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# SIMULATING AN INTEGRATED REVENUE MANAGEMENT APPROACH IN A PRODUCTION SYSTEM WITH PRODUCT SUBSTITUTION

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## ABSTRACT

Most revenue management publications dealing with substitutable products in a manufacturing context have focused on pricing issues. They consider that substitution is a customer's decision which occurs as a response to product price differences. In our study, substitution is considered as the firm's policy. We focus on the extension of the revenue management to practical applications in manufacturing and we are motivated by the Canadian softwood lumber case where product substitution is a common demand fulfillment practice. We aim, first, to propose a generic consumption model integrating both capacity control and product substitution decisions and second, to evaluate, using a rolling horizon simulation, the performance of this integrated model in different settings compared to common demand fulfillment approaches. In addition to practical implications, our study contributes to the existing demand fulfillment literature since we simulate different consumption models integrated with a Sales and Operations Planning model.

## 1 INTRODUCTION

In a limited capacity context, the decision of whether to accept or reject a customer order can affect the available capacity for future orders. Revenue management (RM) is a common practice which effectively allocates limited resources to more profitable demands in a profit-oriented organization (Hung et al. 2014): when expected demand exceeds the available capacity, sales managers have to select the most profitable orders. Consequently, orders can be rejected in anticipation of more valuable ones (Guhlich et al. 2015), not only if not enough resources are available. Such an approach may be considered unacceptable for some customers in manufacturing and may affect customer-manufacturer relationships. Thus, in order to prevent losing sales, sales managers often propose other alternatives to fulfill customer orders such as offering substitutes or allowing partial order fulfillment. They can also purchase from external sources to compensate their shortage.

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This study focuses on the extension of the RM to practical applications in manufacturing. It is motivated by the Canadian softwood lumber case where product substitution is a common demand fulfillment practice, due to the co-production (i.e., from one log, a mix of high-value and low-value products is generated). Canadian dimension lumber is sorted according to grading rules meeting Canadian and US requirements. Higher prices are attributed to higher quality products of the same dimensions. Based on the Canadian softwood lumber case, we consider in this paper, first, that products of the same dimensions can be substitutable only if they belong to successive quality levels, which is called **limited cascading**. Second, it is assumed that softwood lumber customers always accept higher quality products if these are offered at no extra cost. Thus, we consider only the situation when a higher quality substitute is provided at the original product's price, which is called an upgrade. **Upgrading** can be particularly beneficial if the selling firm faces stochastic and seasonal demand (Steinhardt and Gönsch 2012). In such a complex context, a simulation system can be used to evaluate the benefits of integrating upgrading and RM concepts.

The paper contributions are i) to develop a generic consumption model integrating both RM and product substitution and ii) to evaluate, by means of simulation, the performance of an approach integrating RM concepts and upgrading in a co-production context, compared to common demand fulfillment approaches. In addition to practical implications, the present study also contributes to the existing demand fulfillment literature since we integrate different consumption models, executed at the real-time level, with a Sales and Operations Planning (S&OP) model. Such tactical model additionally offers a medium-term visibility to make supply and sales decisions. This integrated decision-support system is too complex to be evaluated analytically and has to be studied by means of simulation before implementation. Thus, we use the platform previously developed by Ben Ali et al. (2014) for the softwood lumber industry, integrating S&OP at the tactical level and a consumption model at the operational and execution level, and we conduct a rolling horizon simulation to compare different demand fulfillment approaches in different settings.

This paper is organized as follows: Section 2 provides a brief review of related literature about product substitution and RM in manufacturing contexts. In Section 3, we present the generic consumption model integrating both RM and product substitution and schematize the interactions with the S&OP model. The proposed model can also be adapted to allow partial order fulfillment and purchasing additional quantities. Section 4 describes the softwood lumber case and experiments that will be carried out. The results analysis is presented in Section 5, followed by concluding remarks and future research opportunities in Section 6.

## 2 RELATED LITERATURE

### 2.1 Product Substitution

Product substitution offers flexibility for logistics and production systems. Among the extensive literature on product substitution, Lang (2010) provides an overview in the context of production and inventory management, which aims to unify the conceptual framework and the classification for product substitution models. The author particularly highlights that substitution has been considered in some demand fulfillment publications, such as Chen et al. (2001) and Fleischmann and Meyr (2004). Besides, in a more recent publication, Ervolina et al. (2009) present an allocation model that comprises optimized availabilities of a firm's core products as well as other product alternatives in an assemble-to-order (ATO) manufacturing environment, where end products are configured from standard components. Ervolina et al. (2009) assumed that supply quantities are exogenous inputs to the model. However, in this paper, we use an integrated demand management process that not only determines product allocations at short-term horizon, but also decides the ideal supply mix in terms of maximizing the firm's profit by integrating allocation planning with a Sales and Operations Planning (S&OP).

### 2.2 Product Substitution and Revenue Management

Many publications investigate RM with substitutable products in the service industry (for example, Petrick et al. 2010; Petrick et al. 2012; Steinhardt and Gönsch 2012; Gönsch et al. 2014, as well as the books by

Talluri and Van Ryzin 2004 and Phillips 2005). Products for which substitution is possible are often called flexible products in RM (Zatta 2016). Another RM literature stream deals with substitution in manufacturing context (Lang 2010). For instance, in Gurler et al. (2009), Sibdari and Pyke (2010) and Kim and Bell (2011), prices are not given as data, but as decisions variables. These studies consider substitution as a customer's decision which occurs as a response to price differences (i.e., if the price of a product increases, customers may look for less expensive alternatives), while in our paper product substitution is the firm's policy and can affect the available capacity for future orders.

## 3 MATHEMATICAL FORMULATION

In this paper, the S&OP model and the consumption model are formulated as linear programs (LP). Tables 1 and 2 present respectively sets, parameters, and decision variables involved in the consumption model.

Table 1: Sets.

| Sets | Description |
|---|---|
| $\mathbf{M}$ | Mills $m$ |
| $\mathbf{P}$ | Products $p$ |
| $\mathbf{PS}^{p'}$ | Products $p$ that can substitute product $p'$ (including $p'$) |
| $\mathbf{G}$ | Customer segments $g$ |
| $\mathbf{T}$ | Periods $t$ that are part of the short-term horizon |
| $\mathbf{D}$ | Set of $d = (p', g', t') \in \mathbf{P} \times \mathbf{G} \times \mathbf{T}$ (Demand) |
| $\mathbf{S}$ | Set of $s = (p, g, t) \in \mathbf{P} \times \mathbf{G} \times \mathbf{T}$ (Consumption sources) |
| $\mathbf{S}^d$ | Set of $s = (p, g, t) \in \mathbf{S}$ considered as sources for a demand $d$ |
| $\tilde{\mathbf{S}}^d$ | Set of $s = (p, g, t) \in \mathbf{S} \backslash \mathbf{S}^d$ (Forbidden sources) |

Table 2: Parameters and decision variables.

| Parameters | Description | |
|---|---|---|
| $j$ | Current period | Index |
| $\alpha_{p,g,t}$ | Selling price of product $p$ to segment $g$ during period $t$ | \$/Qty |
| $c^{hol}_{m,p,t,t'}$ | Holding cost of product $p$ in mill $m$ from period $t$ to period $t'$ | \$/Qty |
| $c^{pro}_{m,p}$ | Production cost of product $p$ in mill $m$ | \$/Qty |
| $c^{tra}_{m,p,g}$ | Transportation cost of product $p$ from mill $m$ to segment $g$ | \$/Qty |
| $\beta_{m,s,d}$ | Unit profit for selling quantities from mill $m$, initially set to $s$, to demand $d$ | \$/Qty |
| $q_d$ | Total quantity required by $d$ (Commitments + new order demand) | Qty |
| $x_{m,s}$ | Quantity from mill $m$ allocated by the S&OP model to $s$ (Decision variables of S&OP model) | Qty |
| $y_{m,s,d}$ | Quantity from allocation $x_{m,s}$ already consumed | Qty |
| **Dec. variables** | **Description** | |
| $\mathrm{Y}_{m,s,d}$ | Quantity consumed from allocation $x_{m,s}$ to fulfill a demand $d$ not yet transported ($t' \geq j$) | Qty |

### 3.1 Generic Consumption Model

We formulate a generic consumption model, which can be adapted for different demand fulfillment approaches. This model has to be executed for each received order and is integrated to the S&OP model executed monthly (Figure 1). We consider an assignment problem in which we can fulfill a demand requiring product $p^{'}$ received from customer segment $g^{'}$ for period $t^{'}$ (i.e., a demand $d = (p^{'}, g^{'}, t^{'})$) from allocations of product $p$. Each allocation is initially set by the S&OP model to fulfill the demand of customer segment $g$ for a period $t$ (i.e., a source $s = (p, g, t)$). Nested booking limits are commonly used (see, for example, Quante et al. 2009; Azevedo et al. 2016; Ben Ali et al. 2014) in order to control the availability of capacity so that quantities initially allocated to $s$ can only be sold to a demand $d$ generating the same or better profits. We generalize the consumption model presented by Ben Ali et al. (2014) with nested booking limits, defined by customer segment and delivery period, and we add the product dimension to enable product substitution.

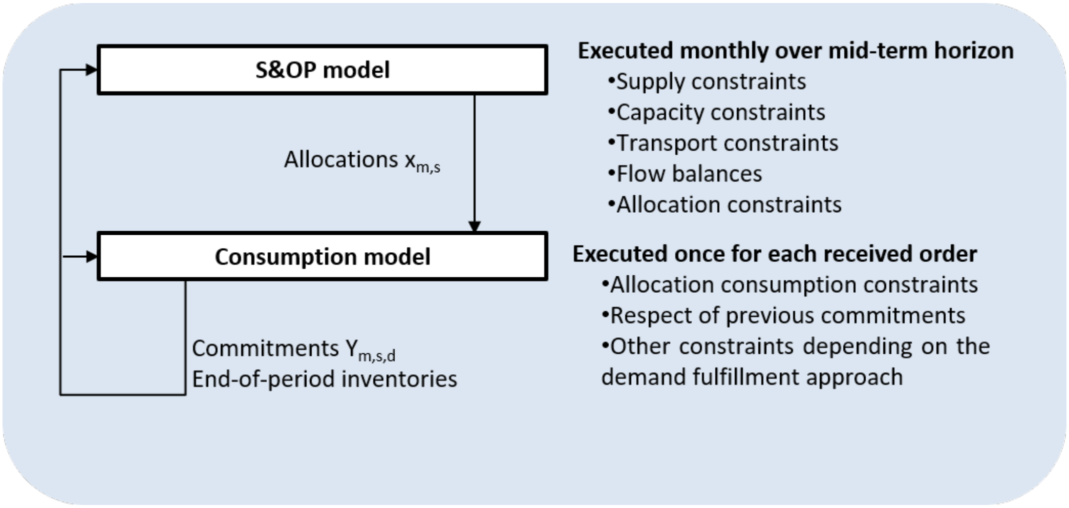

Figure 1: S&OP model and different consumption models.

The goal of our consumption model is to maximize the short-term profit of fulfilling demand requested for periods between the current period $j$ and the end of the short-term horizon, which is expressed by Equation (1). This objective function is subject to the following constraints: First, constraints (2) ensure that quantities consumed from the quantity $x_{m,s}$ available at mill $m$ initially allocated to $s = (p, g, t)$ will not exceed what is available. This includes quantities $y_{m,s,d}$ consumed by delivered orders that we can no longer change (be reassigned). Second, to guarantee previous commitments and new order fulfillment, constraints (3) are expressed so that order reassignment is allowed: quantities consumed to fulfill a demand $d$ have to be equal to the total quantity required by $d$, including the previous commitments and the quantity required by the new order. Otherwise, the new order cannot be fulfilled. Third, constraints (4) force forbidden consumptions to be zero (see Section 3.1.2). Finally, constraints (5) ensure that all variables are non-negative.

$$Maximize \sum_{m \in \mathbf{M}} \sum_{d \in \mathbf{D}} \sum_{s \in \mathbf{S}^{d}} \beta_{m,s,d} \; \mathrm{Y}_{m,s,d} \tag{1}$$

*Allocation consumption*

$$\sum_{d \in \mathbf{D}} (\mathrm{Y}_{m,s,d} + y_{m,s,d}) \leq x_{m,s} \qquad \forall m \in \mathbf{M}, \;\forall s \in \mathbf{S} \tag{2}$$

*Respect of previous commitments and fulfillment of the new order*

$$\sum_{m\in\mathbf{M}}\sum_{s\in\mathbf{S}^d} \mathrm{Y}_{m,s,d} = q_d \qquad \forall d \in \mathbf{D} \tag{3}$$

*Forbidden consumptions*

$$\mathrm{Y}_{m,s,d} = 0 \qquad \forall m \in \mathbf{M},\ \forall d \in \mathbf{D},\ \forall s \in \tilde{\mathbf{S}}^d \tag{4}$$

*Non-negativity*

$$\mathrm{Y}_{m,s,d} \geq 0 \qquad \forall m \in \mathbf{M},\ \forall s \in \mathbf{S},\ \forall d \in \mathbf{D} \tag{5}$$

### 3.1.1 Unit Profit Calculation Under Upgrading Hypothesis

In this study, we assume that higher selling prices are offered for higher quality products and that the seller can fulfill a certain product request with a substitute from a pre-specified set of alternative products. With upgrading, the substitute is a higher quality product than the original product and the seller offers it at the requested product's price. In other words, assuming that we receive an order from a customer from segment $g^{'}$ requiring product $p^{'}$ for period $t^{'}$, the customer accepts to substitute product $p^{'}$ by a product $p \in \mathbf{PS}^{p^{'}}$ at the price of product $p^{'}$. That is, the profit $\beta_{m,s,d}$ can be expressed by:

$$\beta_{m,s,d} = \alpha_{p^{'},g^{'},t^{'}} - c^{hol}_{m,p,t,t^{'}} - c^{pro}_{m,p} - c^{tra}_{m,p,g^{'}}$$

### 3.1.2 Forbidden Consumptions

Naturally, to fulfill a demand $d = (p^{'}, g^{'}, t^{'})$, some consumption decisions are not possible:

- With product substitution, we can substitute a required product $p^{'}$ only by a few products $p \in \mathbf{PS}^{p^{'}}$ ($\mathbf{PS}^{p^{'}}$ includes $p^{'}$). If product substitution is not allowed, $\mathbf{PS}^{p^{'}} = \left\{p^{'}\right\}$.
- We can consume from the allocations that are initially set to previous periods $t$ (i.e., $t < j$) and that have not been consumed until current period $j$.
- In order to ensure the availability of the required quantity in the mill at the delivery period $t^{'}$, we can only consume from allocations initially set to future periods $t$ preceding $t^{'}$ (i.e., $j \leq t \leq t^{'}$).

Furthermore with revenue management, we have to avoid consumptions to fulfill orders from allocations set to more profitable demands. Thus, to fulfill a demand $d = (p^{'}, g^{'}, t^{'})$:

- we cannot consume from allocations $x_{m,s}$ initially set to $s = (p, g^{'}, t)$ where $p \in \mathbf{PS}^{p^{'}}$ and $t = j..t^{'} - 1$ (i.e., initially set to the same customer segment for different periods), which can generate higher profit if sold to $s$ rather than $d$.
- we cannot consume from allocations $x_{m,s}$ initially set to $s = (p, g, t)$ where $p \in \mathbf{PS}^{p^{'}}$, $g \neq g^{'}$ and $t = j..t^{'}$ (i.e., initially set to different customer segments for any periods preceding $t^{'}$), which can generate higher profit if sold to $s$ rather than $d$.

To simplify, we formulate these restrictions in Equation (4) as we cannot consume from allocations initially set to $s = (p, g, t) \in \tilde{\mathbf{S}}^d$ to fulfill a demand $d = (p^{'}, g^{'}, t^{'})$. $\tilde{\mathbf{S}}^d$ is expressed differently depending on whether we consider or not revenue management and product substitution.

## 4 APPLICATION TO A SOFTWOOD LUMBER CASE STUDY

### 4.1 Case Description

As presented by Figure 2 and Table 3, we consider a softwood lumber manufacturer composed of three sawmills equipped with sawing, drying, and planing resources and located in Eastern Canada. In this region, the targeted markets are principally the Northeastern American market (US), the Eastern Canadian market (CAE), and a spot market composed of occasional customers offering low prices.

We consider six products from the 2x4 family. As a common practice in the Canadian softwood lumber industry, products having the same dimensions but different quality can substitute each others. We use real market prices for the CAE market and the US market. We assume that customers from the spot market will offer low prices equivalent to 80% of the US prices and that the manufacturer is able to purchase additional quantities from external sources with a price equivalent to 90% of the local market price (CAE in our case).

In this paper, we consider substitution with limited cascading: substitution is allowed only between products from successive quality levels. In addition, under the upgrading hypothesis, the substitutes of product from grade 3 are products from grade 1&2 and the substitutes of product from grade 4 are products from grade 3.

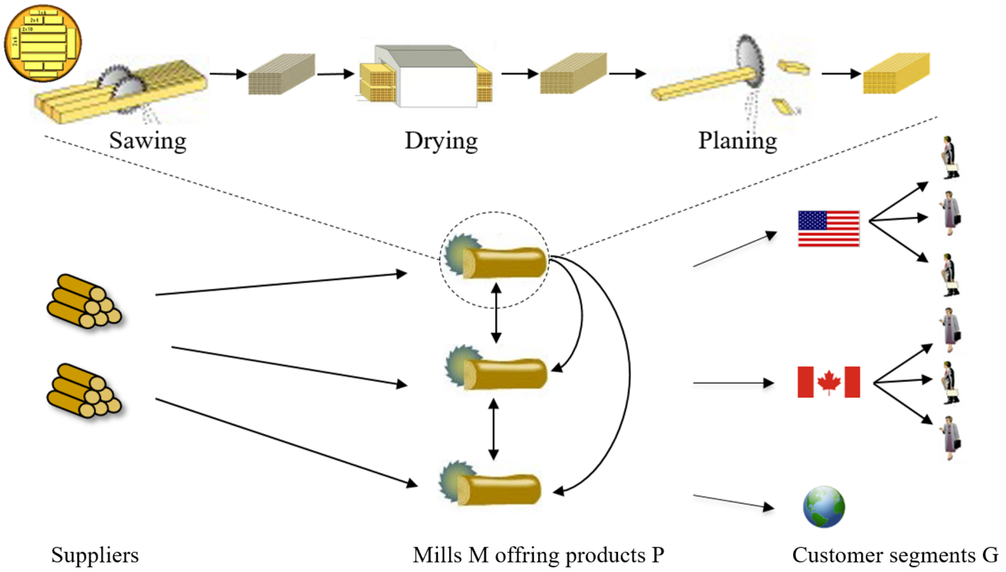

Figure 2: Supply network of a multi-site softwood company.

Table 3: Scope of the simulated case.

| Sets | Size | Details |
|---|---|---|
| **Sawmills** | 3 | Sawing, drying and planing resources. |
| **2x4 family of products** | 6 | 10' Grade 1&2, 10' Grade 3, 10' Grade 4<br>14' Grade 1&2, 14' Grade 3, 14' Grade 4 |
| **Markets** | 3 | US, CAE and spot market |
| **Segments** | 7 | US and CAE markets are composed from 3 segments each.<br>Spot market is considered as one segment. |
| **Average number of orders incoming weekly** | 100 | Average weekly arrival rate is one order per couple (segment, product), where one product is required per order. |

### 4.2 Demand Generation and Customer Segmentation

The yearly global demand is considered as 150% or 200% of the maximum output that can be produced by pushing an infinity of supply into the supply chain. Since the US market represents the largest export market for Eastern Canadian softwood companies, we assume that the demands of US market, CAE market and spot market represent respectively 50%, 25% and 25% of the total demand.

Inspired from the real context, we assume that the spot market is considered as one segment composed of occasional customers offering low prices (80% of the US market prices), while the US and CAE markets can be split in three customer segments each:

- High-priority customers (10% of the market demand), typically home improvement warehouse companies and housing component manufacturers, are ready to pay 20% more than the market price to have shorter transport lead times.
- Medium-priority customers representing the majority of customers (70% of the market demand) pay exactly the market price.
- Low-priority customers (20% of the market demand), typically dealers and distributors, pay 20% less than the market price.

We assume that the manufacturer offers upgrades only to high-priority and medium-priority customers. Randomness in our experiments concerns generating orders for the order promising level and includes inter-arrival times, lead times and quantities required by customer orders. We deploy the procedure described by Ben Ali et al. (2018) to generate different lists of orders for different replications.

### 4.3 Simulation Framework

The goal of the simulation is to highlight the benefits of integrating revenue management (RM) and upgrading (UPG). To this end, we simulate the behavior of the demand management process presented in Figure 1 with the consumption model RM-UPG, integrating RM concepts (i.e., using nested booking limits) and upgrading over a year. To evaluate this integrated approach, a comparison to common demand fulfillment approaches is required. Thus, we consider different consumption models as presented in Table 4:

- The RM model is using nested booking limits to take into consideration customer heterogeneity and profitability variation over time. The RM-PF and RM-EXT models, using also nested booking limits, respectively allow partial fulfillment and purchasing from external sources.
- The FCFS model is making consumption decisions based only on resource availability and without considering nested booking limits. FCFS-UPG, FCFS-PF, and FCFS-EXT respectively allow upgrading, partial fulfillment and purchasing from external sources without considering nested booking limits.

As an upper bound on the profit that we could get, we assumed an ideal process (often called "oracle"), which knows all orders arriving within the planning horizon before making promises and enables a Global Optimization (GO) with a total visibility.

The S&OP model and the different consumption models presented in Table 4 are developed within IBM ILOG CPLEX Optimization Studio version 12.4. A rolling horizon simulation is conducted using an algorithm developed in Visual Basic. NET, which called sequentially the S&OP model (executed each month) and the consumption model (executed on order-by-order basis). Since we consider 100 orders/week, with 10 s for each order processing, a total of 15 h is needed to perform a complete 1-year simulation. It should be noted that a warm-up period of 17 weeks is considered and that 10 replications were performed.

In what follows, we report the average values and the 95% confidence intervals of the yearly profit margin (to simplify we call it profit) in four different scenarios (Table 5), depending on the Demand Intensity (DI) relative to the production capacity and of the Price Difference (PD) between successive quality levels.

Table 4: Different consumption models.

| Model abbreviation | Demand fulfillment approach |
|---|---|
| RM | Revenue Management |
| RM-UPG | RM + UPGrading |
| RM-PF | RM + Partial Fulfillment |
| RM-EXT | RM + EXTernal sources |
| FCFS | First-Come First-Served |
| FCFS-UPG | FCFS + UPGrading |
| FCFS-PF | FCFS + Partial Fulfillment |
| FCFS-EXT | FCFS + EXTernal sources |

A demand intensity DI equal to 100% is estimated as the maximum output that can be produced by pushing an infinity of supply into the supply chain (i.e., the capacity). Thus, we calculate the demand as: Demand = DI x Capacity. In the base case scenario, we consider that DI is 150%. Similarly to Dumetz et al. (2015), we assume that the DI may reach 200%. Regarding the PD, the base scenario case uses real prices, which corresponds to a PD of 24% for 10' products and 21% for 14' products. We consider that the PD can decline until 10% smaller than the base case scenario (we kept the same prices for the products of grade 1&2 and we increased by 10% the prices of products of grades 3 and 4).

Table 5: Simulation scenarios (* Base case scenario).

| Scenarios | Demand Intensity (DI) | Price Difference between successive quality levels (PD) |
|---|---|---|
| Scenario 1 * | 150% | High (24% for 10' products, 21% for 14' products) |
| Scenario 2 | 150% | Low (14% for 10' products, 11% for 14' products) |
| Scenario 3 | 200% | High (24% for 10' products, 21% for 14' products) |
| Scenario 4 | 200% | Low (14% for 10' products, 11% for 14' products) |

## 5 RESULTS AND DISCUSSION

In this section, we evaluate the performance of the approach integrating revenue management and upgrading compared to common demand fulfillment approaches in the base case scenario. Then, we investigate the effects of the sales price structure and the demand intensity on the performance of the integrated approach proposed.

### 5.1 Base Case Analysis

Figure 3 exhibits the profit and the average sales volumes generated by the different demand fulfillment approaches in the base case scenario (i.e., the most realistic scenario for the softwood lumber context in Eastern Canada). The value of integrating revenue management (RM) and upgrading (UPG) is presented in Figure 3, since the RM-UPG model achieves the highest profit (i.e., the closest to the upper bound on the profit that we could get with a Global Optimization GO).

Due to the limited capacity, approximately the same sales volume can be sold when purchasing from external resources is not allowed. In terms of profit, we can see that external sources (RM-EXT and

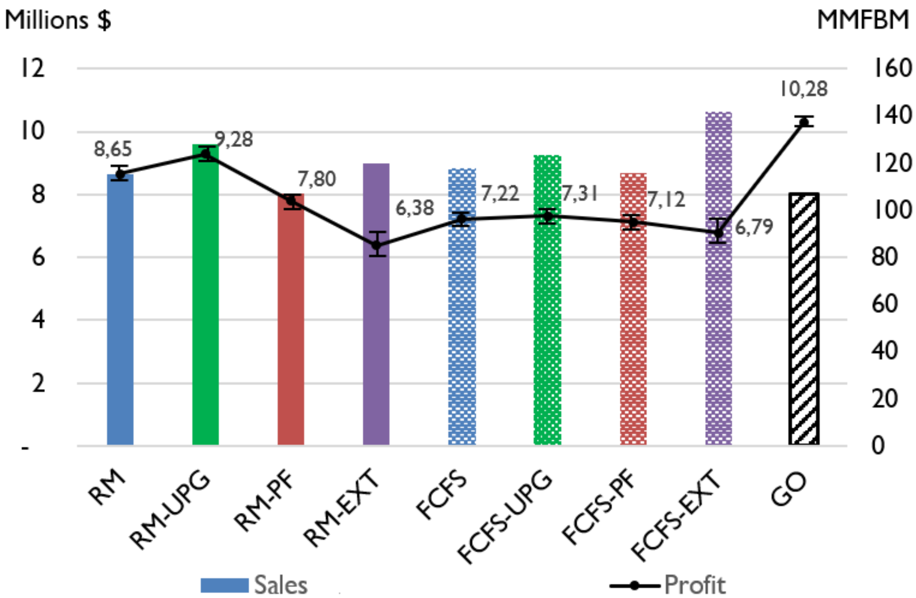

Figure 3: Performance of the consumption models in the base case scenario.

FCFS-EXT) and partial fulfillment (RM-PF and FCFS-PF) approaches are less competitive. For this base case scenario, the RM-UPG and RM approaches achieve a profit gap which is well over 1.5 million dollars compared to other approaches (i.e., FCFS, FCFS-UPG, FCFS-PF, FCFS-EXT, RM-PF and RM-EXT).

Since allowing partial fulfillment and purchasing from external resources are not interesting for the most realistic scenario for the softwood lumber context in Eastern Canada, we will not consider these models for the following analysis.

### 5.2 Effect of the Sales Price Structure and the Demand Intensity

Figure 4 illustrates the performance of the RM and FCFS approaches with and without upgrading in the four scenarios of Table 5. For each approach, we investigate how the profit varies if the Demand Intensity (DI) or the Price Difference (PD) between successive quality levels change (for both DI and PD, we consider two levels as described in Table 5). In addition, the percentage of the profit achieved by each approach compared to the GO is presented for each scenario in Figure 4.

*Effect of the Demand Intensity (DI):* The difference between the FCFS and the FCFS-UPG with DI is not significant, due to the limited capacity and the naive manner in which orders are promised. We can see also that the value of upgrading is more significant if we integrated it with RM concepts for two reasons:

- At the S&OP level, each product is allocated to a specific customer segment. Since upgrading is offering a higher quality substitute at a lower price, a loss of profit is achieved if we provide the product to this specific segment or to other customer segments paying less than the original segment. This is particularly avoided by RM models by means of the nested booking limits.
- Avoiding unprofitable upgrades with RM preserves quantities for future profitable orders. Thus, RM-UPG is able to sell more than RM in all cases, and particularly for high-priority customers. This explains the profit improvement for all cases in Figure 4.

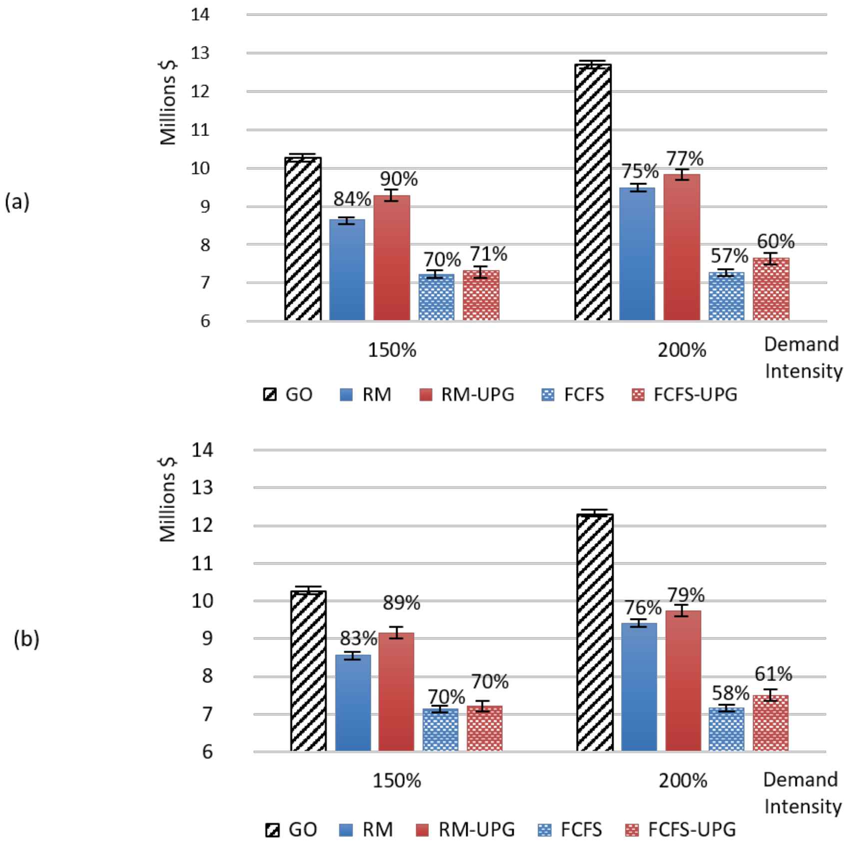

Figure 4: Profit of the RM and FCFS approaches with/without upgrading in different scenarios and the percentage of the profit achieved by each approach compared to the GO; (a) High price difference between successive quality levels; (b) Low price difference between successive quality levels

The gap between RM-UPG and RM decreases with the increasing demand. In fact, RM is able to sell the products to customers who are asking for them, and upgrades will not be necessary to use up the inventories. We should note that the additional sales for RM and RM-UPG with DI of 200% are stabilizing above a certain level due to the limited production capacity.

*Effect of the Price Difference between successive quality levels (PD):* As mentioned in Section 4.3, for low PD scenarios, we kept the same prices for the products of grade 1&2 and we increased by 10% the prices of products of grades 3 and 4. This price difference is not significant to affect the performance of the simulated integrated demand management processes (almost the same volumes are produced and sold with high PD and low PD). This is due to the production recipes which are set to produce as much as possible of high-value products (i.e., products of grade 1&2 in our case represent more than 75% of the production, which is common in sawmills).

## 6 CONCLUSION AND FUTURE WORK

Simulation is widely deployed for manufacturing systems in order to have a system-wide view of the effect of using alternative approaches before implementation. In this paper, we extend the research in demand fulfillment for co-production systems and investigate the benefits of integrating revenue management and upgrading compared to common demand fulfillment approaches.

First, we propose a linear programming model using nested booking limits and allowing product substitution. Based on the Canadian softwood lumber context, we assume that products of the same dimensions can be substitutable only if they belong to successive quality levels. Besides, we consider only upgrading, i.e., where a higher quality substitute is offered at the original product's price. Second, we evaluate alternative demand fulfillment approaches using rolling horizon simulation. Results in different scenarios enable the comparison of multi-level systems composed of a Sales and Operations Planning (S&OP) model at the tactical level coupled with different consumption models at real-time level.

Our simulation results demonstrate that integrating RM and upgrading achieves better performance than common demand fulfillment approaches in a context where demand exceeds capacity. The value of upgrading is more significant when integrated with RM concepts, since the use of nested booking limits prevents from doing unprofitable upgrades. Thus, inventories are preserved for future profitable orders. In the softwood lumber industry, the value of upgrading is not sensitive to the price difference between products from successive quality levels, since high-value products represent the majority of production. The benefit of upgrading is, however, less significant when the demand intensity increases.

Future work will be to analyze other substitution policies, such as downselling and upselling, which can be valid in industrial contexts other than the softwood lumber industry. Considering the sensitivity of customers to substitution may also be of theoretical and practical interest.

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