Planning and coordination for decentralised business units in a lumber production company

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Abstract: Mathematical models are frequently used in various industries to help decision makers to plan their activities. Many researchers develop planning models for a specific business unit. As an example, the forestproducts industry has access to specialised mathematical models for each production centre of thesawmill (sawing, drying, finishing units) which calls for decentralised planning. In the literature, these models are most of the time evaluated/tested separately, or connected using heuristics and testedin a "static" context ("one shot"demand datasets are provided).In this paper, we want to simulate theuse of these tools by companies for a long period of time (new orders are arriving dynamically, planning need to be updated periodically, etc.).Different coordination mechanisms are compared. We show what the performance of the company would be in terms of accepted orders and average inventory using various coordination mechanisms and order acceptance policies such as available-to-promise (ATP) and capable-to-promise (CTP). Our main finding is that previously published coordination mechanisms for decentralised planning leads to bad CTP implementations which open very interesting research avenues.

*Keywords:*Coordination mechanisms, simulation, planning, divergent process, co-production.

1. INTRODUCTION

The wood transformation process consists of three main activities: the *sawing*, *drying* and *finishing* operations. At the sawing operation, logs are sawn according to different plans. The basket of products obtained is composed of green wooden board with different lengths, thicknesses and qualities. These wooden boards are then dried in kilns depending on their physical characteristics. Finally, those boards are planed to get the right thickness and stored until delivery to the customer. This transformation process must take into account the customer demand and the supply of raw material. It is known as a divergent process with co-production. In addition, the combinatorial effect between each activity, as well as the variability in the supply (quality, diameter, length ...) makes it extremely difficult to manage a sawmill. To help decision makers, there are various mathematical models to optimise those three activities.

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In previous work, Dumetz et al. (2016) evaluated and compared the impact of different order acceptance policies for different market contexts.

In this paper, the focus is on the coordination between each activity of the wood transformation process. A simulation approach is proposed to evaluate and compare various coordination mechanisms between the three activities of the sawmill (sawing, drying and finishing operations), depending on the market context of the company and its own production parameters. The entire wood transformation process is taken into account and each activity has its optimisation model. We show that it is very difficult to obtain good performance in a decentralised environment facing a divergent process with co-production because of the combinatorial character of the entire process, even if each activity plans their production using an optimisation model. Thus coordination mechanisms need to be used to maintain a good performance of the company in terms of accepted orders and average inventory.

This article is organized as follows: Section 2 presents a literature review of the various concepts discussed. Section 3 introduces the simulation model carried by Dumetz et al. (2016) and used to perform the experiments. Changes have

been added and are explained. Planning models at the sawing, drying and finishing operations are also explained in this section. Section 4 presents the coordination mechanisms used in all the scenarios. Section 5 shows the results and analyses. Finally, Section 6 concludes the paper and indicates future work to be carried out.

2. LITERATURE REVIEW

For sawing operation, Maturana, Pizani and Vera (2010) mention several authors who have worked on the best way to cut wood and thus select the best plan that creates the best volume, the best value or/and the best yield: Occeña&Schmoldt, (1996); Todoroki &Rönnqvist, (1999); Winn, Wynne and Araman, (2004). But few worked on how to plan the sawing operation to meet demand. As an example, Todoroki and Rönnqvist (2002) proposed a system that takes into account the optimisation at the sawing operation and the demand for sawn products. The product price is also highlighted by undergoing variability over time. It is shown that the problems of over-production/under-production were reduced. Maturana, Pizani and Vera (2010) compared two methods (a mathematical model and a heuristic already used) to select the best cutting patterns over a period of 6 weeks in a sawmill. The demand is considered. The supply is fixed and there is no stochastic event in the machine's yield or the demand.More recently, Alvarez and Vera (2014) proposed a robust optimisation method to plan the production of a sawmill at the sawing operation. They highlight the fact that there is some variability in the yield coefficients of the cutting pattern and they showed that the methodology they used is less prone to variability of inputs. No uncertainty is considered for the supply. At the drying operation, Marier, Gaudreault and Noguer (2016) proposed a MIP/constraint hybrid planning model that dynamically generates load patterns during the planning. This model is used in industry. Marier, Gaudreault and Robichaud (2014) adapted a model developed by Gaudreault et al. (2010) to plan the finishing operations in a sawmill. This MIP model is used by a company and allows them to minimise order lateness.

As for a lot of industries, the sum of local optima is not equal to the global optimum.It is necessary to somehow take into account the transformation process in its entirety. To the best of our knowledge, only Gaudreault et al. (2010) proposed, for the wood industry, an approach considering the possibility of taking into account the entire operational transformation process. In this paper we want to simulate the wood planning process as a whole to assess and compare different control strategies. The aim is to provide tools to mills for the planning, the design and the deployment of control systems. A control strategy is defined, inter alia, a control architecture (that represents the structure and the organisation of the decision levels), optimisation models used in the planning of each activity, the size of the planning horizon, the order acceptance policies used, the coordination mechanisms used to coordinate each operation.

For many years, mathematical models used for production planning help decisionmaking in different industries (see the review of Díaz - Madroñero, Mula&Piedro (2014)). At each stage of the production process, an optimisation is performed to maximise different values such as efficiency, produced value, or minimise other such delays. However, although these models are very useful to optimise each business in the process, some indicators or goals may be in conflict with each other. The need for consistency and overall objective is therefore necessary for industries. The overall objective can correspond to an objective of cost or quality (e.g. customer satisfaction). However, having an overall objective involves the use of coordination mechanisms (Strader et al. (1998)). Rose et al (2002) define coordination as "a set of rules and procedures ensuring the operation of a group." Moreover, the Grai method gives methodology that can be applied to our case: coordination allows each decision unit to work with information, treating his problems in a decentralised manner taking into account the overall objectives. Each unit will have its own model, reduced to its area of intervention. Many authors are interested in coordination problems in industry (Bhatnagar et al (1993). Muhl et al. (2001) showed the importance of coordination in a transformation process composed by different jobs (so several local optimisers), and based on a global optimisation method for an assembly line in the automotive industry. The assembly line is composed of three units: the body assembly, painting and the final assembly. Each unit is optimised and there are various performance indicators to evaluate the unit's performance. The approach is to vary the parameters of each local optimiser modelled as a chromosome. In order to qualify and quantify the variation in these genes, the authors have developed a simulator of the productive system and a weighted indicator system. This study is interesting: it shows the interest in taking into account the local optimisers in a more overall optimisation approach. It also shows the interest of the use of simulation to measure the overall performance of the company. But in our case, the combinatorial effect between the sawmill operations, drying operation and finishing operation, as well as the divergent process with co-production in the forest industry make it very difficult to generate a single plan for all these activities. More recently Arshinder et al (2011) showed an overview of what coordination could be in a supply chain. One can find various coordination mechanisms such as contracts, information technology, information sharing or joint decisionmaking.

In the forest industry and especially regarding the wood transformation process, Gaudreault et al. (2010) studied the problems of coordination and offer three models for each activity (sawing, drying and finishing operations) connected by coordination mechanisms. To the best of our knowledge, this is the only study taking into account the whole process of wood transformation. The combinatorial effects are then highlighted and various coordination mechanisms are studied: upstream planning (See Bhatnagar et al (1993)) when planning each activity is done one after the other (starting with the one closest to the client), Two-phase planning (there is a demand propagation phase where plans are made according to an infinite supply and a real plan of the propagation phase for each activity) and finally bottleneck-first schedule (which consists in a two-phase planning starting from the neck). Infinite supply means that the production planning takes into account an infinite raw

material supply: at the finishing operations the plan is made by considering infinite dried products and at the drying operation the plan is made by considering infinite cut wood boards. Those coordination mechanisms will be better explained in Section 4. For each activity of the wood transformation process, a mathematical model generates a production plan. The authors showed that over a period of sixty days, the mechanism "bottleneck-first planning" has better results (in terms of on-time delivered orders). While this study is very interesting, we want to go further by simulating a rolling horizon and varying control strategies (various market contexts, several order acceptance policies...).
We will use the simulation that is necessary because of the stochastic nature of many variables as highlighted by (Chang and Makatsoris (2001)) and the will to measure the company's performance in different configurations.

3. PLANNING AND SIMULATION MODELS

We want to simulate the entire wood planning process in a decentralised manner and thus use various coordination mechanisms to ensure communication between the sawing, the drying and the finishing operation. Three different planning models will be used for each business unit.Simio will be used to simulate scenarios.

In previous works, Dumetz et al. (2016) evaluated different order acceptance policies for industries facing a divergent process with co-production. The simulation model is shown below in Figure 1.

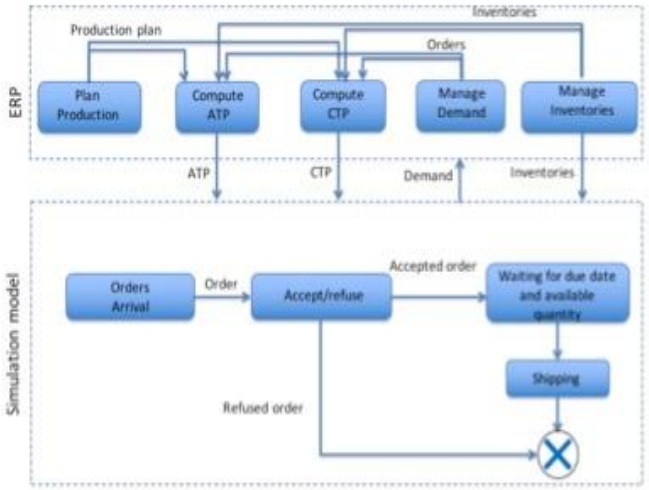

Figure 1: Conceptual representation of the framework

Coupled with a production planning module of a “custom-built ERP” responsible for the creation of a production planning, orders are generated, accepted or refused depending on order acceptance policies (ATP: available-to-promise, CTP: Capable-to-promise ...) then sent.
This production planning module used a mathematical model from Marier et al. (2014) to generate the production planning. The production process was centralised: model used raw material as an input and created a production planning over a given horizon. The outputs were the final products. It has been shown that for a company facing a divergent context with co-production - compared to a traditional manufacturing system such as assembly for example - the use of certain policies over others was more appropriate, according to the type of market and the specific parameters of the company.
In this paper, we propose to decentralise the process, as is the case in reality, using various mathematical models for each activity. So we want to run all three units together and study the coordination mechanisms that link those three units to meet the customer needs.
Three order acceptance policies are highlighted and tested: Stock (we accept the order if it is in stock), ATP (we accept the order if the inventories taking into account the production to the delivery due date are sufficient) and CTP (we modify the plan to include the new order without compromising previous commitments). The simulation horizon is two years; each day is divided into two seven-hour production shifts. The planning horizon is four weeks and the replanning frequency is one week. The demand lead time, which is the time between the reception date of the order and the delivery due date is fixed by a triangular distribution (1,2,3). Moreover, there is no stochastic event during production, the raw material is infinite and no delay is tolerated. A warmup period of a year was set to reach the steady state. More than 300 scenarios are tested with a sufficient number of replications for a significant confidence interval (95%). Number of accepted orders, average finished goods inventory, average sawn and planed products inventories have been used as performance indicators to measure the company’s performance. The same optimisation model used in Dumetz et al. (2016) for the centralised model was used to generate the production plan at the finishing operation. A model was developed for the sawing operation and is based on the finishing operation model. It provides a period-by-period production plan taking into account the raw material supply, the capacity, and the cutting patterns. The drying model comes from Marier et al. (2016). This is an MIP/constraint hybrid planning model that dynamically generates load patterns during the planning.

The scenarios that are tested allow us to show the performance of the company in terms of accepted orders and average inventory for various order acceptance policies, different coordination mechanisms taking into account the context market and the parameters of the company. Coordination mechanisms are explained the next section.

4. COORDINATION MECHANISMS

Each scenario highlights different coordination mechanisms that are described in this section.
We wanted to be able to accurately represent the production process of a North American sawmill at the operational level. Figure 2 below shows the first basic coordination mechanism.

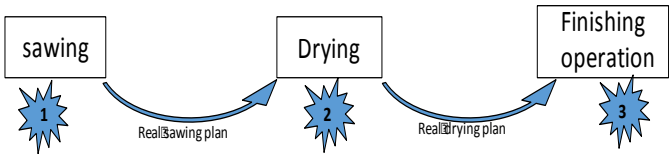

Figure 2: Classical push system

Here, the flow is 100% pushed: the raw material supply enables the production of sawn products (1), which will be dried (2) and planed (3). Customer needs are ignored and each unit operates independently maximising its production. Only commitments are counted to avoid order delays. This simple coordination mechanism is tested for Stock and ATP policies. For ATP policy, a frozen period ensures compliance commitments. Naturally it was more efficient to adopt a policy based on the ATP rather than stock. Using ATP policy, the company can accept 5% more orders than Stock policy depending on the demand intensity. Moreover, the average inventory using ATP policy is 80% less than Stock policy depending of the demand intensity. In addition, the durationof the frozen horizon to ensure that no order will be late is essential. This means coordination ensures the balance between the three activities.

Two-Phase Planning (Figure 3)

This mechanism resulting from Gaudreault et al. (2010) allows taking into account the demand at the finishing operation, the needs of dried products for the drying operation and the needs of sawn products for the sawing operation.

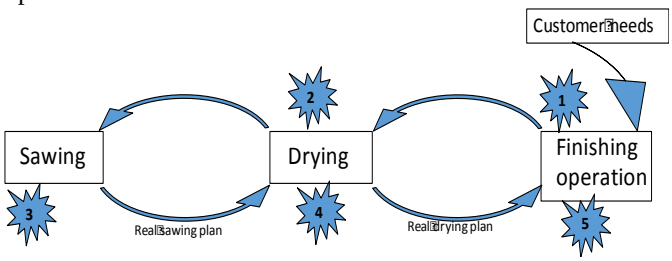

Figure 3: Two-phase Planning

A first phase plans each activity (1 and 2) considering infinite supply. Then real planning is done for the sawing operation (3), the drying operation (4) and the finishing operation (5) considering finite supply.

Bottleneck-first Planning (Figure 4)

This mechanism is also from Gaudreault et al. (2010) and allows taking into account the demand for drying, which is the bottleneck of the process. The demand for planed products s directly passed to the drying operation. A first phase plans the drying operation considering infinite supply (1). Then a real planning phase is made for the sawing operation (2), the drying operation (3) and the finishing operation (4) considering a finite supply.

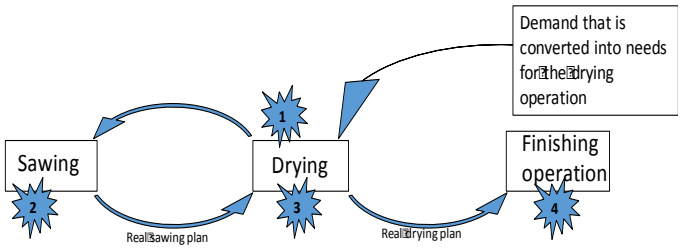

Figure 4: Bottleneck-first Planning

This mechanism has been tested by Gaudreault et al. (2010) and has shown better performance over previous mechanisms. However, we want to test this mechanism in a rolling period taking into account the market context of the company.

Those two last types of mechanism are used with the CTP, where we try to include each new order without compromising previous commitments.

5. EXPERIMENTS

As a base case, we considered results obtained when using a centralised planning algorithm. Planning sawing, drying and finishing operations at the same time using a single model is impossible in practice, but here we are able to do it in a research context using toy datasets. Indeed, in previous work, CTP were used in a centralised manner (Dumetz et al. (2016)). The performance of this type of order acceptance policy in a centralised context was clearly superior to other order acceptance policies depending on the market context and the demand intensity. Figure 5 below shows the results and the performances of both ATP and CTP policies for the same market context. It shows the number of accepted orders according to the demand intensity. We recall that the demand intensity is the number of orders the company received in one year. It is a percentage of the maximal production capacity. CTP accepts more orders than ATP when the demand is low because only CTP can reschedule the production according to customer needs. However, when demand intensity reaches 125%, ATP outperforms CTP because demand is significant and all the production planned can be sold. With a CTP policy, the production processes are modified to suit the recent orders. However, by changing the manufacturing process used, the co-products produced change too, and it could be hard to sell them.

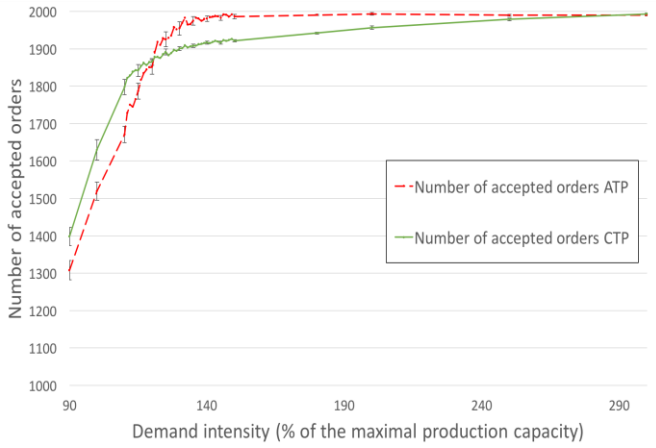

Figure 5: Number of accepted orders according to the demand intensity (ATP and CTP order acceptance policies) [Adapted from Dumetz et al. (2016)]

But what would the performances of the company be using a decentralised planning under a CTP approach? First, let's recall that CTP supposes we are able to tentatively re-plan production in reaction to a new order (with the constraint that we still need to satisfy past engagements). Although it is easy in a centralised context, our first simulation results quickly illustrated that the coordination mechanism described in previous section (two-phase planning and bottleneck first), when implemented "*as is"*cannot provide that. The business units were never (rarely) able to generate a new plan satisfying new orders without putting past orders late. Indeed, given the combinatorial nature of the problem, accepting an order by modifying the plan of sawing, drying and finishing operations without compromising past commitments became impossible.The production change causes changes in production for the next unit and so on: at each cutting pattern change, each recipe change at the drying or finishing operations, and the company performance varied considerably. The performance of a decentralised CTP is therefore below the centralised CTP performance of our previous experiments.

Following these preliminary results, we set up a decoupling point before the finishing operations. Using CTP, this allows making a new finishing operation plan to try to include the new order without compromising the previous commitments.
We need enough replications to obtain a significant confidence interval (95%), we need to run around 300 simulations, each replication starts 1:30 hours of computation time.These new scenarios are currently running and the results will be soon analysed

6. CONCLUSION

In this research, the simulation framework developed by Dumetz et al. (2016) was used to simulate the wood planning process at the operational level in a decentralised manner. We took into account the market context and the production parameters of the company. Scenarios are still being simulated and if the paper is accepted we will show them in a revised version. But we can show that it is very difficult to obtain good performance in a decentralised environment facing a divergent process with co-production. Even if each activity uses an optimisation model to plan its production. This is due, among other things, to the combinatorial nature of the problem, as well as mathematical models; although they are extremely useful when planning a single unit or in a centralised manner.
In a future work, a tactical level will be integrated and horizontal coordination mechanisms will be highlighted. The framework will be used to perform a more complex study by integrating stochastic events in the demand and the production.

ACKNOWLEDGMENTS

We would like to thank the research consortium FORAC and its partners, as well as the financial support from CRSNG.

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