

Margins-based planning applied to newsprint manufacturing

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ABSTRACT: The North American newsprint industry is facing a difficult financial situation due to a major market decline. The application of supply chain management concepts could greatly help this struggling industry by enhancing the cost-effectiveness of operations. In this paper, an integrated tactical planning model based on optimization was used to exploit manufacturing flexibility in order to adapt production to changing market conditions. This model was applied to a real case study of a newsprint mill with overcapacity in its thermomechanical and deinking pulping lines. Results show that by using a margins-based planning model to identify better-adapted operating policies in case of varying wood chips and recycled paper prices, earnings before interest, taxes, depreciation and amortization (EBITDA) can be increased by up to 35%. The benefits of exploiting manufacturing flexibility were found to be more important in difficult market scenarios, highlighting its pertinence for providing more-robust planning approaches. Pulp and paper companies would benefit from using a margins-based planning model to manage the complexity of their operations in the face of market volatility.

Application: Pulp and paper manufacturers have the potential to use advanced planning tools to better manage the flexibility of production assets.

Forestry commodity producers have been struggling in the last few years. Especially, the North American newsprint sector is severely affected, facing a major decline in domestic market and several mill closures. The traditional way of manufacturing, which aims at being the lowest-cost producer by maximizing throughput, may have worked for many years; however, it now seems insufficient or no longer adapted to the current business environment. Huge efforts must be made to rationalize production and inventory in order to adapt production capacity to the shrinking market, while still minimizing costs.

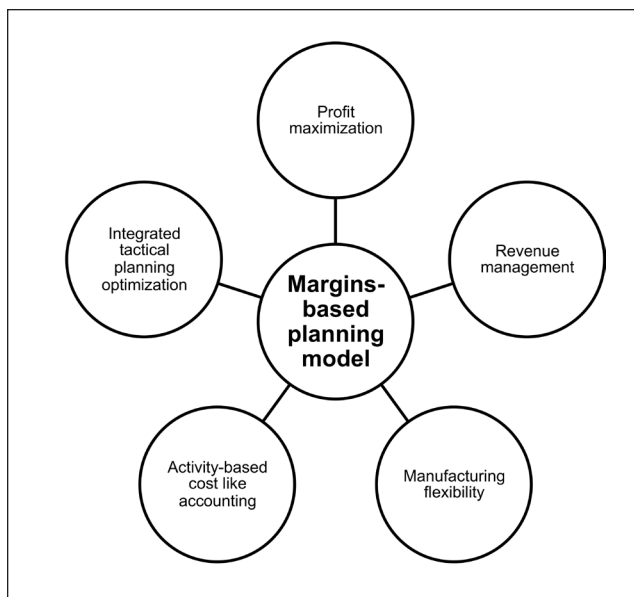
Over the past decades, both industry and academia paid a lot of attention to supply chain management to increase the cost-effectiveness of overall operations. Specifically, the latest trends in this domain are to manage the supply chain holistically; that is, by integrating procurement; production; distribution and sales; the different facilities of a company; and the strategic, tactical, and operational planning levels [1]. Supply chain management concepts could greatly help the North American pulp and paper industry, including newsprint producers, to compete globally [2].

A lot of research recently has been conducted on supply chain management in the forest products industry, but perhaps not as much as in other sectors [3]. D'Amours et al. reviewed major planning problems and models developed in this industry [4]. Carlsson and Rönnqvist presented logistics and planning problems addressed by a Scandinavian pulp company [5]. Feng et al. developed a sales and operations planning model for an oriented strandboard mill running in a

make-to-order environment [6]. In the chemical commodity industry, Kannegiesser and Gunther developed a mathematical model for the global value-chain planning of a manufacturer [7]. Specifically, their model optimizes profitability by coordinating sales quantity, price, and supply decisions throughout the value chain.

Such advanced planning models help planners to identify more profitable operating policies, as well as understand complex interactions of a system. Nowadays, major software companies such as SAP and Oracle offer advanced planning solutions as modules linked to the enterprise resource planning (ERP) software. Models typically need to be fine-tuned with specific constraints to represent accurately company operations and industry specificities.

For the model to provide valuable plans, operating costs of different production modes should be well estimated. Lail argued that financial data and process information should be better brought together to support decision making [8]. According to Lail, information related to costs, such as price changes from suppliers or changes in production capabilities, is often misperceived, resulting in less profitable plans. To this purpose, managerial accounting methods such as activity-based cost accounting (ABC) were developed in the mid-1980s to get more reliable product costs and enhance decision making [9]. Recently, Korpinen et al. [10], Laflamme-Mayer et al. [11], and Korbel [12, 13] developed ABC models and operations-driven costing methods for various types of facilities in the forest products sector. They concluded that the ABC method is applicable for cost predicting and controlling of pulp and paper mills.



1. Margins-based planning framework.

In earlier work, Dansereau et al. [14–16] proposed a margins-based framework and a tactical planning model that seeks to maximize the profitability of a company under various market conditions by better managing the flexibility of assets. This framework was developed to help decision makers manage the supply chain of integrated forest biorefineries, which will likely face a difficult market environment with price volatility.

The framework consists of five elements integrated in an optimization model (**Fig. 1**). First, a company should seek to maximize profit, not only minimize production costs. Second, to achieve the latter, sales should be managed to manufacture the most profitable products combination, inspired notably by revenue management concepts. Third, to produce this desired combination, flexibility in manufacturing should be exploited. However, different manufacturing modes have different operating costs in terms of raw materials, chemicals, steam, electricity, labor, and other factors. Therefore, the fourth aspect relates to the use of costing methods inspired by ABC accounting. Through a better representation of cost consumption patterns of production recipes, ABC accounting enables quantification of cost tradeoffs between different manufacturing modes. Finally, these concepts should be included in an integrated tactical planning model that considers the overall supply chain, from procurement to production, distribution, and sales.

Even for a commodity pulp and paper manufacturer, applying margins-based planning could lead to increased profitability. The various products of the portfolio can be manufactured through different production recipes, with different costs and margins. Better management of production can only be assessed if product margins are well calculated.

The objective of this paper is to show the potential for an integrated newsprint manufacturer to use a margins-based

planning framework. Specifically, process configurations leading to manufacturing flexibility are evaluated in different raw material price scenarios to quantify their cost-reduction opportunities. A case study of an existing newsprint mill in North America is used to illustrate the framework and benefits.

MODEL DESCRIPTION

The model used in this case study was formulated as a mixed-integer linear programming problem with a discrete time horizon of 12 months. It is a tactical planning model for which the objective is to maximize the global profit of the company (Eq. [1]):

$$\max Profit = \left(\begin{aligned} &ProductSales + SteamSales + ElectricitySales \\ &- SupplyCost - TransportCost - StorageCost \\ &- VariableOperatingCost - VariableElectricityCost \\ &- PeakElectricityCost - TransitionCost - StartupCost \\ &- OfflineCost - ShutdownCost - FixedOperatingCost \end{aligned} \right) \quad (1)$$

For each month, the model determines how much of each product should be sold to different customers, which recipe to use on each process, for how long, and its throughput. It determines raw material quantities to buy from each specified supplier, as well as the inventory of each material to be kept at each month. Steam and fuel and electricity flows, along with changeovers, are also determined.

The model is subject to constraints related to procurement and sales, flow and inventory, production, process mass balances, steam, and fuel and electricity balances. Some features of the model that enable margins-based planning and representation of specificities related to pulp and paper and biorefinery processes are summarized in **Table I**. The complete mathematical formulation can be found in Dansereau et al. [15].

CASE STUDY DESCRIPTION

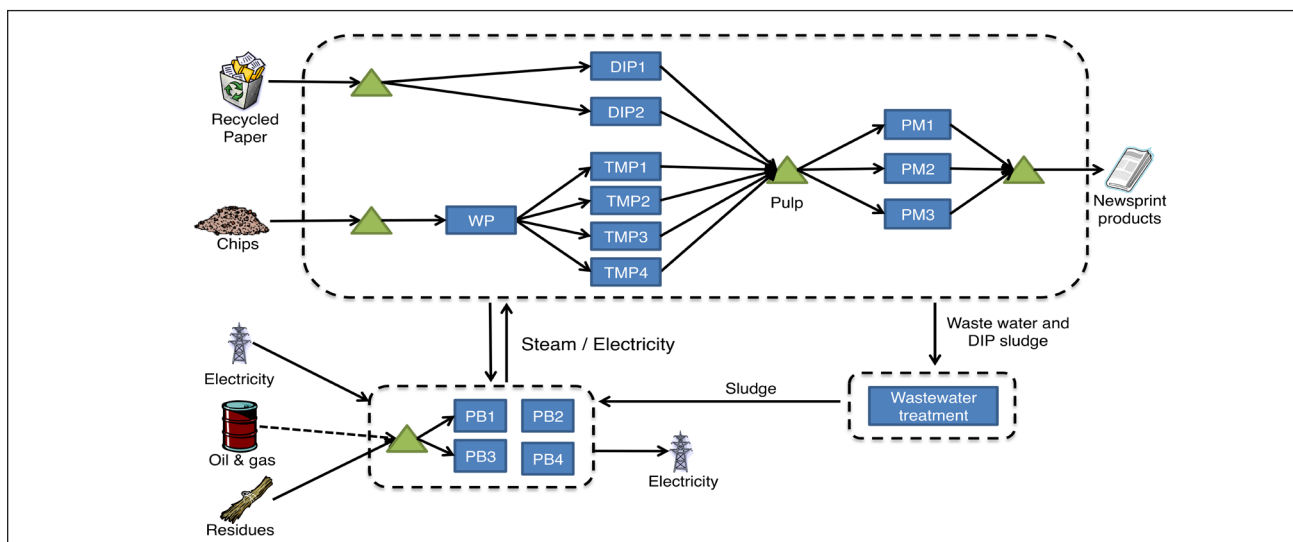
The case study is based on an existing newsprint mill equipped with four thermomechanical pulping (TMP) lines of approximately 165 bone dry (b.d.) metric tons/day each. Two deinking pulping (DIP) lines of 200 b.d. metric tons/day and 400 b.d. metric tons/day, respectively, complete the pulp furnish for the paper machines. In total, four different grades of newsprint products are produced on three paper machines of about 275 b.d. metric tons/day each. Thus, there is overcapacity in pulp production processes.

On the utility side, the mill is equipped with a 25-MW cogeneration plant that burns sludge, hog fuel, wood residues, and construction debris, providing all the necessary steam for the operations and selling extra electricity to the grid. In addition, the mill has three other boilers running on electricity and fossil fuel that are idled and used only during cogeneration maintenance. A wastewater treatment plant is also located on the site. A simplified representation of the modeled supply chain is presented in **Fig. 2**.

Thermomechanical pulping lines, DIP lines, and paper ma-

Modeling Feature	Explanation
Processes, recipes, and costing	Processes are modeled as units or a group of units representing a transformation to an intermediate or final product. Each process can be used with different recipes that have different yields to products; different throughput capabilities; and different requirements for quantities of raw materials, chemicals, steam, fuel, electricity, labor, and so forth. These recipes represent the activities that consume resources for the cost model. Some of these resources are consumed on a throughput basis (e.g., raw materials, chemicals), while others are consumed on a time basis (e.g., labor). For example, even if a unit is run at a lower throughput, the same number of workers will be assigned. Following ABC-like costing principles, costs are then allocated based on the consumption of resources in process recipes.
Steam balance, cogeneration, and steam condensing turbines	Specific units such as boilers and TMP lines will produce the required steam for all processes. The efficiency of a steam-condensing turbine for producing electricity diminishes nonlinearly with the quantity of steam processed.
Electricity balance and pricing	Electricity can be bought from the grid and/or produced partly by turbines. Electricity contracts for large consumers consist of a variable consumption price (CAD/kWh) and a contracted peak price (CAD/kW) for the power consumption.
Seasonality	Supply, energy, and chemical consumption in processes vary over the year.
Changeovers	Changing recipes on a process incurs a changeover and a time penalty representing the loss of production capacity.
Process idling and startup	Processes can be idled for a certain period if necessary. The model determines which processes are to be idled and for how long. However, reopening a line incurs a startup cost.
Scheduled maintenance shutdowns	Every year, processes have to be shut down for a few days to perform maintenance tasks. These shutdowns incur costs and reduce available capacity.
Transportation and distribution	Transportation costs are different for each customer/supplier. Total transportation and distribution costs will vary depending on the basket of customers and suppliers selected by the model.
Inventory	Raw materials and products can be kept in inventory within minimum and maximum limits. Storage costs will vary according to the level of inventory kept every month at the facility.
Planning heuristics	It is possible to represent some planning heuristics that are used, such as a minimum number of hours on a recipe, minimum idling time, maximum number of recipes that can be used on equipment during one time period, and so forth.

1. Features of the model that enable margins-based planning.



2. Case study supply chain.

Configuration	Description
TMP recipes	100% spruce, 0% fir, 0% birch
	95% spruce, 5% fir, 0% birch
	70% spruce, 25% fir, 5% birch
Paper machine recipes	100% TMP, 0% DIP
	95% TMP, 5% DIP
	50% TMP, 50% DIP

II. Description of TMP and paper machine recipes.

chine units are modeled with different recipes to represent various possible operating conditions. For each of these recipes, different products, mass and energy balance parameters, as well as cost consumption patterns developed using ABC accounting principles, are associated with them.

For TMP lines, black spruce, balsam fir, and white birch chips can be used in different ratios, with limit considerations for certain wood essences for preserving pulp quality. Spruce is the preferred feedstock for TMP, giving the best pulp quality. It can be used at 100% in these units, but it will consume more electricity because it is denser. For the other wood species, fir can be used up to 30% and birch up to 5%.

In paper machines, different ratios of inlet pulp are considered for the various paper grades, ranging from 100% TMP to 50% TMP and 50% DIP. These different ratios influence pulp operations and costs, with different lines being opened, functioning at partial capacity or shut down. It is also assumed that customers do not require a minimum DIP content in their product. **Table II** summarizes the different recipes that were modeled in TMP lines and paper machines.

Additional constraints were added to the model to represent process limitations. For instance, the case study mill has only one wood chip pile; therefore, the TMP recipes were the

same on all lines. Due to piping and pulp mixing limitations, recipe selection in paper machines was constrained to a maximum of two changes per month. Certain paper machines are also not able to produce specific grades of paper. If a unit is to be used during a month, it should be operated for a minimum number of hours.

Data for the pulp and paper operations have been provided by an industry partner. The model has been validated under different operating modes (TMP pulping and paper machine recipes) using historical data and actual procurement, production, shipping, and sales data used for budget forecasting.

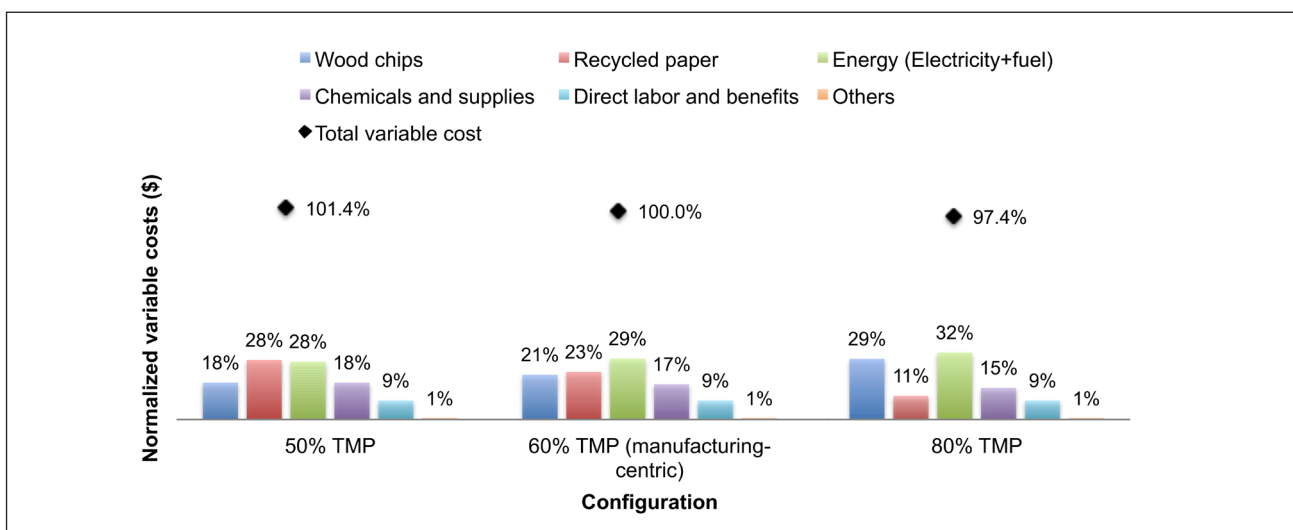
Overall, the case study consists of one mill, 21 suppliers, and 55 customer clusters. Furthermore, 107 different materials, 32 processes, and 336 recipes are accounted for a total of 52,957 variables, including 6,912 binary and 194,354 constraints. This model was implemented in IBM ILOG CPLEX Optimization Studio 12.2 on an AMD Athlon dual core processor with 2.8 GHz and 4 GB RAM. Global optimum solutions are obtained in 2-1000 s, depending on the analysis made.

Costing information and optimization results generated by the model are outputted in a standard profit and loss statement. This information can be more detailed up to the recipe, process, or product level or aggregated into more general categories depending on the level of detail required. Therefore, model outputs can be easily analyzed by mill planners and decision makers because they resemble budget information typically produced by a company.

RESULTS AND DISCUSSION

Recipe flexibility in paper machines

To show the value of margins-based planning, the model has been run under two different process and flexibility configurations. The manufacturing-centric configuration represents the current case at the pulp and paper mill. The TMP lines and paper machine recipes are selected before optimization using a heuristic that facilitates operations and that is believed



3. Variable costs of different process configurations.

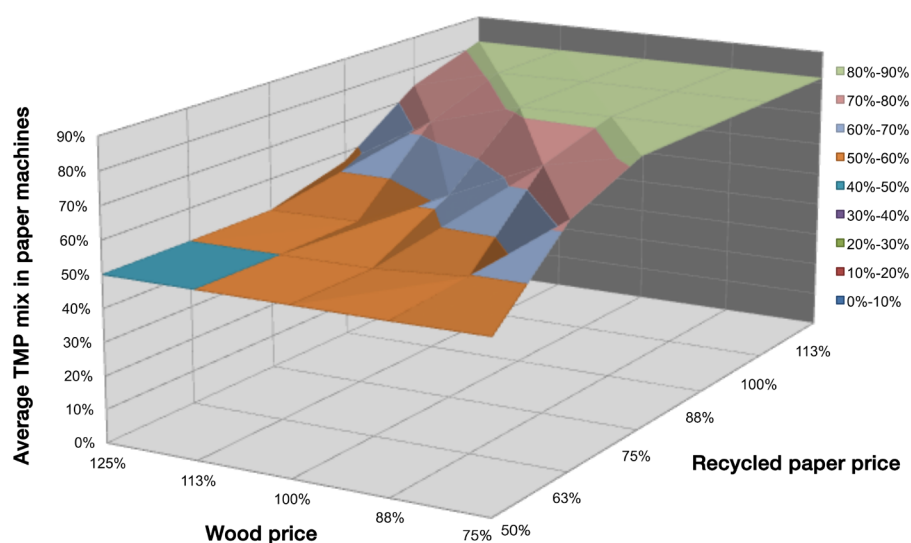
to minimize production costs. The TMP lines always run with a mixture of 75% spruce and 25% fir, and paper machines use an inlet pulp ratio of 60% TMP and 40% DIP. To achieve the latter pulp mix, three TMP lines out of four are used at full capacity, one DIP line is closed, and the other DIP line is used at 80% of the maximum capacity.

In the margins-based configuration, the model optimizes the recipe selection and throughput of pulping lines and paper machines to maximize profitability, considering various constraints related to processes and planning. This can imply partial or total opening/shutdown of TMP or DIP lines, with associated shutdown and startup costs.

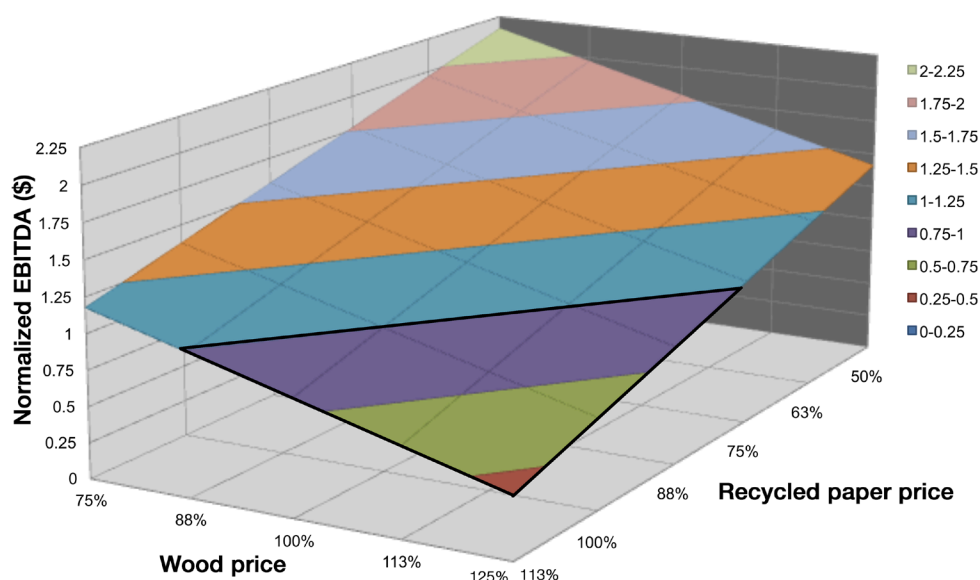
Pulping costs are incurred by the procurement of various

raw materials, the chemical consumption in DIP lines, the electricity consumption in TMP lines, the fuel consumption in boilers due to higher/lower steam needs/production from processes, as well as the startups and shutdowns of lines. To illustrate the cost-production pattern of different production recipes, **Fig. 3** introduces variable costs of three different TMP mixes in paper machines in the base case market scenario (wood chips and recycled paper prices at 100% of their value). For confidentiality reasons, costs are normalized by the cost of the manufacturing-centric configuration in the base case scenario.

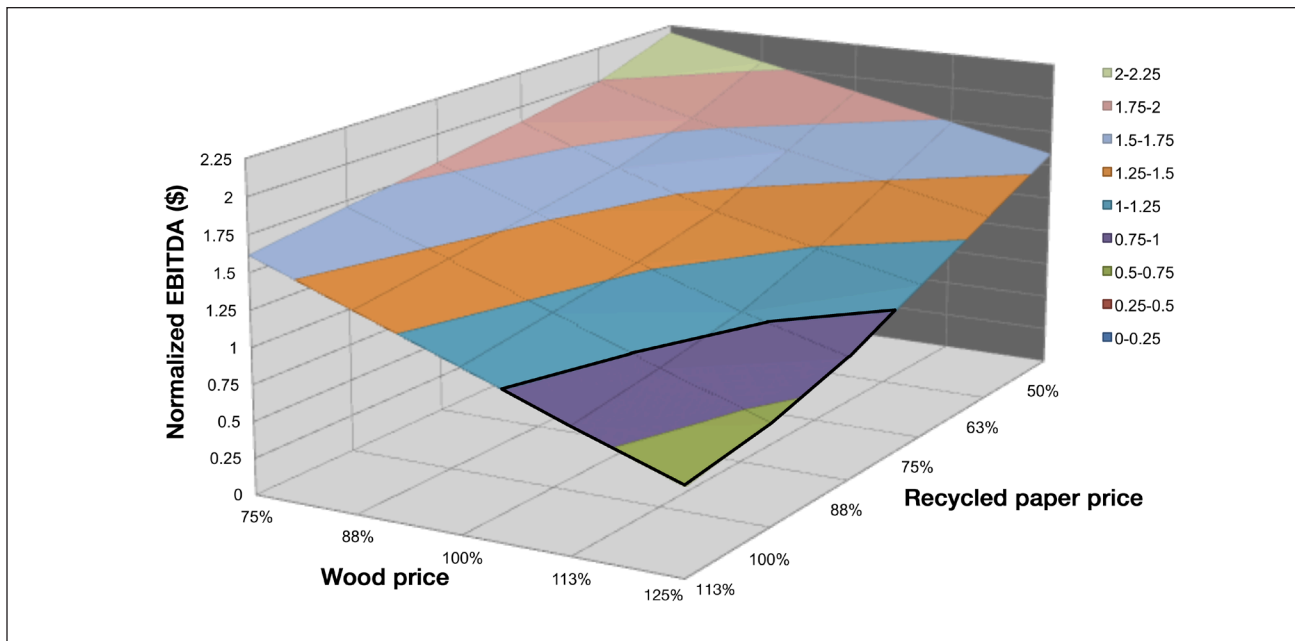
With a pulp mix composed of 80% TMP, all TMP lines run at full capacity. Steam production is maximized, which minimizes



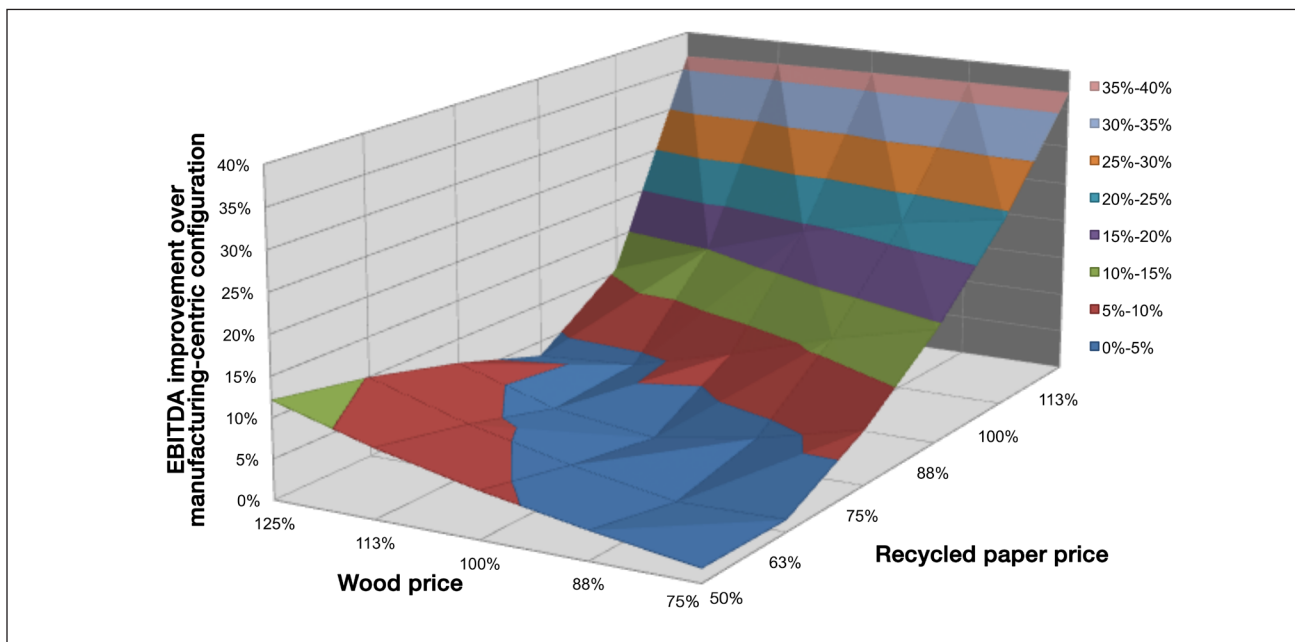
4. Average thermomechanical pulp (TMP) mix in paper machines over the year.



5. Normalized EBITDA—manufacturing-centric policy.



6. Normalized EBITDA—margins-based policy.



7. Increase in profitability of the margins-based configuration compared to the manufacturing-centric configuration.

the input of fuels in boilers; however, electricity consumption is at its highest. As DIP lines are not fully used, the consumption of recycled paper and chemicals in DIP lines is lower.

In these market conditions, producing paper with a higher ratio of DIP pulp incurs total increase in variable costs of 1.4%. By diminishing the DIP content in newsprint paper up to 20%, there would be an opportunity to decrease variable costs by 2.6%. To put this in perspective, a variation of 1% with this normalization translates into an increase of about 7% in earnings before interest, taxes, depreciation and amortization

(EBITDA), which is equal to 85% of the profits generated by one month of production. In such a low-margins industry, any effort to increase profitability matters.

The manufacturing-centric and margins-based instances were run in different market scenarios. Recycled paper price was varied between 50% and 150% of the base case price, with 12.5% increments. At the same time, wood chip price was varied between 75% and 125% of the base case price. These intervals are about equal to the variations seen over the last decade in the case study region. However, results in

Figs. 4–7 are presented for recycled paper price variations going up to 113% because the recipes selected by the optimization model did not vary at higher prices.

Figure 4 shows the average TMP mix in paper machines over the year for the margins-based configuration, the remainder being DIP pulp. When raw material prices are at opposites (low wood chips price and high recycled paper prices, or vice versa), results of the model recommend using a pulp mix that minimizes throughput of the pulping process using the most expensive feedstock. In between these two extremes, there is a compromise between the different operating modes of pulping lines, due to different cost production patterns.

Figures 5 and 6 show, respectively, the EBITDA of the manufacturing-centric and margins-based policies in these market scenarios. Results are normalized by the EBITDA of the manufacturing-centric policy in the base case scenario.

In Fig. 5, profitability increases linearly with diminishing raw material prices because only one manufacturing option is considered. For the margins-based configuration (Fig. 6), the profit increase is nonlinear as different pulping and paper-making recipes are used. In these two figures, the purple, green, and red zones represent cases where profitability is worse than the base case. These zones are to be avoided to ensure minimum profitability. It can be seen that the surface of these zones is significantly smaller in the margins-based case compared to the manufacturing-centric one. The exploitation of manufacturing flexibility is therefore able to provide more robust plans with higher margins, even in the case of increasing raw material prices.

The increase in profitability due to operating with a margins-based operating policy compared to a manufacturing-centric is presented in Fig. 7. The profit improvement is obtained by the following formula (Eq. [2]):

$$EBITDA \text{ improvement} = \frac{EBITDA_{\text{margins}} - EBITDA_{\text{manufacturing}}}{EBITDA_{\text{manufacturing}}} \quad (2)$$

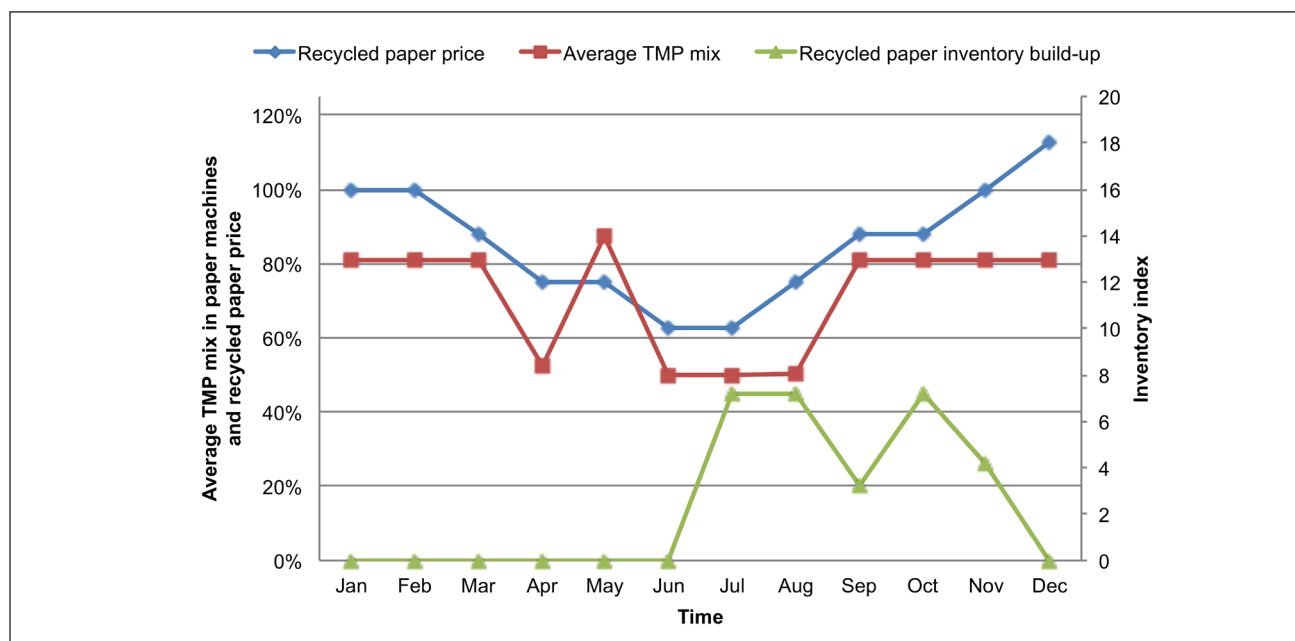
For each combination of wood chip and recycled paper prices, the EBITDA from the manufacturing-centric policy is subtracted from the EBITDA from the margins-based policy, and then normalized by the EBITDA from the manufacturing-centric policy.

In the lower part of Fig. 7 (blue zone), the manufacturing-centric policy is adapted to the different market conditions. Using the standard recipe with 60% TMP and 40% DIP results in close-to-optimal solutions; however, when raw material prices increase, the margins-based policy tends to be much more profitable. The overcapacity in pulping processes is exploited to minimize costs, providing production plans more adapted to market conditions. For instance, with high prices of recycled paper, profitability can be increased by up to 35% by using less of this raw material in the pulping process. Therefore, the benefits of exploiting manufacturing flexibility appear to be greater in the most difficult market scenarios.

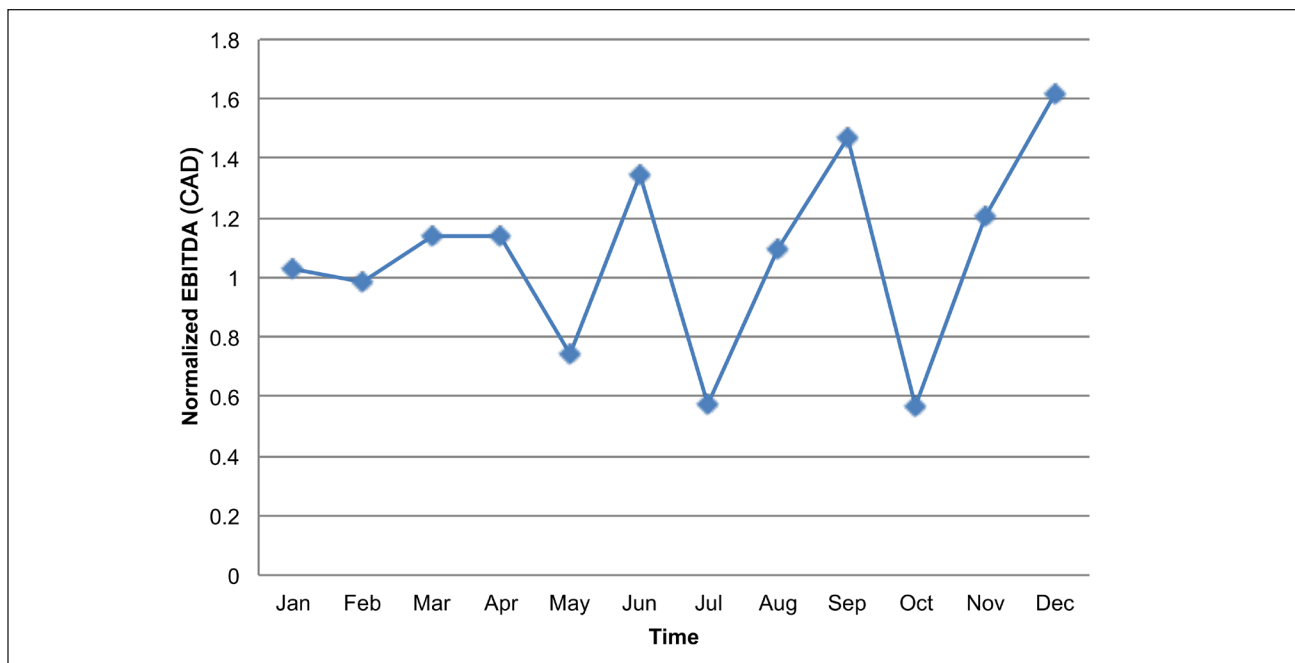
Tactical planning with price volatility of recycled paper

In the previous section, results were presented for scenarios where raw material prices do not change over the year. In practice, market conditions change over time, and planning needs to be constantly adapted to new situations.

In this section, the manufacturing-centric and margins-based configurations were run in a hypothetical scenario of one year, where recycled paper price decreases during spring and increases at the end of summer. Wood prices were considered to be constant for the whole year. The recycled paper



8. Pulp mix in paper machines, recycled paper price and inventory—margins-based configuration.



9. EBITDA generated over the year—margins-based configuration.

price curve, the average pulp mix in paper machines selected by the margins-based configuration, and the recycled paper inventory are presented in **Fig. 8**. The EBITDA generated every month is presented in **Fig. 9**. Results are normalized by the average monthly EBITDA of the manufacturing-centric configuration.

These results show that when the price of recycled paper is above the threshold value of 75%, it is more profitable to use as much TMP as possible in newsprint grades. Below this threshold value, it starts to be more profitable to use more DIP in paper. There is an exception in May, during which the cogeneration boiler is shut down for a few days for maintenance. Fossil-based boilers must typically be started to compensate the loss of steam. However, by running TMP lines at full capacity, extra steam can be produced from refiners, thus minimizing the need for more costly fossil fuels. Also, when recycled paper prices start to increase, inventory of this raw material is built up to save on procurement costs.

Peaks of lower profitability in May, July, and October shown in Fig. 9 are explained by shutdowns reducing production capacity and by inventory buildup of recycled paper. Globally, in this market scenario, operating with a margins-based policy translates into an increase in EBITDA of 7.6% compared to a manufacturing-centric policy, because of a combined effect of fiber procurement and fossil fuel savings.

One possible and practical approach for planners would be to use the model monthly with available forecasted data, such as those presented in **Table III**. Production plans could then be updated every month in a rolling horizon fashion, using new forecasted values for market conditions.

CONCLUSIONS

In this paper, a case study of a newsprint manufacturer with the flexibility of changing the pulp mix in the paper machines was introduced. An integrated planning model was used to identify the best manufacturing option in different raw material price scenarios, considering the different trade-offs in procurement and production. Case study results showed that profitability could be increased by up to 35% in some scenarios by adapting pulping production to fit market conditions. Exploiting manufacturing flexibility appeared to be most beneficial in difficult market scenarios.

Manufacturing flexibility options are often present in pulp and paper facilities, but are often not fully exploited because market and process information cannot be properly analyzed. Because process and utility interrelations can be complicated, trade-offs between different manufacturing options are generally difficult to identify. An integrated planning model, considering the possible recipes that can be used in the different processes as well as their associated costing patterns,

Input Data	Description
Procurement	Monthly list of suppliers, with corresponding availabilities and cost for each material they provide; fuel, chemical and electricity cost estimates for each month.
Sales	Monthly list of possible customers, with requested quantity, price, discount, distribution cost, and so forth.

III. Forecasted procurement and sales data.

can help decision makers identify and understand trade-offs and in turn propose more profitable production plans. These results convinced the case study company to adapt more frequently and more aggressively the pulp mix in their paper machines to take advantage of changes in procurement prices. The company was aware of this potential for flexibility, but was not able to systematically address it because it lacked tools to quickly evaluate production trade-offs. **TJ**

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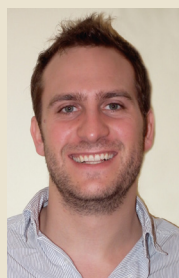
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ABOUT THE AUTHORS

One of the biggest challenges for the pulp and paper industry and the future forest biorefinery relates to the management of market volatility. Exploiting the flexibility of manufacturing systems is getting increasing consideration as an effective mean to mitigate this risk. However, it is often not fully exploited because market and process information cannot be properly analyzed due to the lack of appropriate tools.

To address this issue, we developed an integrated planning tool based on optimization to identify cost trade-offs between manufacturing options and to exploit the flexibility of manufacturing systems. In this paper, we demonstrate the usefulness of this tool with a case study of an existing commodity pulp and paper manufacturer. The most challenging part of the study was related to the model development and its validation to represent existing operations adequately.

The next steps involve the addition of biorefinery process options to the model to optimize the management of a more complex product portfolio. We believe that it is through the use of such models that stakeholders will be able to understand and address the



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complexity of the forest biorefinery supply chain and make it more profitable.

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