained from them in a mathematical model. These activities are modeled by stepwise functions which vary incrementally when a given amount of activity cost driver is consumed. They so hardly complicate the mathematical because they imply the use of integer variables in the objective function which model the fact that all of activity resources are incurred when the first unit of activity cost driver is engaged. We will call them Resource Integer Variables (RIV). Other integer variables are required to model the acquisition of extra-capacity or outsourcing opportunities (Tsai and Lai 2007; Tsai et al. 2008). If no RIV are used, the model considers that an expense is made proportionally to the activity cost driver consumed whereas if it is considered that there is sufficient available capacity – which has been sized when acquired – the cost of producing one more unit does not increase the expense apart for the material cost: use them or not is the same because they have already been acquired.

To simplify the mathematical model, all the activities at stake in the mathematical model are performed for each unit and are not subject to a resource capacity. In our case, resources are committed each time an activity is performed, function of cost drivers with no variation of intensity. The only resource which is directly proportional to the use in the presented sawmill is energy. Neither batch-level activities like setups or handling operations are used, nor product-level activities like products improvement or design and nor facility-level activities like maintaining buildings, ensuring security or insuring the installations. Practically, it comes to associate one activity to each operation which uses energy – sorting, debarking, sawing, green sorting, drying, quality sorting and chips and sawdust treatment. The activity cost driver is the quantity of energy consumed per unit of time or volume and the resource cost driver is the cost per quantity of energy. A process which generally requires setup operations is sawing, but instead of adding an activity for tools changing or saws cleaning, when a new dimensions and species log is processed, a length offset is added on the unit-level activity related to the sawing operation.

As we saw in the assumptions, activities are not disaggregated into intensity levels which means that activity cost drivers are based on a dimension which is linked to the production measurement and the cost is so only an image of the capacity – time – usage: an information which is already present. They do not discriminate products and are consequently irrelevant for the mathematical model: adding them would overfeed it.

VI.2.c. Resources

Activity	Sorting	Debarking	Barks Conveying	Sawing	Chips and Sawdust conveying	Green sorting	Tunnel drying	Chamber drying	Barks kiln drying	Quality sorting	Packaging
Administration	13 114 $	3 278 $	1 093 $	5 464 $	2 186 $	8 743 $	4 808 $	3 934 $	1 967 $	8 743 $	8 743 $
Ground and buildings	24 850 $	3 096 $	6 193 $	24 095 $	10 096 $	24 095 $	7 398 $	1 761 $	1 145 $	24 095 $	24 095 $
Machinery unit	183 782 $	67 805 $	52 171 $	436 101 $	80 074 $	371 466 $	133 281 $	56 950 $	296 941 $	485 260 $	0 $
Number of machinery units	1	1	1	1	1	1	5	10	1	1	1
Handling	72 352 $	36 176 $	18 088 $	0 $	36 176 $	0 $	152 304 $	152 304 $	76 152 $	0 $	85 680 $
Labor	372 232 $	80 920 $	24 276 $	129 472 $	48 552 $	210 392 $	490 579 $	395 189 $	197 594 $	210 392 $	216 866 $
Driving forces (max)	0,050 $/m3	0,298 $/m3	0,162 $/m3	0,985 $/m3	0,162 $/m3	0,218 $/m3	3763 $/Batch	1568 $/Batch	736 $/Batch	0,495 $/m3	0,000 $/m3
Driving forces (min)	0,029 $/m3	0,124 $/m3	0,162 $/m3	0,407 $/m3	0,162 $/m3	0,041 $/m3	1076 $/Batch	448 $/Batch	468 $/Batch	0,092 $/m3	0,000 $/m3

Table 2 Resources

In this application case, boundaries are the entrance and the exit of the sawmill: we are not interested in the way raw materials come to the sawmill neither the way products are delivered to customers. The sawmill buys the raw materials which are brought to the logyard and customers come to pick their products: no transportation costs are considered. Resources at stake here are all the expenses engaged by the company to produce in a year. They can be divided into seven independent sections which are directly driven to activities or not:

- Administration expenses relate to the administration department. They include the administrative expenses and the general director salary.
- Ground and buildings section regroup expenses linked to the buildings and their maintenance. They are composed of buildings or ground constructions paying off and the ground taxes. The first one takes into account the number of year of the service life and the interest rate. The second is proportional to the surface occupied by the company.
- Machinery expenses cover the paying off of each of the company's machines like scanners, saws, kilns dryer, conveyors etc. Annual investments are computed independently for each machine the same way as buildings and other constructions. It includes also tools and spare parts for maintenance operations.
- Handling charges expenses relate to vehicles like wheel loaders or fork lifters.
- Labor section is about all employees hired to run the sawmill. Secretaries, managers, workers or sales agents.

- Driving force represents one of the most expensive section because it concerns the energy consumed by the machinery to produce. Electricity and heat production are the two sources of energy of the sawmill.

The Table 2 sums up the aggregated resources values. In all cases, whatever the changes brought to the model, these values remain the same.

VII. **Results**

In this section we will first demonstrate that the 3-phases method enables to obtain at least a good solution for any kind of sawmill with one or more drying units and a large products portfolio. To lead this demonstration, we will compare solutions for various sawmills parameters and configurations to the ones computed on Cplex. Then we will use the 3-phases method to show why introducing activities subject to a resource capacity without giving the model the corresponding stepwise function distorts the model. To finish, we will demonstrate why pricing costs cannot be objectively determined because of the joint production.

VII.1. Solving method

VII.1.a. Cases presentation

Several cases have been developed to show how powerful is the 3-phases method compared to trying to solve the model directly through of a commercial solver like CPLEX. Each case is a variation of the one presented in the previous section. They are described in the Table 3. The Table 4 gives the characteristics values of the different cases we modeled to put the 3-phases method to the test.

Each case adds or removes difficulty to the basic model. There are mainly two kinds of complexity in our model. As we saw in the previous sections, the first issue we are facing with is the presence of symmetries or equivalent solutions. That is why removing price or demand variation is not necessarily a simplification. The second problem is of course the important number of integer variables in addition to the complexity of the fabrication operations: more integer variables and processes we add, more difficult is the resolution.

		Description
1	Basic Case (1 month)	Case described in the article with a time horizon reduced to 1 month.
2	Basic Case (6 months)	Same as case 1 but with a time horizon of 6 months.
3	With Barks Treatment	Case described in the article to which a bark treatment has been added at the output of the debarking operation. It consists in a barks treatment operation

		following by a bark dryer. The dried barks are sold to a customer same way as chips and sawdust. The time horizon remains 6 months.
4	Without Price Variation	Case described in the article without any products price variation from a period to another. The price of a given product is the January average price of this product. The demand still varies. The time horizon remains 6 months.
5	Without Time Variation	Case described in the article without any process operation time variation from a period to another. The operation time of a given process is the January average price of this process. Consequently, process costs no longer vary. The time horizon remains 6 months.
6	Without Inter-processes Stocks (1 month)	In the basic case model, it is possible to stock inputs or outputs before or after a transformation operation respectively. In this variation case, we add constraints to force the model to make its stocks only at strategic locations, as it is usually done in a sawmill, because of the production lines: • Right after the Reception and sorting unit (when a log is delivered at the sawmill, it is sorted before being stored); • At the entrance of the Drying unit (a log is debarked then sawn and its lumbers sorted in a single run); • At the exit of the Drying unit; • After the Packaging unit (a dried lumber is sorted and packaged in a single run); The Time horizon is reduced to 1 month.
7	Without Inter-processes Stocks (6 months)	Same as case 6 but with a time horizon of 6 months.
8	Reduction of the Number of Dryers	Cased described in the article but with half of the drying capacity. The time horizon is 6 months.
9	Reduction of the Number of Types of Dryers	Cased described in the article but only with the chambers drying operation technology. The capacity is equivalent because a larger number of dryers has been set. The time horizon is 6 months.
10	Reduction of the Number of Products	The number of products of the case described in the article has been halved. The demand of remaining products does not change from the basic case (demand is so halved). The time horizon is 6 months.

Table 3 Cases descriptions

		Number of Variables		Number of Integer Variables		Number of Constraints	
		Global	*Phase 2*	*Global*	*Phase 2*	*Global*	*Phase 2*
1	Basic Case (1 month)	73405	47112	5208	5208	43815	25575
2	Basic Case (6 months)	437853	282971	30576	30576	257478	150358
3	With Barks Treatment	444171	286975	31122	31122	264290	154310
4	Without Price Variation	430661	275779	30576	30576	257478	150358
5	Without Time Variation	437853	282971	30576	30576	257478	150358
6	Without Inter-processes Stocks (1 month)	73405	47112	5208	5208	52371	30876
7	Without Inter-processes Stocks (6 months)	437853	282971	30576	30576	307710	181480
8	Reduction of the Number of Dryers	437853	282971	30576	30576	257478	150358
9	Reduction of the Number of Kind of Dryers	361413	206531	15288	15288	224718	117598
10	Reduction of the Number of Products	220856	142258	15288	15288	137722	79742

Table 4 Models Dimensions

VII.1.b. Results

Each of the case runs under a time limit of 10 hours for the second phase of the 3-pases method and for the CPLEX resolution. For the three phases of the 3-phases method and for the Cplex resolution, a 2% gap must be reached in order to a solution can be considered as an satisfactory. The Table 5 sums up the results obtained for the different cases. Real profit and real costs refer to the consideration of activities constrained by capacity resources and facility-level activities – overhead – which are not set in the model objective function.

	Gap		Profit		Real Profit		Costs		Real Costs	
	3phases	*Cplex*	*3phases*	*Cplex*	*3phases*	*Cplex*	*3phases*	*Cplex*	*3phases*	*Cplex*
1	55s	7,30%	746109 $	992766 $	127326 $	373984 $	661618 $	791857 $	1280400 $	1410640 $
2	4,73%	N/A	7082736 $	N/A	3616954 $	N/A	6201424 $	N/A	9667206 $	N/A
3	3,96%	169,39%	6036348 $	2473909 $	2378389 $	-1184052 $	6697819 $	4059470 $	10355778$	7717431 $
4	5,49%	N/A	8411860 $	N/A	5868624 $	N/A	6190262 $	N/A	8733498 $	N/A
5	3,46%	N/A	6713735 $	N/A	3247954 $	N/A	5722250 $	N/A	9188031 $	N/A
6	45s	4,73%	909747 $	1173680 $	290967 $	554900 $	769105 $	899631 $	1387886 $	1518411 $
7	3,62%	43,53%	7263797 $	5509470 $	3798017 $	2043689 $	6278689 $	4979439 $	9744469 $	8445219 $
8	7,09%	71,20%	4085752 $	2866878 $	958683 $	-260192 $	3402015 $	3112274 $	6529085 $	6239344 $
9	3,86%	N/A	7342459 $	N/A	4372137 $	N/A	6345966 $	N/A	9316288 $	N/A
10	3,58%	3,02%	3882006 $	4044859 $	416223 $	579076 $	3634898 $	3839203 $	7100681 $	7304986 $

Table 5 Optimization Results

The principal conclusion is that within the time limit defined, the 3-phases method always enables to obtain a feasible solution with a gap inferior to 10 percent. On the other hand, if in some cases CPLEX is able to find better solutions, most of the time no solution or very bad ones can be found compared with the 3-phases method.

On Figure 9 are traced the results of the cases whose the result is better with CPLEX. Curves named CPLEX and 3-phases represent the evolution of the gap between the final objective function value and the current objective function value during the CPLEX mixed integer programming resolution of the model by CPLEX and the resolution of 3-phases method second phase respectively. The third curve enables to compare the final objective function value reached at the end of the third phase by the 3-phases method with the one reached by CPLEX.

The three cases – which are these which have the smallest number of variables and constraints – presented on the diagram are those for which CPLEX found a better solution than the 3-phases method. Cases 1st and 6th show that for the smallest models, CPLEX can find a better solution as fast as the 3-phases method, even if the gap is not below 2%. The 3-phases method is then decelerated by the resolutions of the first and third phases, the second one during from 3 to 5 seconds. The 10th case is also interesting because neither CPLEX nor the 3-phases method can find a solution whose the gap is below 2% before the 36 000 seconds time limit. However, the 3-phases method enables to find a solution during the second phase considerably faster than CPLEX which finds its first solution after 3 000 seconds.

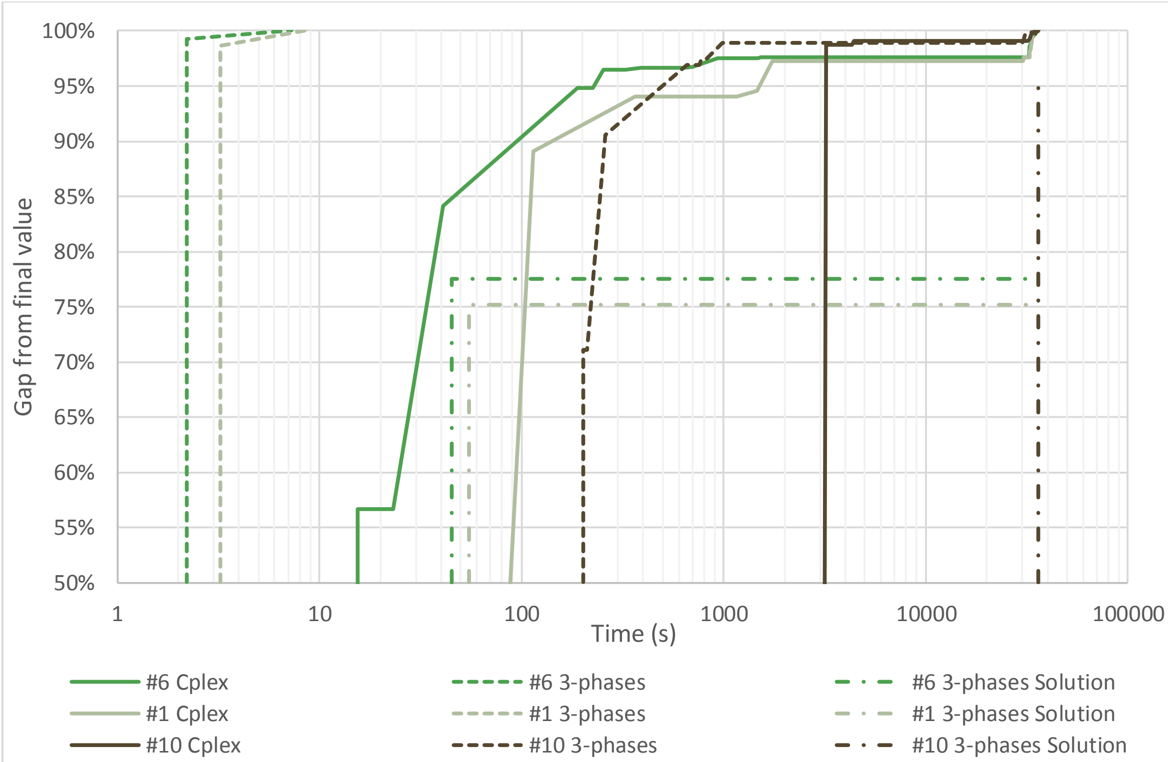

Figure 9 Comparison of CPLEX and 3-phases resolutions

VII.2. Why not use RABC instead of ABC?

In the section VI.2.b we pointed out that activities subject to resources capacity must not be embedded in the model without having RIV to incur the whole amount of resource associated to an activity at the first unit of costs object consumed. We also explained that from a running horizon to another, in the reality or according to a production planning, the use of capacity vary. Nevertheless whatever the use of capacity, the activity cost driver must not be changed once established.

	Apparent Profit	**Profit**	**Real Profit**	**Cost**	**Real Cost**	**Income**
ABC	N/A	746109 $	127326 $	661618 $	1280400 $	1407726 $
RABC without RIV (Iteration 1)	395374 $	570460 $	-48323 $	486197 $	1104980 $	1056657 $
RABC without RIV (Iteration 2)	21369 $	450671 $	-63909 $	387744 $	902325 $	838416 $
RABC without RIV (Iteration 3)	-34748 $	175836 $	-339406 $	170334 $	685576 $	346170 $
RABC without RIV (Iteration 4)	*Do nothing*	N/A	N/A	N/A	N/A	N/A

Table 6 RABC instead of ABC

In this section we show what the consequences are by feeding the model with costs computed from an ABC method without using RIVs in the objective function. The 1st case is used to support the study. Once a production planning is obtained, we compute the activity cost drivers according to the use of

capacity which is needed by the production planning. A new production planning is then computed, the activity cost drivers reevaluated and so on. On the 4th iteration no profitable solution can be found.
The apparent profit is the profit computed by the production planning tool based on the RABC made on the previous iteration result. The profit column and the corresponding cost is the value of the profit computed without incurring the amount of capacity constrained resources. The real profit is the one which takes into account all the resources of the time horizon.
The result of the 3rd iteration is negative because of the third phase: the integer variables being fixed, the model is "forced" to produce even if it is not profitable.

VII.3. Pricing costs

In the section IV.4.c, we focused on the problematic linked to the pricing costs setting. As explained, there is infinite possibilities to share a process production cost between its outputs. Because of the high number of products of the different cases, we build a new 1 month horizon case with only 2 logs that are sawn according to their respective sawing patterns whose outputs proportions are given in the line Volume of the Table 7. The policies are applied on a production planning determined thanks to the 3-phases method.

VII.3.a. Allocation policies

We apply two different sharing policies very different from the one described in the previous section. The two sharing policies compute a new pricing cost for each output – in-progress or final product – at each period of the production planning by using the production costs from RABC as we suggested in the section IV.4.c. Each period is divided into two theoretical parts to be able to compute the evolution of each operation production:

- The first part corresponds to the final state of the previous period to which is added all the production of the period: volumes and pricing costs rise.
- The second part is the first part to which has been subtracted all the production of the period: volumes and pricing costs decrease.

Practically, we compute all the productions of outputs before inputs consumptions.
The first sharing policy is based on the volume proportion obtained from an input through a process whereas the second one allocates the same amount of production cost to all of the outputs – if 3 products are obtained from a process, each output will be assigned a third of the process production

cost. In this little case, the only divergent operation regarding the assumptions is the sawing operation. The Table 7 sums up the allocation values for the two processes.

Policy	***Process***	**Product 1**	**Product 2**	**Product 3**	**Product 4**	**Byproducts**
Volume	Sawing Process 1	41%		24%		35%
	Sawing Process 2		35%	17%	10%	39%
Portion	Sawing Process 1	33%		33%		33%
	Sawing Process 2		25%	25%	25%	25%

Table 7 Production costs allocation policies

VII.3.b. Results

On The Figure 10, we can see the cumulated processes cost and revenue. Because byproducts are not obtained at the same time than products, processes pricing costs do not evolve the same way for the two policies.

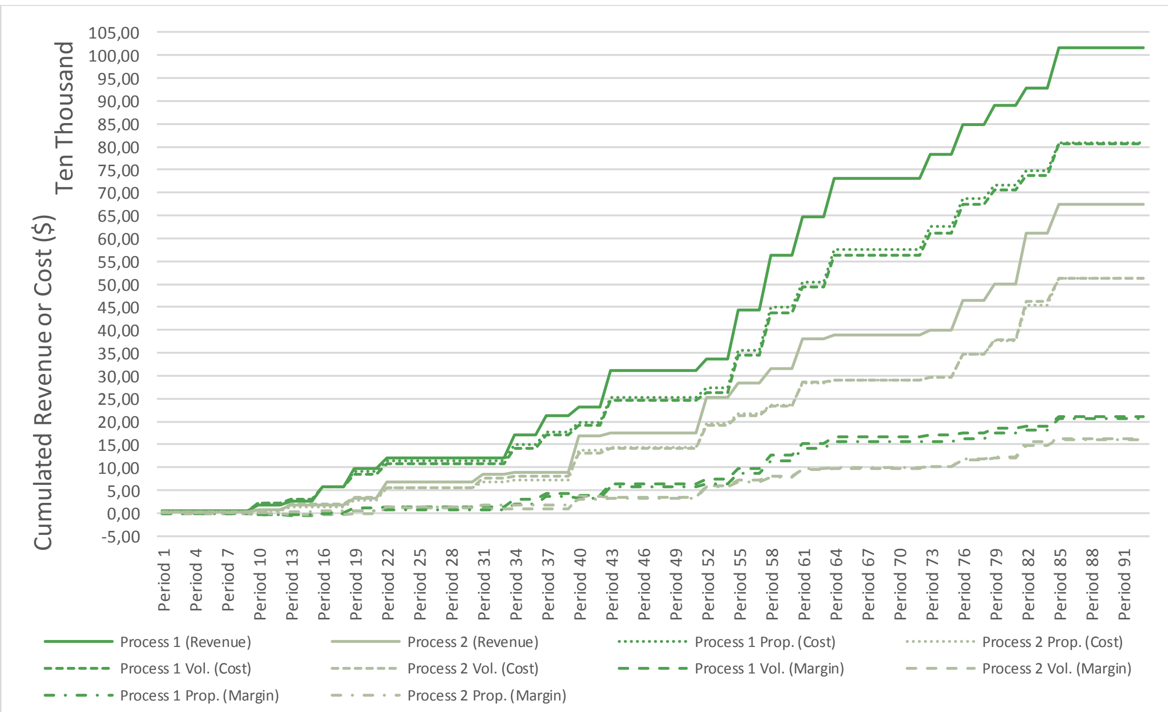

Figure 10 Processes Costs and Revenues

Moreover, as we can see on Figure 11 and Figure 12, the arbitrary allocation coefficient has a high influence on the supposed margin of each product. This is particularly observable on byproducts or low prices products because the pricing cost is rapidly higher than the revenue. While value-added products have not been produced – especially during the first periods – even the process appears to be not profitable.

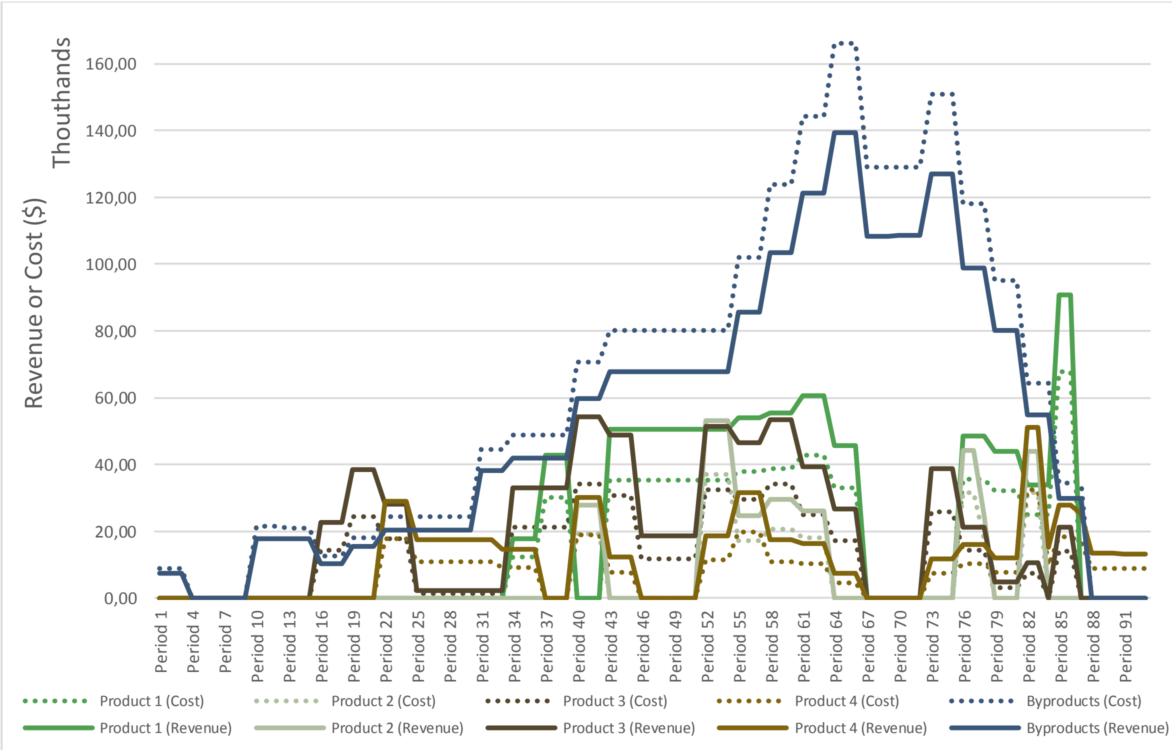

Figure 11 Products Costs and Revenues (Volume Policy)

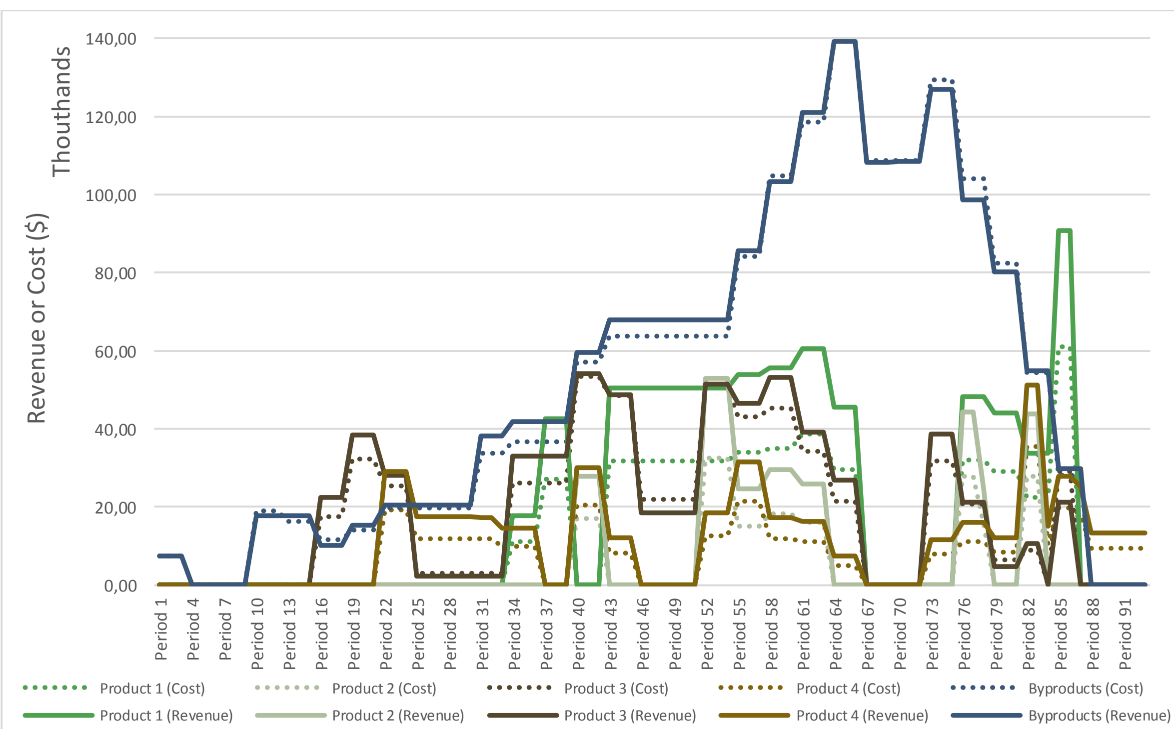

Figure 12 Products Costs and Revenues (Proportion Policy)

Some of the products – like the product 3 and byproducts in our case – are obtained from several processes, it may be that they are not as profitable when obtained from one as when obtained from the other. Indeed, if the product 3 is obtained from the process 1, its coproduct – product 1 – will be able to support a higher part of the divergent process which will make it more profitable than when it is obtained from the process 2. Any distinction will be made between product 3 obtained from the process 1 and the product 3 obtained from process 2. Both of them is added to the stock of product 3 already built and rise the total pricing cost and the volume consequently.

Case study

The previous section focuses on the way to adapt the ABC method to a divergent production line. By using an application case built on data from the literature, we demonstrated how the production costs from an ABC method can be used to support supply chain management, especially to determine a production plan through solving a mathematical model. On the other hand, we introduced the concept of pricing costs and we presented several ways to compute them in order to estimate the products margin. The following section is dedicated to the development and the implementation of an ABC method in collaboration with an industrial partner specialized in the first and second transformations of wood. The work presented in this section is the result of a three months internship during which I joined the financial department of the company to help them to improve the way they compute production and pricing costs. This project has been led by myself in accordance with the company requirements. Every one or two weeks, I presented them my progress to validate my choices. After the analysis of the company and their management accounting method, I decided to build an Excel document in which several VBA macros and many user forms are implemented in order to be sustainable and used by accountants and decision makers.

I. Context

I.1. The industrial partner

In order to implement the concepts proposed in this thesis, an internship was done with one lumber company from the Province of Quebec. This company counts three production locations in Quebec and produces around 283 000 cubic meters – 120 million PMP – of dimension and technical lumbers, 3.7 millions square meters – 40 millions square foots – of eastern white cedar shingles and sidings for outside coating and 5 millions of horticultural mulch bags, 35% of which is sold in Canada while the remaining 65% being sold in the United States of America.

I.2. Planing unit

This case study focuses on planing operations, one particular production unit within the lumber production process. This unit has been selected because the industrial partner has gathered lots of production data. Planing is the last operation on lumber before shipping to clients or further processing like siding production. An optimizer determines the grade of each piece of wood according to selling price and stock levels. Production management software records a lot of production data to support the supply chain management decision-making. Performance indicators, like obtained outputs volumes, reflect a push production strategy: trying to sell what is produced rather than produce what is needed to sell like a pull strategy. The goal is more to use the sawmill at its higher production level by prioritizing the high value-added products production. Historical data is thus mostly based on the result of resource consumption instead of resources themselves. One of the consequences of this production strategy is that the company has never tried to know how much it costs to produce one or another product until now. No production cost computation method is used, the only managerial accounting method which is in place is the joint costs method based on the net realization value (NRV) which serves the inventory valuation at the end of each month. The in-progress product NRV is the market value of the corresponding final products from which the not yet realized operations production costs are subtracted.

From an accounting point of view, the lumber production unit is a plant of its own which integrates all the first transformation operations from the raw material receipt to the planing inclusively which are sawing, drying and planing. All of the planing outputs are considered as finished products and are assigned a market value whether they are sold to clients or processed in second transformation – siding. In this second case, accounting department records a sale/purchase – no loss or profit – when products exit the planing unit, either to be sold or sent to the siding plant.

I.3. Section structure

In the next subsection, we will describe in detail the planing unit operations and structure. Then, we will present the traditional method used to calculate the value of inventory and compute products margins. In a third part, we will focus on the development of the ABC method to finish with the computation of the final products' pricing costs.

II. **Sawmill description**

II.1. Lumber production department

As outlined in the previous subsection, the lumber production department includes the sawing unit which debarks and saws logs then grades and packs in bundles the green wood pieces. After being stored outside for drying, bundles are industrially dried using steam driers. Bundles are then de-stacked, planed, graded and repacked according to the clients' needs or further processed. The department counts three storage areas:

- The logyard where logs are stored;
- The area holding green wood bundles destined to drying or planing operations – every products are planed but not necessarily dried;
- The area where bundles of finished products are waiting for shipment or further processing.

Areas we are interested in are the two last ones that can be further divided into 4 inventories as showed in the Figure 13 :

- (GR) In-progress green raw products inventory, at the end of the sawing unit which have just been sawn and that are to be the dried or planed;
- (DR) In-progress dried raw products inventory, at the end of the drying unit which have been sawn then dried but not yet planed;
- (GP) Finished green prepared products inventory, at the end of the planing unit which have been sawn and planed and are to be sold;
- (DP) Finished dried prepared products inventory, at the end of the planing unit which have been sawn, dried and planed and are to be eventually dried a second time then sold or directly sold or further processed.

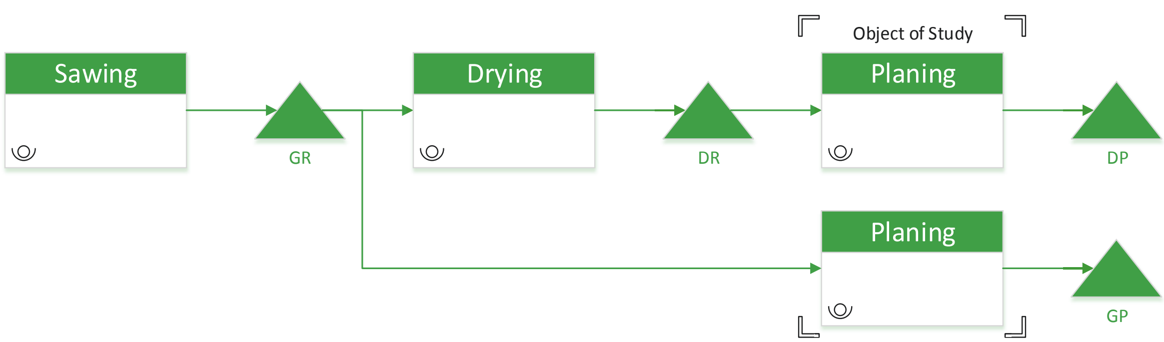

Figure 13 Operations and inventories

II.2. Planing structure and operations

As illustrated by the Figure 14, the planing unit includes several operations that can be performed or not on a product:

- Destacking: bundles from sawing or drying units are destacked and each piece of wood is placed on the production line (conveyor or manually);

- Visual sorting: each piece of wood is manually sorted and eventually trimmed to remove too damaged pieces;
- Slitting: depending of the required dimensions, wood pieces can be sawn into two parts – a 4x4 can be transformed into two 2x4;
- Planing: lumbers are planed to improve the surface finishing or to obtained a specific section – with special tools;
- MSR (Machine stress rating): a flexural test is realized on the weakest section of each piece of wood in order to guarantee to the client mechanical characteristics of structural building lumbers. The machine is used just for specific processes;
- Geometric scanner: the scanner analyzes the position of knots on the wood piece;
- Hygrometer: moisture rate is measured to ensure quality requirements;
- Visual grading: a qualified operator checks all the wood pieces and gives them a grade.
- Stamping: the system prints the lower grade on each wood piece between the one given by the optimizer (based on the demand, the inventories level, the MSR value, the geometric scan and the moisture rate) and the one determined by the operator;
- Manual trimming: if the operator did not give a grade or to fulfill a specific order, the lumber exits the production line and an operator manually trims it and prints the grade;
- Trimming: according to the optimizer or the grading operator, the lumber is trimmed and stored in a case according to its dimensions and its grade – one case per combination;
- Stacking: when a case is full, operators and stacking machines assemble the bundle according to customer or further operations requirements – number of pieces per layer, bundle height, etc. If the bundle is to be dried a second time, wood laths are added between the layers;
- Packing: still according to customer or further operations requirements, the bundle is strapped, labeled and eventually wrapped or painted on the end of the lumbers.

A technician manually controls some pieces of wood to check if the testing machines are calibrated correctly.

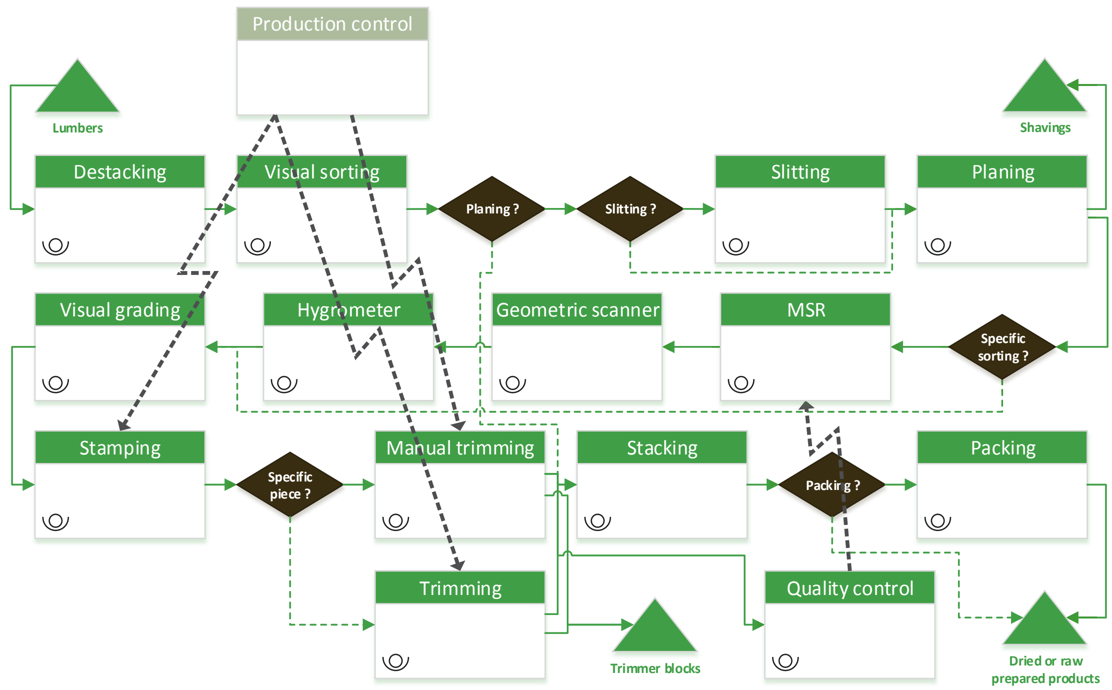

Figure 14 Flow chart of the planing operations

III. Traditional costing method

In this section, we will introduce the method used to valuate inventories and evaluate product margins. Step by step, we will present the method and outline its main weaknesses.

III.1. Joint costs method

III.1.a. Average production cost

The first step of the method is the computation of the production cost of the two production operations whose fabrication has already been started: drying and planing. To do that, the total amount of resources dedicated to the operation for the month is divided by the corresponding budgeted production volume:

$$C_k^m = \frac{TC_k^m}{TQ_k^m} \qquad (9)$$

with:

- C_k^m : cost per unit of volume of the operation k during the current month;
- TC_k^m : total budgeted production cost of the operation k during the current month;
- TQ_k^m : total budgeted product quantity processed by the operation k during the current month.

Because there are divergent processes, we consider that a product will be transformed into one or two of the following categories:

- High value-added products, called specialty products;
- Non value-added products, called commodity products that include chips, shavings, sawdust and barks.

An in-progress product is defined according to the operations required to turn it into a finished product rather than according to the operations performed to obtain it. For example, if we consider a product with a given grade and species obtained from the sawing unit, if a given quantity is to be dried and planed and the remaining is to be planed only, then two different products will be recorded in the inventory.

One advantage of this computation is that it can be computed directly from usual data (volume). However, it is a very poor approximation because from a product to another, and even between two production runs of a given volume of a particular product, the required amount of resources vary – time and energy consumptions can double from a product to another or for a product manufactured in summer vs. winter.

III.1.b. Divergent processes recording

The second step consists in analyzing the quantities of outputs obtained from each input for each products inventory. Outputs of an operation are the inputs inventory of the following ones. Each operation's outputs must be linked to the inputs of the next production steps to be able to trace each in-progress product to a finished product. It is from the finished product market value that the in-progress product NRV will be computed. Because of wood heterogeneity, processes may vary from a production run to another for a given product. Until recently, when the software used to support production planning establishment had been improved, the planing unit data were rather well documented but unfortunately on paper reports and were consequently not always recorded and even less kept. That is why, output proportions for each process used by accountants were practically never updated and are most of the time based on very bad approximations sometime very different from the real production.

III.1.c. NRV computations

It is in the third step that products NRVs are computed. To do that, the total value of each finished product obtained during the previous month from a given in-progress product in an inventory is computed:

$$R_{i_j}^{m-1} = P_{avg_i}^{m-1} . Q_{i_j}^{m-1} \tag{10}$$

where :

- $R_{i_j}^{m-1}$: revenue of finished product i obtained from product j during the previous month;
- $P_{avg_i}^{m-1}$: average price per unit of volume of finished product i during the previous month;
- $Q_{i_j}^{m-1}$: quantity of finished product i obtained from product j during the previous month.

We obtain the average price of each product:

$$P_{avg_j}^{m} = \frac{\sum_i R_{i_j}^{m-1}}{Q_j^m} \tag{11}$$

where:

- $P_{avg_j}^{m}$: average price per unit of volume of product j for the current month;
- Q_j^m : quantity of product j which has been in the inventory during the current month,

and the average price of each category of finished products obtained from the current product:

$$P_{avg_{c_j}}^{m} = \frac{\sum_c R_{c_j}^{m-1}}{\sum_c Q_{c_j}^{m-1}} \tag{12}$$

$$P_{avg_{s_j}}^{m} = \frac{\sum_s R_{s_j}^{m-1}}{\sum_s Q_{s_j}^{m-1}} \tag{13}$$

where:

- $P_{avg_{c_j}}^{m}$: average price per unit of volume of finished commodity products c obtained from product j during the current month;
- $P_{avg_{s_j}}^{m}$: average price per unit of volume of finished specialty products s obtained from product j during the current month;
- $R_{c_j}^{m-1}$: revenue of finished commodity products c obtained from product j during the previous month;
- $R_{s_j}^{m-1}$: revenue of finished specialty products s obtained from product j during the previous month;

- $Q_{c_j}^{m-1}$: quantity of finished commodity products c obtained from product j which has been in the inventory during the previous month;
- $Q_{s_j}^{m-1}$: quantity of finished specialty products s obtained from product j which has been in the inventory during the previous month.

From this average price per unit of volume, the NRV of each in-progress product – because the NRV of a finished product is equal to the revenue generated by this product – is computed by subtracting from this average price per unit of volume the average costs per unit of volume of all the operations not yet realized which will enable to obtain the finished products from this product:

$$NRV_j^m = \left({P_{avg}}_j^m - \sum_k C_k^m\right).Q_j^m \quad \textbf{\textit{(14)}}$$

where:

- NRV_j^m : NRV of product j for the current month.

We also compute the NRV of each finished products category obtained from each in-progress product:

$$NRV_{c_j}^m = \left({P_{avg}}_{c_j}^m - \sum_k C_k^m\right).Q_{c_j}^m \quad \textbf{\textit{(15)}}$$

$$NRV_{s_j}^m = \left({P_{avg}}_{s_j}^m - \sum_k C_k^m\right).Q_{s_j}^m \quad \textbf{\textit{(16)}}$$

which implies:

$$NRV_j^m \neq NRV_{c_j}^m + NRV_{s_j}^m \quad \textbf{\textit{(17)}}$$

where:

- $NRV_{c_j}^m$: NRV of finished commodity products c obtained from product j during the current month;
- $NRV_{s_j}^m$: NRV of finished specialty products s obtained from product j during the current month;
- $Q_{c_j}^m$: quantity of finished commodity products c obtained from product j during the current month;
- $Q_{s_j}^m$: quantity of finished specialty products s obtained from product j during the current month.

III.1.d. Inventories evolution and production costs

Material cost of a product is computed for the green raw products which are common to the three others inventories – each product from DR, DP and GP inventory was a green raw product – by subtracting to the log costs the revenue of the byproducts sale.

Based on the previous month, each inventory P at the beginning of the month – end of the previous month – is defined by a global quantity and an average production cost:

$$TC_P^{m-1} = QS_P^{m-1}.C_P^{m-1} \quad \textbf{\textit{(18)}}$$

where:

- TC_P^{m-1} : Average production cost – transformation and material – of inventory P at the end of the previous month;
- C_P^{m-1} : Average production cost – transformation and material – per unit of volume of inventory P at the end of the previous month;
- QS_P^{m-1} : quantity in inventory P at the end of the previous month.

Next, we compute inventories movements, starting from green raw products, to determine the global product quantity which has been in each inventory P – green raw, green prepared, dried raw and dried prepared – during the current month and the production cost associated with this product quantity – transformation and material cost:

$$TC_P^m = TC_{k_P}^m + \sum_x \left(\frac{Q_{P_x}^m}{Q_{P_x}^m + QS_{P_x}^{m-1}} . TC_{P_x}^m \right) \quad \textbf{\textit{(19)}}$$

where:

- TC_P^m : total production cost – transformation and material – which enable to obtain all the products which have been in the inventory P during the current month. They can or cannot be in the inventory at the end of the current month;
- $TC_{k_P}^m$: total budgeted production cost of the operation k which enables to obtain all the products of the inventory P during the current month;
- $Q_{P_x}^m$: total quantity of products in the inventory P processed from the input inventory P_x during the current month;
- $QS_{P_x}^{m-1}$: quantity of products in the input inventory P_x at the beginning of the current month;
- $TC_{P_x}^m$: total production cost – transformation and material – of the input inventory P_x during the current month.

III.1.e. Joint costs computation

As we will see in the next paragraph, there are two ways to valuate a product: by using the NRV of this product or by using the NRV of the two categories of finished products – dried prepared products are finished products – obtained from this product. First of all, we need to determine the production cost per unit of volume of the product and of the two categories of products that this product will give. To do that, we allocate to each product or category of products of an inventory – function of their NRV – a part of the production cost associated with this inventory. Note that in order to a product can be considered as profitable, its NRV must be higher than its production cost.

The production cost allocated to a product is given by the following formulas:

$$TC_j^m = \frac{NRV_j^m}{\sum_j NRV_j^m} . TC_P^m \quad (20)$$

$$C_j^m = \frac{TC_j^m}{Q_j^m} \quad (21)$$

where:

- TC_j^m : total production cost – transformation and material – associated with product j from the inventory P for the current month;
- C_j^m : production cost per unit of volume – transformation and material – of product j for the current month.

The production costs allocated to the two products categories which will be obtained from this other relation:

$$TC_{c_j}^m = \frac{NRV_{c_j}^m}{\sum_j \left(NRV_{c_j}^m + NRV_{s_j}^m\right)} . TC_P^m \quad (22)$$

$$C_{c_j}^m = \frac{TC_{c_j}^m}{Q_{c_j}^m} \quad (23)$$

$$TC_{s_j}^m = \frac{NRV_{s_j}^m}{\sum_j \left(NRV_{c_j}^m + NRV_{s_j}^m\right)} . TC_P^m \quad (24)$$

$$C_{s_j}^m = \frac{TC_{s_j}^m}{Q_{s_j}^m} \quad (25)$$

where:

- $TC_{c_j}^m$: total production cost – transformation and material – associated with finished commodity products c obtained from product j from inventory P for the current month;

- $C_{c_j}^m$: production cost per unit of volume – transformation and material – of finished commodity products c obtained from product j from inventory P for the current month;
- $TC_{s_j}^m$: total production cost – transformation and material – associated with finished specialty products s obtained from product j from inventory P for the current month.
- $C_{s_j}^m$: production cost per unit of volume – transformation and material – of finished specialty products s obtained from product j from inventory P for the current month.

III.1.f. Inventory valuation

The valuation of a product according to its production cost is given by:

$$TCS_j^m = C_j^m . QS_j^m \quad \textbf{(26)}$$

where:

- TCS_j^m : total production cost – transformation and material – associated with product j from the inventory P at the end of the current month;
- QS_j^m : quantity of product j in the inventory P at the end of the current month.

The second way to valuate a product based on the two categories of products production costs that are obtained from this product is computed as follow:

$$TCS_j^m = TCS_{c_j}^m + TCS_{s_j}^m \quad \textbf{(27)}$$

$$TCS_j^m = C_{c_j}^m . QS_{c_j}^m + C_{s_j}^m . QS_{s_j}^m \quad \textbf{(28)}$$

and:

$$C_{c_j}^m . QS_{c_j}^m + C_{s_j}^m . QS_{s_j}^m \neq C_j^m . QS_j^m \quad \textbf{(29)}$$

where:

- $TCS_{c_j}^m$: total production cost – transformation and material – associated with finished commodity products c obtained from product j in inventory P at the end of the current month;
- $TCS_{c_j}^m$: total production cost – transformation and material – associated with finished specialty products s obtained from product j in inventory P at the end of the current month;
- $QS_{c_j}^m$: quantity of finished commodity products c obtained from product j in the inventory at the end of the current month;
- $QS_{c_j}^m$: quantity of finished specialty products s obtained from product j in the inventory at the end of the current month.

III.2. Limits of the method

The first observation that we can make on this method is the mix-up of the two very important notions we introduce in this thesis: production cost and pricing cost. The NRV which determines the pricing cost of each in-progress product is computed by subtracting a production cost from the revenue generated by this product. The principle of allocating a part of resources needed to obtain a product to this product function of its market value is a good start for a pricing cost computation. However, using a part of remaining operations proportionally to the production volume of the product to compute it, is not a good one.

Indeed, even if all the products in the planing line follow the same path, they do not use the same operations and when they do, they are not processed the same way. Only some of them are slitted, planed with specific tools, subjected to a flexural test whereas some others will just go through the line to be repacked. Moreover, processing speed can quadruple from a process to another which means that they do not use resources equivalently. Nevertheless, the planing production cost is the same for all of the products and proportional to the volume processed. For example, consider two products A and B for which the same volume is processed. Product A requires a specific planing tool and a flexural test, while B does not. Using the joint costs method, both products will be allocated the same planing production cost. Thus, under this costing technique, B supports a proportion of the extra resources required to produce A.

Moreover, the whole cost of an operation is allocated to one of the products inventory. However, some of the products are dried a second time after they have been planed. Although it affects only a small proportion of the total production, this extra cost is supported by all products going through the planing line.

Finally, the method would be more relevant if accurate production costs were used. As described, the method can be applied only at the end of the production time horizon because as production costs are not defined, we do not know resources consumed in the production over time. We can just draw a report of the production at the end of the financial period, when we know all of the products that have been produced during this period. Anyway, this method is too disconnected from production reality to help managers to take any decision on the supply chain management.

IV. **Development of the ABC method**

IV.1. Activities formulation

First step in the development of an ABC method is to draw up the activities dictionary (Cooper 1992; Atkinson, Kaplan, and Young 2004; Brewer et al. 2007). An activity is expressed by an action verb followed by a complement. It gathers one or several functions which enable to realize this activity. Depending on the level of details we want to achieve, the number of activities can vary a lot.

As we showed in the section V.2.a.iv, each activity is associated with a hierarchical level depending on the cost object which triggers it and its relation with the resources associated with it – if they are subject to a capacity constraint or not. Because employees – which represent 66% of the expenditures incurred by the planing unit – are not employed function of production level, we assume that activities are capacity constrained: only overtime is possible. Moreover, the planing unit being a balanced production line, a process is defined by its production speed – the output volume per unit of time. That is why most of the activities are unit level activities, as we can see in the Table 8.

#	Activity	Functions or associated machinery	Hierarchical level
1	Slit lumbers	• Slitting machine unstacking unit • Slitting machine • Post-slitting sorting	Capacity constrained unit level
2	Plane and trim lumbers	• Planing machine unstacking unit • Planing machine • Manual trimming • Trimmer	Capacity constrained unit level
3	Sort lumbers	• Human visual sorting • Optic scanner • Moisture reader • Automatic stamping • Manual stamping • Pocket sorting machine	Capacity constrained unit level
4	Perform a flexural test	• MSR	Capacity constrained unit level
5	Pack lumbers	• Stacking machine • Bundle equalizer machine • Strapping machine • Wrapping	Capacity constrained unit level
6	Clean facilities	• Cleaner	Capacity constrained unit level
7	Check conformity of products	• Perform quality tests on lumber samples • Prepare support documents • Analyze new products	Capacity constrained unit level
8	Subcontract planing		Variable unit level
9	Change process	• Sorting and trimming operator • Planing machine unstacking unit operator • Planing machine operators	Capacity constrained batch level

10	Maintain buildings	• Plowing, building maintaining and fixing	Facility level
11	Manage planing unit	• Staff management • Production planning • Production planning software maintaining	Facility level

Table 8 Planing activities

IV.2. Resources cost drivers

Once the activities dictionary is defined, the goal is to trace all the resources to the activities. This step is very difficult task because it requires a very precise knowledge of the functioning of the unit and of the resources that enable it. That is why accountants and production managers are both involved in this work. Most of the time, the first step consists in finding good approximations which will be adjusted over time.

Each resource will be associated with a resource cost driver. It will allow allocating a resource to several activities. Activities are associated to a single cost object, while resources can be consumed by one or several activities. Electrical power for example, is shared between all the activities linked to operations. Some employees are dedicated to several tasks which refer to different activities: salaries must be separated among all of them. The Table 9 lists the resources classes, the associated resources and their associated resource cost drivers.

Resource		Resource cost driver
Machinery		
	Machinery paying off	%
	Production planning software paying off	%
	Spare parts	%
	Electricity parts	%
Sharpening		
	Knives and saws	%
	Supplies	%
Power		
	Lighting and power	% kWh
Salaries		
	Foreman	% employees
	Sorting and trimming employee	% time
	Sorting employee	% time
	Unstacking machine operator	% time
	Planing machine operator	% time
	Strapping employee	% time

	Wood painting and wrapping employee	% time
	Training	% resource
	Social benefits (direct labor)	% resource
	Quality and operation technician	% time
	Cleaner	% time
	Electrician	% time
	Maintaining and lubricating employee	% time
	Sharpening employee	% time
	Building maintaining employee	% time
	Planing unit director	%
	Social benefit (service labor)	% resource
Transport		
	Planing transportation	%
	Subcontracting delivery	%
Buildings		
	Building payoff	%
	Supplies	%
Overhead		
	Insurances	% surface
	Employees charges	%
	Maintaining	%
	Computers payoff	%
	Security supplies	%
	Office supplies	%

Table 9 Resources cost drivers

Thus, sharing is often done according to time, surface, volume or other measurable unit percentage that can be allocated to an activity more than another, depending on the unit in which the resource is acquired.

IV.3. Activity cost drivers

According to the activity hierarchical level, we will determine an activity cost driver for each activity. Recall that the activity cost driver traces resources linked to an activity to the cost objects that trigger this activity. It is expressed by a currency unit per unit of measurable quantity of activity consumed to perform this activity (Deherripon 1996:77). Accurate production data is very important at this time, because this measurable quantity refers to values that can be recorded throughout the production. Again, time, surface, volume or production unit – like piece or batch – are measurable unit that can easily be used for this purpose.

Sometimes, as introduced by Cooper and Kaplan (Kaplan and Cooper 1998:chap. 6), depending on the level of detail needed, an activity can be disaggregated into several more detailed. Authors propose three kinds of activity cost drivers:

1. Transaction drivers refer to the most basic way for a cost object to consume an activity. It consists in counting how many times an activity is performed. Consequently, each cost object

consumes the same amount of resources. If these cost drivers are the easiest to set in place and habitually the less expensive, they are also the less accurate. Number of pieces, setups or batch are examples of transactions drivers;

2. Measurable unit drivers relate to activity cost drivers that are consumed proportionally to a quantifiable measure: more a cost object consumes to perform an activity, proportionally higher is the cost. Time, surface, distance, length and volume are measurable units that can serve this purpose.
3. Intensity drivers are the most complex activity cost drivers. The resources associated with the performance of an activity depend on the cost object itself. This kind of activity cost driver can be used when two products consume the same amount of activity cost driver but one involves specific resources or higher complexity which implies a higher allocated cost.

The most relevant activity cost driver in the planing unit – for activities 1 to 7 included and 9 – is a measurable unit driver – hours – based on time consumption. Indeed, when the production line is set according to a specific process, it runs continuously until the next setup at a given speed – here is why activity 9 is defined to batch level. Duration, input volume and outputs volumes are recorded in the production database, so it is quite easy to access the production times. Activity 7 is realized aside the production line and samples of each kind of lumber are randomly analyzed to control the calibration of the optic scanner, the MSR and the moisture reader. Different lumber products do not require the same analysis according to their quality grade and dimensions but the time to perform the activity is function of the complexity of the test. That is why a measurable unit driver – minutes – is relevant and sufficient. Even if the line is balanced and for a given process, activities 2, 3, 5 and 7 are always triggered consuming the same amount of activity cost driver, it is important to keep them independent to be able to analyze their contribution to the process cost. We also keep activity 9 independent rather than integrate setup time as an offset time to concerned processes because machines are set up between two shift and employees are paid in overtime to perform the activity. When activity 4 is not triggered by a process, the machinery is removed from the production line and replaced by a simple conveyor. Same way, two different entrances are possible on the production line whether products need to be slitted or not.

Because the subcontractor invoices volume produced, the measurable unit of activity 8 is volume. Moreover, each process is associated with a specific cost. That is why the activity cost driver is an intensity driver for which each level corresponds to a given process.

V. Pricing cost computation

Pricing cost computation is a very difficult task which involves a lot of parameters. To support pricing decisions, we will present the Excel tool that we built which enables, thanks to numerous macros coded in VBA to set in place the ABC and to compute the pricing costs. Step by step, resources are defined then allocated to activities which are consumed by processes. Once a process is defined and the activities costs are allocated to it, process costs are linked to the processes' outputs. We start by presenting the Excel tool then discuss several issues and choices made during the implementation.

V.1. From resources to activities

The Excel project is built to support the workflows required by the ABC method. A first sheet is so dedicated to the sharing of the resources between activities. On the lines of the sheet, as presented in the Table 9, resources are sorted by classes and are defined by an amount and a resource cost driver. Activities are listed on the columns in order to make the allocation at the intersection of a line and a column. A conditional format forces the user to allocate 100% of the resource to the activities. Depending on whether a resource is subject to a capacity or not, the activity cost driver of an activity is computed in two different ways:

- Capacity constrained activity: the activity cost driver is defined by a unit measurement and each of its level – only one for transaction and measurable unit drivers or at least two for intensity driver – by a capacity expressed in the unit measurement and a percentage of the activity amount of resources associated with the level. The activity cost driver consumption rate of each level is obtained by dividing the resource amount by the capacity.
- Non capacity constrained activity: same way as the first category, the activity cost driver is defined by a unit measurement and each level is directly given an activity cost driver rate.

At the bottom of the sheet, consumable resources – all material except wood like wrapping sheet, paint, staples etc. – are listed. They are defined by a cost per unit of measurement and as a consumable not subject to a capacity constraint. Each input will be associated with the quantity of consumable resource it uses.

V.2. From activities to processes

In this second sheet, each line is dedicated to a specific process. In the first columns, process specifications are indicated on the first columns. A process is given a name, an input, a beginning and an ending date. On the next columns are set the consumed input volume and the inventory on which this latter must be taken from. Indeed, an input can either be produced in another process or available in inventory. That is why the user chooses if the input must be taken from the produced volume or from the available stored volume. The user defines which inventory is chosen first or if only one of them can be used. On the following columns, quantities of each consumable resources are listed. Finally, each activity is defined by a group of three columns. The first one is the quantity of activity driver involved in the process, the second one the intensity level – level 1 for transaction and measurable unit drivers – and the third one is the amount of the activity used by this process. This way, we are able to now each activity contribution to the process cost and processes can be consequently compared according to their activity consumptions.

Until now, we considered that a process was the combination of an input and its transformation recipe. To solve the issue of the pricing cost determination, we have to specify further the concept of recipe: the recipe includes all the activities which are triggered by all of the outputs without taking into account specificities of outputs. In other words, a recipe ends when one of the output triggers an activity on its own. In our case, the planing recipe includes activities 1, 2, 3, 4, 6, 7 and 9: activities from the entrance point to the end of the trimming operation, when lumbers are sorted in the pockets sorting machine. Reason is that all byproducts – shavings and trimmer blocks – are specific products. Otherwise, the recipe would end just after the planing machine – after shavings are obtained. Another process would start after the planing machine which would include all the operations until the pocket sorting machine. Each lumber is stacked, packed and wrapped independently according to further operations or customer requirements, so these operations cannot be included in the process recipe. According to the way the Excel tool is designed, a new non-divergent process must be defined when activities are performed on a specific product. For instance, a process will be set to turn a non-packed product into a product ready to be shipped or further processed.

V.3. From processes to outputs

Once the production cost is calculated, pricing cost can be established. For each process defined, the user will be able to dynamically allocate to the process outputs a part of the cost associated with the process. For the company, this tool is a support to the product-mix decision. Revenues generated by the products are obviously one of the primary criteria. We implemented two ways to compute the pricing costs to guide the user in his decisions that can be chosen using the drop-down menu named “Pricing cost allocation”. The first one is the most simple and aims to arbitrarily allocate a percentage of the cost defined by the user to a specific product. As we see on the Figure 15 – which is just an extract of the all process – in the outputs list-box, two percentages are set by the user. The first one, entitles “% Vol.”, is the input proportion that is transformed into the considered output. The second one, named “% Ct.” is the percentage of process cost that is allocated to the product. The user is free to set a percentage equal to the volume percentage, to the weight or any other value.

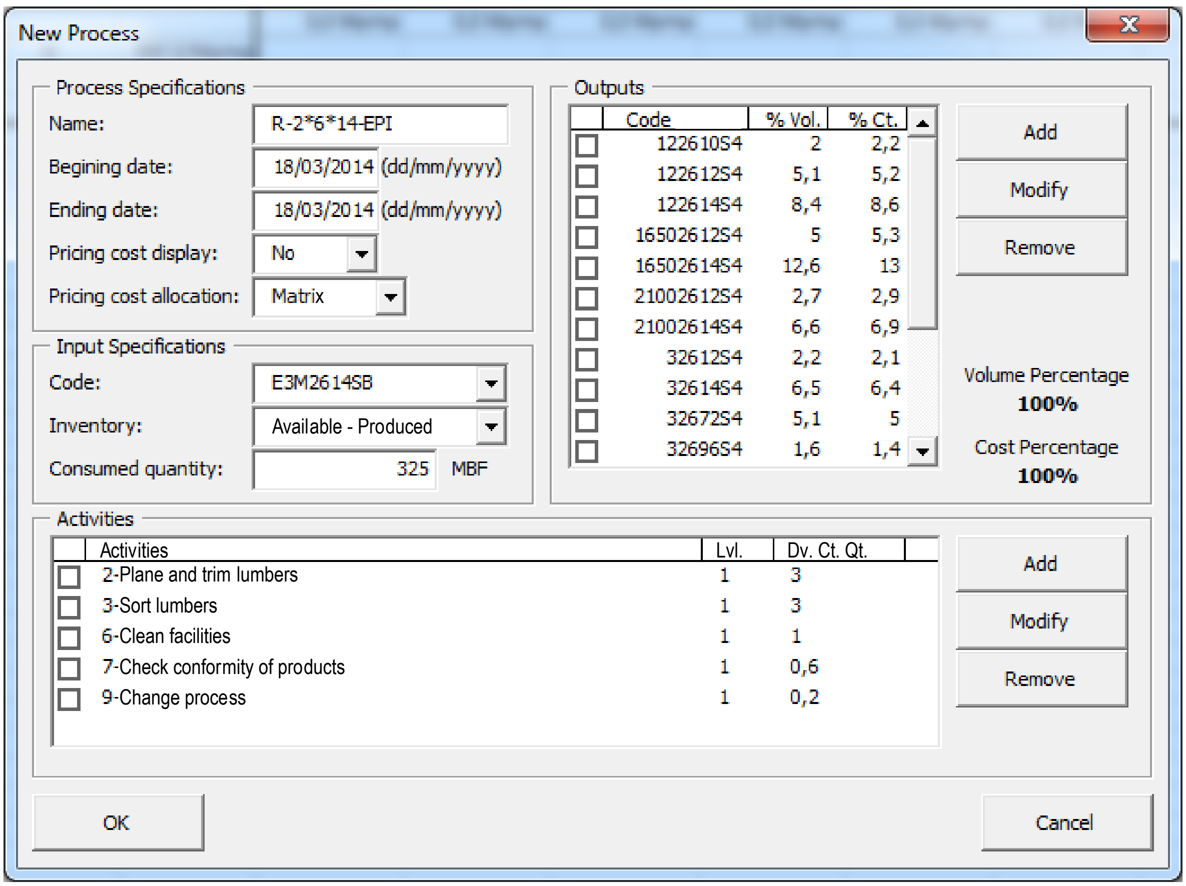

Figure 15 Process setting user form

The other method is more relevant regarding the company’s interests because it computes an allocation that is function of the revenue generated by an output: more the revenue obtained from the sale of the product is important, higher is the cost allocated to the product. This way, if one of the outputs is to be disposed – a zero price – then no cost is allocated to it. In case the process beginning date is different from the ending one and the price of a product varies, a weighted average value of the price is computed based of the proportion of the total quantity sold at each price value.

		Process 1	Input Consumption	325 MBF				
		Process Benefit	10,00%					
		Input Cost	Material Cost	2	3	6	7	9
		100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
Output 1	Computed Allocation Coef.	2,2%	2,2%	2,2%	2,2%	2,2%	2,2%	2,2%
	User Allocation Coef.	2,2%	2,2%	2,2%	2,2%	2,2%	2,2%	2,2%
	Cost	2 503 $	3 $	14 $	6 $	1 $	1 $	3 $
	Total Cost	2 530 $						
	Produced Volume	7 MBF						
	Minimum Price	401,29 $/ MBF						
	Computed Price	433,30 $/ MBF						
	User Price	433,30 $/ MBF						
	Maximum Price	463,29 $/ MBF						
	Revenue (User Price)	2 816 $						
	Benefit	287 $						
	Benefit (%)	10,17%						
Output 2	Computed Allocation Coef.	5,2%	5,2%	5,2%	5,2%	5,2%	5,2%	5,2%
	User Allocation Coef.	5,2%	5,2%	5,2%	5,2%	5,2%	5,2%	5,2%
	Cost	5 915 $	7 $	33 $	15 $	1 $	1 $	8 $
	Total Cost	5 980 $						
	Produced Volume	17 MBF						
	Minimum Price	402,38 $/ MBF						
	Computed Price	441,80 $/ MBF						
	Chosen Price	441,80 $/ MBF						
	Maximum Price	467,72 $/ MBF						
	Revenue (Chosen Price)	7 323 $						
	Benefit	1 343 $						
	Benefit (%)	18,34%						

Table 10 Pricing Cost

Cells colored in gray in the Table 10, are those that are taken into account to compute benefits and costs. They are also the one the user is able to modify. This way, he can lower the allocation percentage or the price of a product and increase another one and see instantly the impact on the benefits made on both products. Several processes can be displayed on the Excel sheet to enable the user to compare profitability of each of them and analyze if a product must be obtained from a process rather than from another. A graph like the one on Figure 16, gives an overview of the results. The first process uses the second method to compute the pricing costs. Consequently, percentage of benefit for each product is equal. The second one uses the first method: allocation percentage chosen by the user. In this case, we can see that some of the products are not profitable whereas some others has a very high benefit.

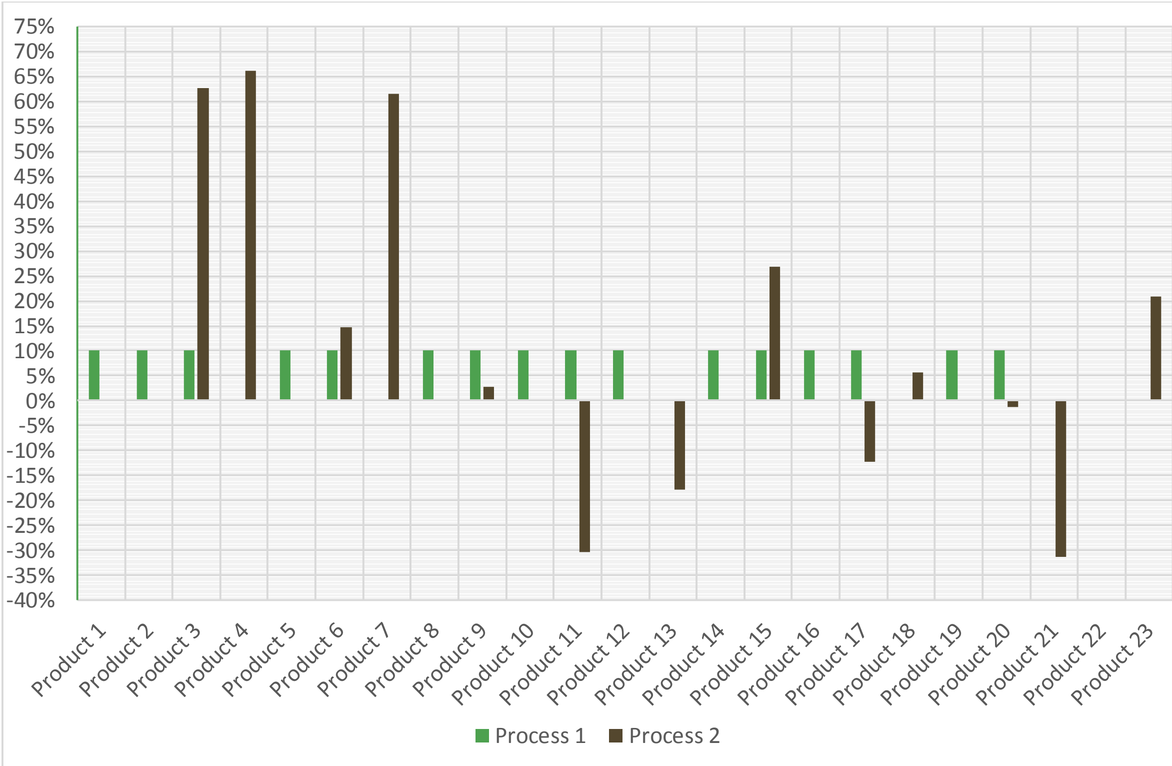

Figure 16 Products margin per process

Conclusion

As demonstrated in this thesis, ABC can be a very powerful tool to help the decision maker to manage the supply chain when divergent processes occur in the production line. Contrary to convergent manufacturing industries, this kind of companies cannot consider only final products as cost objects but need to analyze each process input throughout the production line. Under these conditions, we conclude that production costs have to be distinguished from pricing costs.

The first one is the result of the ABC method application which depends on the sawmill features and the way resources are acquired – the resources capacities. Whatever the use made of the sawmill, that there is production or not, production costs do not change once they are set until a change is made in the sawmill features or the resources capacities. From this production costs, the decision maker can build his production planning regarding the procurement and demand scenarios. As a support tool for this decision step, we designed a production planning tool based on a mathematical model. Because of its high level of complexity due to the integer variables which model the drying operation of the sawmill, we proposed a three phases method which enable to solve the mathematical model in a reasonable time by a commercial solver like Cplex or Gurobi.

Considering the production planning, the second one consists in sharing each input production costs among outputs obtained from this input taking into account the revenue the output will generate. Sharing policies are set according to sales environment. The correct policy depends only on context and decision maker requirements. If the production cost is determined objectively based on the resource consumption, the pricing cost is subjective and has for objective to analyze the profitability of the sawmill.

But the agility of this method makes it as easy to adapt to any industrial field as it is strongly dependent on the way it is implemented. Every activities is described by resources cost drivers and an activity cost driver whose values depend on the period and the features of the sawmill at the time the decision is taken. It cannot be transposed unchanged from a company to another and even in the same company, the cost drivers must be updated once or twice a year.

One of the major improvements that could be made to improve the production planning operation is to integrate the tactical and strategic level in the model to size the resource capacity but it would require the addition of a lot of integer variables which would complicate the resolution of the mathematical model. Another improvement that could be implemented is the integration of the pricing costs computation policies in the production planning tool in order to identify unprofitable operations and products. In this case one of the most interesting policy would be the one given in the section IV.4.c.ii which use GT assumptions. By doing so, it would be relevant to replace the activity cost drivers by the same policy. The total amount associated with an activity would not be allocated to processes inputs according to the activity cost driver but according to the revenues that processes outputs will generate. In this particular case, pricing and production costs would be mixed up.

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Appendix

I. CIGI Conference Proceeding

CIGI 2013

La comptabilité par activités appliquée aux processus divergents pour la prise de décision : cas d'application dans une scierie

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Résumé – Plusieurs décisions d'importance en gestion de la chaîne logistique telles la planification des investissements, le choix des produits à fabriquer et la planification de la production doivent être fondées sur des données précises, notamment au niveau des coûts pertinents. Or bien souvent, les coûts de production sur lesquels sont basées ces décisions sont calculés de façon approximative. Les méthodes de comptabilité par activités (CPA) sont des méthodes qui se basent sur la consommation des ressources par les produits tout au long du processus de transformation. Bien que la CPA soit utilisée depuis plus de deux décennies dans les systèmes de production convergents, leur adoption en contexte de production divergente nécessite toutefois quelques adaptations importantes. Cet article propose une méthodologie d'application des méthodes de comptabilité par activités dans les systèmes de production divergents. La méthodologie est illustrée à l'aide d'un cas d'application portant sur l'un des systèmes de production divergents en quête de nombreuses innovations au Québec : une scierie.

Abstract – Key decisions in supply chain management regarding investments, the choice of products to make, production planning and the choice of customers must be based on precise information such as costs. However, fixed and variable costs used in decision models are often based on approximations. Traditional activity-based costing (ABC) methods work on the assumption that product are consuming resources all along the process of manufacturing, and are very useful for decision-making purposes. While ABC has been successfully applied in convergent manufacturing supply chains, their application to divergent production systems remains challenging for numerous reasons. This paper proposes a methodology to apply ABC methods in divergent production systems. This methodology is validated using a case study from the sawmilling industry.

Mots clés – Comptabilité par activités, systèmes de production divergents, planification de la production.
Keywords – Activity-based costing, joint products, production planning.

1 Introduction

Dans un contexte économique où la concurrence est rude et mondiale, le pilotage de la chaîne logistique d'une entreprise doit être fait de façon à maximiser la création de valeur ajoutée pour le client. La recherche d'efficacité et de productivité passe forcément par une connaissance précise de l'ensemble des coûts pertinents.

L'utilisation des coûts issus des processus de comptabilité financière (aussi appelée comptabilité générale) pour la prise de décision en gestion de la chaîne de valeur comporte plusieurs risques et inconvénients. En particulier, les mécanismes d'allocation des frais généraux issus de la comptabilité traditionnelle s'avèrent inadéquats pour établir des coûts unitaires pertinents à la prise de décision (Kaplan and Cooper 1987).

Une des méthodes les plus novatrices à l'heure actuelle qui permet de calculer les coûts de production de l'ensemble des extrants d'une entreprise est probablement la méthode de comptabilité par activités (CPA). Elle permet de créer une relation directe entre les caractéristiques du processus de fabrication d'un produit et les dépenses engendrées pour la réalisation de ce processus. Chaque produit ou sous-produit se voit ainsi attribuer un coût qui est fonction de la consommation de ressources directes et indirectes qu'il a induite.

Parmi les mérites attribués à la CPA dans la littérature, on note la préférence des décideurs pour le type d'informations qu'elle produit par rapport aux données issues de la comptabilité traditionnelle (Charles and Hansen 2008a) ainsi que sa capacité à fournir une image précise de l'allocation des coûts aux produits (Baykasoglu and Kaplanoglu 2008). L'application de la CPA permet donc une meilleure compréhension de la façon dont les produits, les activités et les processus consomment des ressources, génèrent des coûts et des revenus.

En particulier, la CPA permet une meilleure allocation des coûts directs et indirects aux produits. Dans plusieurs industries requérant des investissements importants dans la machinerie, l'outillage ou d'importante dépenses énergétiques, ces coûts constituent une portion considérable des coûts totaux de l'entreprise (Kaplan and Cooper 1991). C'est notamment le cas dans l'industrie forestière, par exemple. De nombreux modèles de planification ont été proposés pour différents processus de gestion de la chaîne logistique (Carlsson et al. 2009) ; tous ces modèles s'appuient sur des données sur différents types de coûts.

1.1 Problématique

L'application de la CPA aux systèmes de production divergents nécessite de relever un certain nombre de défis. Dans un système de production divergent, on produit simultanément un panier de produits à partir d'un ensemble de matières premières. L'allocation des coûts aux différents produits est source de défis particuliers. Un panier de plus de 1000 produits peut ainsi être fabriqué à partir d'une vingtaine d'intrants. De plus, les caractéristiques d'un même produit peuvent changer et engendrer ainsi d'importantes variations dans la réalisation et la performance d'un procédé. Une autre difficulté est rencontrée lorsque le panier de produits fabriqué (ou les recettes de production utilisées) changent au cours de l'année. Dans ce contexte, un calcul basé sur des coûts moyens annuels peut s'avérer inadéquat pour supporter un processus de prise de décision. Pour toutes ces raisons, il s'avère nécessaire d'adapter la CPA telle qu'elle est traditionnellement pratiquée afin de supporter la prise de décision en matière de pilotage des chaînes logistiques divergentes.

1.2 Plan de l'article

La suite de l'article est structurée selon le modèle suivant. Tout d'abord, nous commencerons par détailler le contexte dans lequel la CPA a été utilisée et les difficultés inhérentes à son application aux processus divergents. La section 3 décrira la méthodologie développée pour déterminer des coûts appropriés pour la prise de décision dans les systèmes de production divergents. La quatrième section présente les cas d'application qui seront utilisés pour valider notre approche et en démontrer les avantages. Le cas d'application industriel étant prévu pour cet hiver, cette portion des résultats sera présentée à la conférence.

2 Contexte

La mondialisation soulève de nombreuses problématiques qui conduisent les entreprises à revoir leur façon de produire. De plus en plus, les entreprises considèrent la nécessité de se munir d'outils permettant de gérer leur production et l'ensemble de leur réseau logistique. Il ne suffit plus de produire en fonction de ce que notre fournisseur est en mesure de nous proposer, il faut désormais tenir compte de la demande du client. L'optimisation des paniers de produits, le choix des clients et des fournisseurs deviennent par conséquent des questions déterminantes, garanties de la pérennité de l'entreprise (Frayret et al. 2008). Les coûts de production sont un des principaux outils d'analyse de l'entreprise. Nous allons donc voir ce qui a amené les entreprises à laisser de côté les méthodes comptables pour se tourner vers des méthodes leur donnant une meilleure visibilité sur les moyens financiers à mettre en œuvre pour produire de la façon la plus rentable possible. Nous commencerons donc par dresser un portrait des méthodes traditionnelles de calcul des coûts de production. Nous étudierons ensuite l'évolution de la méthode de comptabilité qui a fait l'objet de nombreuses recherches et sur lesquelles porte notre étude : la CPA. Nous finirons par proposer notre propre méthode de CPA dans le contexte particulier d'une scierie.

I.1. Comptabilité de gestion des systèmes divergents

Une des problématiques intrinsèques aux processus divergents est l'allocation des coûts de production entre les différents produits issus d'un même intrant. Dans une scierie, les opérations d'écorçage et de sciage présentent cette caractéristique. Comment répartir équitablement le coût du processus entre les écorces et la grume d'une part et les différentes pièces de bois d'œuvre et les sciures d'autre part ? Traditionnellement (Brault and Giguère 2003), la finance impose de n'attribuer aucun coût aux sous-produits – les écorces et les copeaux – sinon la différence entre le montant récupéré lors de leur vente et les coûts qui ont permis leur traitement après leur moment d'obtention. . De cette façon, plus les sous-produits sont vendus chers plus le coût de production du bois d'œuvre diminue.

Plus particulièrement dans l'industrie du sciage, le coût de production est parfois simplement obtenu en divisant les dépenses totales par le volume obtenu (White 1980). Certaines scieries utilisent aussi des méthodes plus précises avec une séparation des dépenses en coût fixe et coût variable, mais là encore, le coût de production au mètre cube est le même pour tous les produits d'un même panier de produits et le coût des sous-produits reste inconnu. Les marges sont donc estimées. C'est pour cette raison que certains produits, jugés non profitables, sont délaissés par les commerciaux et restent parfois indéfiniment en inventaire.

I.2. Comptabilité par activités

Depuis une trentaine d'années, la comptabilité traditionnelle est remise en cause (Kaplan and Cooper 1987). Kaplan met alors en avant le fait qu'il est primordial de connaître le coût de production des produits. Les méthodes de CPA ont surtout été développées dans cette optique, majoritairement dans le cadre des industries manufacturières. Elles avaient pour premier objectif d'analyser la consommation des ressources indirectes à un niveau microscopique de l'entreprise (Kaplan and Cooper 1991). En découlait alors des décisions concernant les investissements à effectuer, les produits à fabriquer, le choix de la taille des lots à produire etc. On tirait des conclusions sur ce qui avait été fait.

Kaplan et Cooper définissent quatre étapes dans l'établissement d'une méthode de CPA (Kaplan and Cooper 1998). La première consiste à déterminer les différentes activités de l'entreprise ; la deuxième à allouer les ressources aux activités, notamment par la hiérarchisation et parfois au regroupement de celles-ci ; la troisième à identifier les produits, services et clients de l'entreprise et la quatrième à déterminer les vecteurs coûts. Ces activités ont été plus ou moins normalisées avec le temps (Kaplan and Cooper 1998). Elles sont réalisées selon quatre niveaux hiérarchiques :

4. Activités réalisées pour chaque unité d'un produit ;
5. Activités réalisées pour un lot de produit ;
6. Activités réalisées pour chaque produit ;
7. Activités réalisées pour l'usine.

Afin d'objectiver au maximum l'établissement de la méthode, Deherripon (Deherripon 1996) propose un processus détaillé pour passer d'une méthode de comptabilité traditionnelle à une comptabilité par activités. Il passe pour ce faire à travers une analyse des responsabilités des dirigeants, qu'il décline en fonctions de bases, elles-mêmes subdivisées en fonctions élémentaires. Chaque fonction élémentaire est ensuite associée à une activité – un ensemble homogène par rapport à son vecteur de coût – et un centre de coût comptable. Les ressources – effectifs, dépenses générales ou amortissements – sont attribuées aux activités.

Dans le cas de processus divergents, il n'est plus possible de s'en tenir uniquement à ce type de méthode. Comme le propose Tsai (Tsai 1996), les processus vont intervenir pour la répartition de toutes les ressources autres que celles liées aux matériaux que l'on attribuera directement aux produits. Ainsi, les ressources directes seront allouées aux processus dont elles dépendent, et les ressources indirectes seront distribuées entre les différentes activités. De la même façon que les produits consommeront les ressources liées aux processus au moyen de vecteurs de coûts, les processus consommeront les ressources des activités selon d'autres vecteurs de coûts.

Avec le développement des modèles mathématiques, on commence à utiliser les méthodes de CPA non plus pour juger de l'utilisation des ressources – demande – mais pour déterminer comment les utiliser – approvisionnement. On cherche alors à savoir comment gérer ses habiletés au cours du temps. La théorie des contraintes qui permet une optimisation du profit sur le court-terme est alors couplée à l'utilisation d'une méthode de CPA, plus axée sur le long-terme ((Kaplan and Cooper 1998) et (Kee and Schmidt 2000)). Shapiro (Shapiro 1999) ajoute également la théorie du management par les ressources (Resource-based view).

Comme pour les systèmes de production convergents, Tsai and Lai proposent également pour les systèmes de production divergents l'utilisation d'un modèle mathématique pour la gestion des ressources, l'expansion de la capacité ou la sous-traitance (Tsai and Lai 2006). Les deux auteurs concluent alors qu'en contexte de prise de décision stratégique, il n'est pas nécessaire d'étendre l'allocation des coûts aux produits, seule une allocation au niveau des différents processus d'une activité est suffisante.

Toutefois, en contexte de planification tactique ou opérationnelle, l'obtention de coûts de production par produit peut s'avérer particulièrement pertinente. Ces coûts permettent notamment de supporter différents types de décisions :

- L'introduction ou non d'un nouveau produit ;
- Le choix des produits à fabriquer en priorité ;
- La négociation du prix de vente des produits;
- Détermination de la rémunération du vendeur (commission sur la marge).

Le coût du processus, lié aux caractéristiques de l'intrant, pourra être distribué entre les différents extrants selon le volume ou la masse, la valeur marchande, la quantité ou toute autre méthode pertinente aux yeux du décideur (Tsai 1996). En 2008, Tsai (Tsai et al. 2008) compare aussi l'utilisation de la théorie des contrainte, avec celle d'un modèle mathématique basé sur une méthode de CPA proche de celui de leur article de 2006, et celle d'un autre modèle mathématique lui aussi basé sur une méthode de CPA mais qui permet de dimensionner la capacité disponible de certaines activités selon que leur gestion est discrétionnaire ou non. Les trois modèles permettent de déterminer comment doivent être utilisés ou non les processus et leur ressources, à court, à moyen et à long terme et avec un dimensionnement des ressources approprié à chacun des horizons.

Certains ont également proposé l'application de méthodes de CPA au domaine de l'industrie du bois d'œuvre. Wessels et Vermaas (Wessels and Vermaas 1998) proposent une allocation par produit pour une scierie munie de deux lignes de sciage, de séchoirs et d'un module de classement. Une équation générale permettant l'allocation selon plusieurs vecteurs de coûts – comme le volume ou le nombre d'unités – du coût global d'un processus. Les dépenses partagées par plusieurs activités sont partagées par le biais de relations linéaires dont les coefficients traduisent les utilisations réciproques des activités entre elles.

Une autre méthode, plus aboutie, est proposée par Korpunen, Mochan et Uusitalo (Korpunen, Mochan, and Uusitalo 2010). Des formules spécifiques sont définies pour chacun des processus de la scierie permettant ainsi de suivre l'évolution du coût associée à une bille et ses produits au long de son cheminement dans l'usine. Toutes ces méthodes ont en commun de ne pas prendre en compte la variabilité des processus – comme les temps opératoires ou la consommation d'énergie – au cours de l'exercice. En effet, selon la période de l'année et la localisation de la scierie, les caractéristiques de certains processus – comme le séchage – vont varier de façon très significative et par voie de conséquence les coûts aussi.

3 Méthodologie

Cette section présente la méthodologie développée pour déterminer les coûts pertinents pour chacun des produits à l'aide de la CPA. Le protocole vise à établir des coûts pertinents à la prise de décision dans un contexte décisionnel donné, tel un problème de planification de production d'un processus divergent. Nous supposons ici que la prise de décision sera optimisée à l'aide de la formulation puis de la résolution d'un modèle mathématique à l'aide d'un solveur, de règles de gestion ou d'une heuristique.

Ce protocole, représenté par la Figure 17, se décompose en plusieurs étapes qui seront décrites dans les sous-sections 3.1 à 3.5.

3.1 Génération de demande et de prévisions

La première partie du protocole consiste à générer un scénario de demande. Dans ce cas, la demande peut être de source externe (issue d'un carnet de commandes ou de livraisons) ou internes (issue d'un plan de production d'un processus en aval dans la chaîne logistique). Différentes approches peuvent être utilisées pour établir ce scénario de demande :

- Des données issues directement de la demande du marché. La demande est dans ce cas très largement supérieure – voir infinie – à ce que la scierie est en mesure de produire. On peut alors considérer que l'usine peut vendre n'importe quel produit qu'elle fabrique. On obtient alors la combinaison de produits idéale ;
- Des données issues de la demande réelle d'une entreprise. Ce scénario correspond généralement à la demande réelle de l'entreprise, soit le carnet de commande client ;
- Des prévisions faites à partir d'un modèle ou plus intuitives basées sur un historique de données réelles ou établies selon les besoins de l'étude. On utilisera alors des prévisions pour une période donnée postérieure à un historique de demande utilisé pour l'initialisation et le calcul des prévisions au dernier jour de l'historique.

I.3. Établissements des coûts totaux pertinents à l'étude

Le deuxième volet de la méthodologie consiste à établir le coût annuel qui sera utilisé pour déterminer, au moyen de la méthode de CPA, les coûts des processus nécessaires pour la génération d'une première planification. Celui-ci sera là encore défini selon trois cas de figure :

- Le coût annuel du scénario induit par le scénario de demande client. Nous avons dans ce cas un coût budgété ;
- Le coût annuel engendré par une année de l'historique ;
- Le coût annuel correspondant à l'utilisation de l'usine au maximum de sa capacité.

3.2 Répartition des coûts selon la méthode de CPA

Un des points critiques de l'établissement d'une méthode de CPA se situe au niveau du choix des vecteurs de coûts qui lient les activités aux processus ou ceux qui lient les processus aux produits. Ce sont ces derniers qui vont être garants de la précision des coûts obtenus. Il faut bien avoir à l'esprit qu'il serait absurde de chercher à calculer un coût de production avec cinq chiffres significatifs si l'on ne peut avoir accès qu'à des données approximatives.

Comme l'expliquent Deherripon (Deherripon 1996) ou Kaplan et Anderson (Kaplan and Anderson 2003), il se pose également le problème de l'homogénéité des vecteurs de coûts. En effet pour une même activité, certaines fonctions d'appliqueront à des lots tandis que d'autres dépendront plutôt du volume traité. Kaplan et Anderson (Kaplan and Anderson 2003) proposent alors une méthode basée sur le temps – Time-Driven Activity Based Costing – où le vecteur coût est alors un coût par unité de temps qui tient compte de la capacité utile d'une activité en terme de durée disponible. La méthode proposée par Korpunen (Korpunen, Mochan, and Uusitalo 2010) utilise majoritairement les vitesses linéaires de ses processus, ce qui correspond là aussi à des vecteurs coûts basés sur le temps. Différentes bases de répartition des coûts peuvent être utilisées, telles le volume, la masse ou encore le temps associés aux processus. Dans tous les cas, la base retenue doit permettre une répartition juste des coûts indirects aux différents processus et aux produits via le processus de CPA, et doit également permette d'exprimer la capacité de ces processus. Pour fins d'illustration dans la suite de cet article, nous utiliserons uniquement le temps comme vecteur coûts.

Dans l'éventualité où le temps est utilisé comme vecteur coût, (Korpunen, Mochan, and Uusitalo 2010), il faut tenir compte des temps non productif induits par certaines activités sur les processus. En effet, les temps de changement d'outils, de nettoyage des machines d'un lot de produit à l'autre ou de mise en position devront être ajoutés de façon équitable aux temps de production des produits pour chaque processus. On pourra alors utiliser un coefficient de correction qui augmente le temps du processus en fonction d'une caractéristique du produit. Dans le cas où une autre base de répartition est utilisée, on doit tenir compte des sources d'improductivité associées à la production, tels les produits échouant au contrôle de qualité ou les matières premières gaspillées. Différentes bases de répartition peuvent également être utilisées pour différents processus au sein d'un même système. Le Tableau 1 définit les notations utilisées dans l'équation qui régit le vecteur coût liant un processus aux produits est la suivante :

Notation	**Définition**
k	Indice produit
t	Temps (jour)
N	Nombre de processus
I_{p_i}	Intrant du processus p_i
p_i	Processus numéro i
C_{k,t,p_i}	Coût du processus p_i effectué à la période t pour le produit k
$C_{p_i}^{tot}$	Coût annuel du processus p_i
Δ_{k,t,p_i}	Temps opératoire du processus p_i effectué à la période t pour le produit k
$\Delta_{p_i}^{tot}$	Temps maximal annuel (capacité) disponible pour le processus p_i

Tableau 1 Notation vecteurs coûts

$$C_{k,t,I_{p_i}} = C_{p_i}^{tot} \times \left(\frac{\Delta_{k,t,I_{p_i}}}{\Delta_{p_i}^{tot}}\right), i \in \{1, \dots, N\} \quad \textbf{(1)}$$

Cette équation signifie qu'un coût est engagé à chaque fois qu'un produit est transformé par un processus. On fera bien attention à la décomposition de l'intrant choisie qui engendre le coût d'un processus donné. On pourra selon les cas utiliser le volume, la masse, l'unité ou encore un lot d'un intrant d'un processus. Ce choix doit tenir compte du fonctionnement réel du processus, tant du point de vue du procédé de fabrication que de la mise en œuvre de celui-ci. Certains processus ne peuvent s'exécuter que pour une quantité minimale d'intrant donnée tandis que d'autre peuvent être exécutés quelle que soit la quantité d'intrant.

3.3 Algorithme de planification

Cette étape consiste à générer un plan de production pour tout l'horizon de planification. Différentes méthodes de planification peuvent être utilisées ; nous recommandons l'utilisation d'un modèle mathématique résolu à l'aide d'une technique appropriée (programmation linéaire ou en nombres entiers).

Il est également possible de combiner de diverses façons les scénarios de demande et les coûts annuels initiaux pour alimenter l'algorithme de planification.

3.4 Recherche d'un plan équilibré

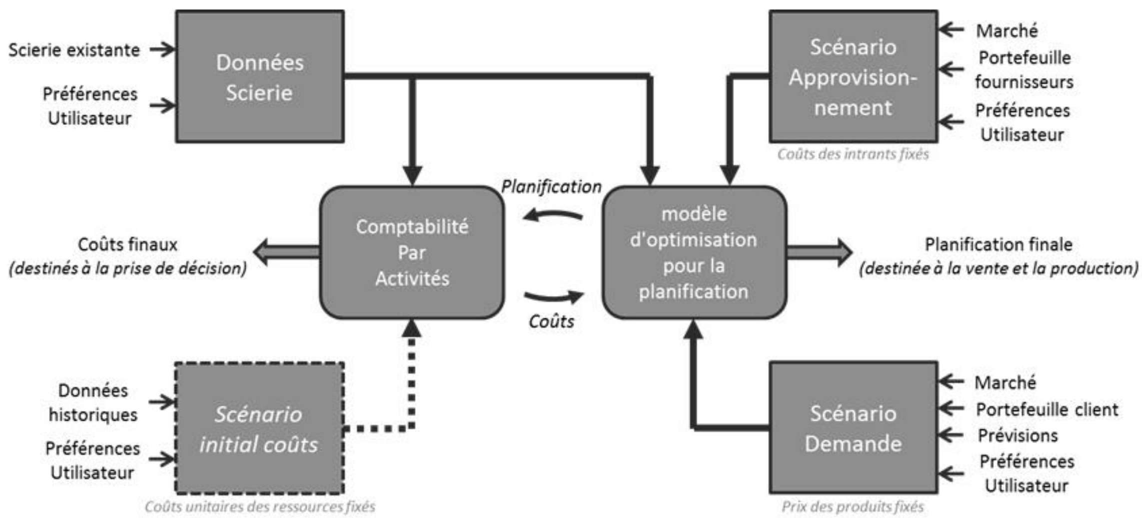

Figure 17 Protocole

La première étape du protocole consiste à appliquer la méthode de CPA de façon à obtenir pour chaque processus un coût par unité de vecteur de coût – par unité de temps dans notre exemple. Ce coût sera donc fonction des ressources allouées au processus et de la capacité – la durée d'utilisation par exemple – de ce dernier. Nous avons choisi d'utiliser pour ce calcul initial les capacités théoriques des processus.

La deuxième étape consiste à générer une première planification au moyen du modèle d'optimisation. Cette planification engendre un coût annuel différent de celui qui a permis de l'établir et le profit calculé lors de la résolution du modèle mathématique n'est donc pas celui que fera la scierie en suivant la planification.

La troisième étape est donc la mise à jour des données utilisées pour le calcul des coûts par la méthode de CPA.

Ces nouveaux coûts peuvent être utilisés par le modèle mathématique pour la détermination d'une nouvelle planification qui fait ainsi l'objet de la quatrième étape.

Comme de nouveaux coûts de production peuvent être calculés à partir des données d'une planification, il est possible de procéder à plusieurs itérations des étapes trois et quatre.

Ce protocole peut également être utilisé pour des fins autres que ceux propres à la planification. Par exemple, une analyse de la rentabilité d'un nouveau produit peut être réalisée en l'intégrant aux patrons de coupe utilisés. Il permet notamment d'établir un coût de production réaliste pour ce produit, qui tient compte de l'ensemble des produits et des coûts. Cette information peut par la suite être utilisée pour établir un prix de vente pour un ou plusieurs nouveaux produits – ou pour réévaluer les prix de vente des produits actuels.

4 Cas d'application

Dans les paragraphes qui vont suivre, nous allons présenter le cas d'application, défini à partir de données issues de la littérature. Ce cas a été développé pour valider la méthodologie présentée dans cet article. Le modèle de scierie que nous avons choisi pour construire notre étude se base sur celui proposé par Korpunen (Korpunen, Mochan, and Uusitalo 2010). Hormis les temps opératoires et les heures de fonctionnement des différents processus, les mêmes données ont été utilisées. Ce cas d'application couvre l'ensemble des processus d'une scierie, de l'arrivée des billes de bois à l'expédition des produits à l'exception du processus de finition. Le nombre de types de billes (16) et de produits finis (28) utilisé dans ce cas est toutefois plus faible que le nombre de produits réalisés par une scierie canadienne typique où le processus de finition est présent.

Plusieurs raisons motivent l'utilisation de ce cas d'application. En premier lieu, la mise en place d'une méthode de CPA nécessite l'accès à un grand nombre de donnés sensibles, notamment sur les coûts et les rendements des activités et des processus d'une entreprise. Une première validation ainsi que la création d'un prototype s'avèrent souvent nécessaires pour convaincre un partenaire industriel de participer à la réalisation d'un projet réel impliquant l'ensemble de ses données. De plus, il permet de valider la méthodologie dans différents contextes de planification.

4.1 *Processus utilisés*

La Figure 18 illustre les processus utilisés dans cette scierie ainsi que les différents flux de matières entre ces différents processus. Huit processus qui transformeront différents types d'intrants constitueront ainsi la scierie :

- Le triage des billes ;
- L'écorçage des billes ;
- Le sciage des grumes ;
- Le classement du bois vert qui traitera individuellement les différentes pièces de bois d'œuvre ;
- Le séchage d'un lot de bois d'œuvre d'une même essence constituée par des pièces de mêmes caractéristiques dimensionnelles ;
- Le classement du bois sec qui traitera séparément les différentes pièces de bois d'œuvre ;
- L'expédition qui constituera les commandes en fonction des volumes de bois d'œuvre requis et les conditionnera ;
- Le traitement des sciures et des copeaux provenant d'une bille au processus de sciage.

Il est à noter que l'écorçage et le sciage sont les processus divergents de ce système de production. Le séchage est le processus critique d'une scierie puisqu'il nécessite la constitution d'importants lots dont le temps de traitement sera près de dix milles fois supérieur aux temps opératoires des autres processus.

4.2 *Coûts pertinents et bases de répartition*

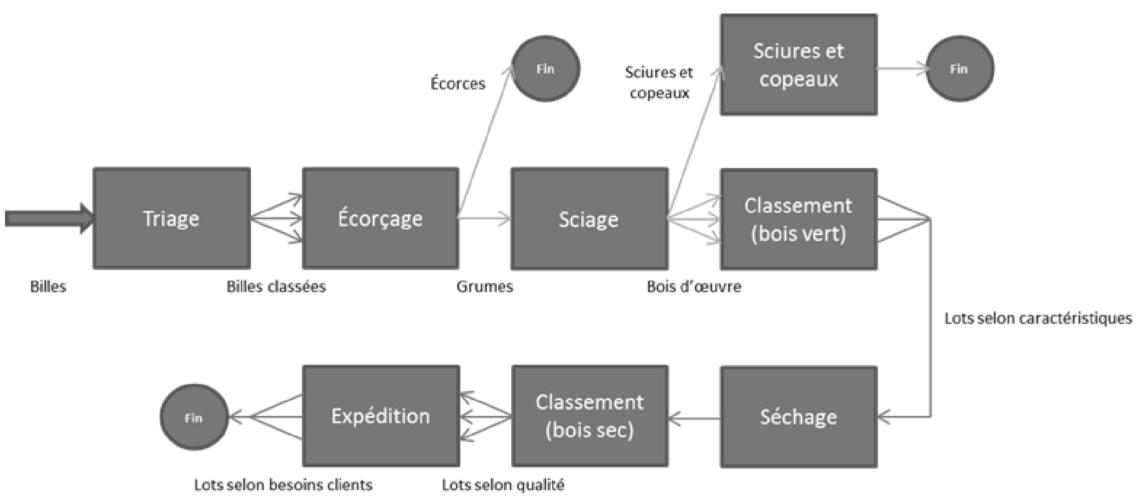

Figure 18 Modèle de Scierie

Le cas réalisé prend en compte l'ensemble des coûts associés aux opérations de la scierie, du triage jusqu'à l'expédition. Ainsi, nous ne tiendrons pas compte dans cette étude des coûts liés à l'acheminement des billes jusque dans l'enceinte de l'usine ni ceux liés au transport des différents produits jusqu'au client.

La majeure partie des dépenses est liée à la production. Puisque l'étude de Korpunen (Korpunen, Mochan, and Uusitalo 2010) couvre essentiellement la production, nous assumons que les départements de recherche et développement, des ventes, de la maintenance ou des opérations de lancement sont intégrés à un département que nous nommerons coûts généraux ou englobés dans les différents processus. Tel que le préconise la méthodologie de Tsai (Tsai 1996), et en considérant le cas particulier de notre cas de littérature, tous les coûts seront alloués aux processus qui seront ensuite consommés par les intrants de ces processus.

Nous considérerons les ressources annuelles suivantes pour chacun des processus :

- Coûts généraux : ils comprennent l'amortissement des bâtiments administratifs et un coût proportionnel à la surface du terrain occupé, le salaire du directeur et du personnel de soutien et les frais d'administration. Dû à leur rôle de gestion et de support, ces frais sont répartis entre les différents processus au prorata du nombre d'employés de production – main d'œuvre directe – de ces derniers ;
- Coûts des bâtiments : ils correspondent à l'amortissement des bâtiments du processus et du coût proportionnel à la surface du terrain occupé ;
- Coûts de machines : ils sont égaux au coût d'amortissement des machines utilisées par le processus;
- Coût de la main d'œuvre : ils comptent le salaire des ouvriers, contremaitres ou autre catégories de personnel qui sont affectés au processus ;
- Coûts de manutention : ils permettent de distribuer le coût des engins de manutention comme les chariots élévateurs entre les différents processus ;
- Coûts des forces motrices : ils incluent les coûts très importants liés à la consommation d'énergie électrique ou thermique du processus.

4.3 Caractéristiques des produits

Le bois est un matériau dont les caractéristiques vont énormément changer d'une bille à l'autre. Même si on retrouve une certaine homogénéité au niveau des dimensions et de l'essence, différents patrons de sciage sont possibles pour une bille donnée. De nombreuses activités de recherches industrielles et académiques ont permis le développement d'outils permettant de déterminer des méthodologies appropriées pour la classification des billes (Wéry et al. 2012b) ou les patrons de sciage type applicables à une morphologie de bille donnée (Jacques 2010). Par exemple, l'outil OptiTek a été développé à cette fin par FP Innovations. Cependant, ce problème est en soi très complexe.

Dans le cadre de cette étude, nous utilisons un seul patron de sciage par type de bille comme le propose Korpunen (Korpunen, Mochan, and Uusitalo 2010). Quatre longueurs de billes sont utilisées, disponibles chacune dans quatre diamètres différents totalisant ainsi seize types de billes. À chacune des billes sera associé un unique patron de coupe. Ces billes permettent d'obtenir vingt-huit produits, dont certains peuvent être obtenu de plusieurs billes différentes.

4.4 Génération du scénario de demandes et prévisions

Afin de tenir compte de l'évolution du profil de demande au cours de l'année, nous avons conçu un générateur le plus flexible possible. Celui-ci prend en compte différents paramètres :

- Une tendance annuelle traduisant le gain ou la perte de marché au cours du temps ;
- Une saisonnalité mensuelle pour respecter la variation de demande de certains produits au cours de l'année ;
- Une saisonnalité quotidienne permettant de prendre en considération les jours habituellement non travaillés et laissant la possibilité d'accentuer la demande sur d'autres ;
- Une variation aléatoire quotidienne définie pour chaque mois permet de donner du réalisme à notre scénario.

Pour garantir une évolution réaliste de la demande au cours de l'année, nous avons utilisé la méthode de journalisation Bouchard-Montreuil (Bouchard and Montreuil 2011). Cette dernière permet de faire varier progressivement la valeur des facteurs de saisonnalité mensuels et des coefficients de variation aléatoire.

La génération de prévisions s'inspire de la méthode décrite dans l'article de Bouchard et Montreuil (Bouchard and Montreuil 2011). Nous avons en revanche utilisé nos propres équations pour initialiser le calcul. Deux années d'historique au minimum sont nécessaires pour déterminer tendance, facteurs de saisonnalité et demande désaisonnalisée. Pour calculer les prévisions à partir d'un jour donné de l'année qui suit l'historique, le calcul de la tendance, des facteurs saisonnier et de la demande désaisonnalisée doit s'effectuer pour chaque jour qui précède ce jour à partir du premier jour de l'historique. Comme certains jours de la semaine peuvent ne pas être travaillés, nous avons considéré que l'horizon de prévision devait correspondre à un nombre de jours travaillés. Ainsi, pour une prévision sur un horizon de deux jours lorsque la fin de semaine n'est pas travaillée, nous aurons le vendredi les prévisions pour lundi et mardi.

4.5 Modèle et outils de planification utilisés

Pour réaliser la planification des opérations de la scierie, nous avons adapté le modèle mathématique intégré au sein de la plate-forme logicielle LogiLab, qui permet d'optimiser un réseau de la forêt jusqu'aux clients en maximisant les profits de celui-ci sur plusieurs périodes (Jerbi et al. 2012).

LogiLab a été conçu de façon à laisser à son utilisateur un maximum de flexibilité dans la conception et l'utilisation du modèle mathématique. Il nous a donc été possible de l'adapter pour optimiser la planification de notre scierie. À des fins de modélisation, les jours seront subdivisés en plusieurs périodes – des blocs de trois heures par exemple.

Les paramètres d'entrée sont les suivants :

- Les temps opératoires définis quotidiennement pour chaque processus, pour chaque produit indépendamment. L'utilisateur peut donner les moyennes mensuelles des temps et générer des temps journaliers en utilisant la méthode de journalisation Bouchard-Montreuil présentée plus haut dans la section concernant la génération de demande et de prévisions ;
- Les coûts issus de la CPA, les coûts des billes ainsi que les prix des produits pourront faire l'objet d'une journalisation par la méthode Bouchard-Montreuil ;
- Les capacités disponibles (temps d'utilisation disponible) pour chaque jour et chaque processus ;
- Les caractéristiques des processus. Chaque processus se voit défini par un ensemble de recettes qui définissent les relations entre les intrants et les extrants. Ces recettes sont surtout déterminantes pour les processus de type « un pour plusieurs » comme le sciage et « plusieurs pour plusieurs » comme le séchage où les patrons de coupe et la taille des lots respectivement sont déterminants dans le fonctionnement de la scierie. Les autres processus sont de type de type « un pour un ». Les temps opératoires supérieurs à la période seront arrondis au nombre entier de périodes supérieur. Ces processus seront alors nécessairement disponibles vingt-quatre heures par jour et sept jours par semaine.

- Le coût d'inventaire journalier de chaque produit au niveau de chaque processus et les volumes maximums et minimums que l'on peut stocker ;
- La position relative ou absolue – au moyen de coordonnées ou de relevé GPS respectivement – des processus les uns par rapports aux autres ;
- Les coûts, les distances et les délais de transport des produits entre les différents processus ainsi que les quantités transportées par voyages s'il y a lieu.

4.6 Protocole expérimental

La méthodologie proposée à la section 3 et représentée à la Figure 17 sera utilisée dans le cadre d'une planification monolithique. Différents scénarios de demande quotidienne ont été générés sur un horizon allant de quelques jours à plusieurs mois. Puisque la plupart des scieries opèrent à pleine capacité lorsqu'elles sont ouvertes, les scénarios ont été générés de façon à ce que la demande soit approximativement égale à l'équivalent d'une journée de production. La scierie utilisée dispose d'une capacité totale de production de 200 000 mètres cubes de bois par année soit 830 mètres cubes par jour ouvrables – au nombre de 239 – tous produits confondus. Le scénario de coût initial est pris sur le volume de production et dans l'optique que l'usine fonctionne à pleine capacité.

4.7 Exploitation des résultats

Une fois résolu, le modèle renvoie plusieurs informations pour chacune des périodes de l'horizon de temps considéré, qui rappelons-le, correspondent à des blocs de trois ou quatre heures :

- Le volume de chaque produit à acheter à chaque fournisseur – à la première période de chaque jour uniquement ;
- Le volume de chaque intrant à traiter par chaque processus ;
- Les volumes d'extrants produits ;
- Le volume à vendre à chaque client – à la dernière période de chaque jour uniquement ;
- Les stocks en fin de période pour chaque produit ;
- Le temps pris pour traiter le volume de chaque intrant ;
- Le pourcentage de la capacité utilisé pour chaque produit ;
- Le coût de traitement de chaque intrant ;

Des bilans sont faits à chaque jour et à chaque mois de l'horizon de temps afin de pouvoir jugée de l'influence de chaque paramètre sur le modèle et de la pertinence de la planification proposée lors de la résolution de celui-ci.

4.8 Résultats préliminaires

Les premiers résultats obtenus confirment ce qui est énoncé dans la section 3.5 : Le coût annuel d'une planification n'est pas égal à celui qui a permis de l'obtenir. De plus, on remarque qu'une planification optimale de la scierie ne correspond pas nécessairement à une utilisation de celle-ci au maximum de sa capacité. Certains processus ne sont utilisés qu'à la moitié de leur capacité alors que d'autres en revanche peuvent être considérés comme des goulots de production. Plusieurs facteurs peuvent expliquer ces phénomènes :

- La variation de la demande et des prix influe fortement sur la rentabilité des opérations.
- La ligne de production n'est pas toujours balancée. En effet, certains processus comme le sciage ou le séchage sont dépendants des caractéristiques des extrants traités et de la saison alors que d'autres, comme le triage ou l'expédition non.
- Les vecteurs de coût ne sont pas les mêmes pour tous les processus. Certains seront fonction du nombre de pièces traitées, comme le triage, alors que d'autres seront fonction du volume, comme l'expédition.

On remarque aussi que certains produits obtenus conjointement à d'autres et dont la demande est faible, ne peuvent finalement pas être vendus au moment où le client en fait la demande. Ceci est dû au processus de séchage qui ne peut traiter que des lots : le temps de constituer le lot, une grosse partie des ventes est perdue et le produit reste en stock en sortie des séchoirs. L'influence de plusieurs paramètres doit encore être évaluée pour pouvoir conclure sur les conditions d'utilisation de la CPA pour le support à la prise de décisions. De plus amples informations seront données au cours de la conférence.

5 Conclusion et travaux futurs

Dans le cadre de cet article, nous avons discuté de la pertinence d'appliquer les principes issus de la comptabilité par activités pour des fins de planification de la chaîne logistique. Les défis et avantages propres à l'application des méthodes de CPA aux systèmes de production divergents ont été identifiés et discutés.

Une méthodologie itérative permettant de déterminer une allocation des coûts aux différents produits qui reflète tant le panier de produits que le carnet de commandes de l'entreprise a été proposée. Celle-ci est validée à l'aide d'un cas d'étude construit à partir de données issues de la littérature scientifique. Afin de valider l'applicabilité de la méthodologie à une situation réelle, d'une part, et à confirmer l'utilité et la pertinence des coûts ajustés issus d'une méthode de CPA sur la qualité de la planification, d'autre part, nous avons également établi un partenariat avec un industriel. L'entreprise retenue est une scierie québécoise fabriquant des lambris et des moulures. Sa production est caractérisée par une très large gamme de produits de spécialité, souvent conçus et produits pour des clients spécifiques. L'étude réalisée dans ce cas industriel se concentrera sur un seul processus divergent de la scierie. L'application industrielle sera complétée au cours de l'année 2013.

Les conclusions associées à la première expérimentation ainsi que le protocole détaillé associé à la deuxième seront présentés en détail à la conférence.

6 Références

(See the Bibliography section)