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Logistics approaches assessment to better coordinate a forest products supply chain

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ABSTRACT

This paper presents two mathematical models to plan the key activities of a forest products supply chain encompassing different harvesting areas. These areas supply four sawmills with logs, which in turn send lumber to the construction market and chips to one paper mill. In particular, three logistics approaches are compared (i.e., Make-to-Order (MTO), Vendor Managed Inventory (VMI), and a centralized planning approach), and key performance factors used (e.g., demand satisfaction and wood fiber freshness), with the goal of optimizing harvesting, storage, transportation, and production operations while improving the competitiveness of this proposed forest products supply chain. Results demonstrate the importance of an effective balance between chips and lumber production to ensure adequate quality of finished products as well as higher profits for the entire supply chain. These results also confirm the ability of the VMI approach to reduce logistics costs for the overall forest products supply chain.

Introduction

With stiff competition in the forest products market, the diversity of stakeholders involved in the logistics activities, and an ever-increasing demand for high-quality products, there has been increased interest in applying planning and coordination techniques to the forest industry. In this paper, we study the case of a forest products supply chain composed of several business units, namely multiple forest harvesting areas, four sawmills, and one pulp and paper mill. All operations of these business units are interconnected; the forest supplies the wood necessary for producing lumber at sawmills, and wood chips obtained from lumber production are used to produce pulp and paper. As a result, poor timber quality will produce low quality lumber while low quality chips will impact paper quality. Chip quality is defined by fiber density, chip size distribution, freshness, and brightness (Ding et al., 2005; Harrison et al., 2004). These characteristics are related to tree species, age, and stocking operations.

Because there is an interdependent relationship between the business units, a lack of coordination of their activities may affect the whole supply chain profitability. Nevertheless, the business units tend to adopt self-serving interest as they attempt to optimize their own operations without specific consideration for the other supply chain members. The paper mill is considered as the most important social sponsor in the supply chain by providing many jobs opportunities while sawmills have a more modest number of employees. As a result, poor-quality chips could lead to unprofitable paper production and even the closure of the paper mill. A reduction in chips supply could also significantly affect the paper mill profitability. Supply and production planning decisions may also appear as a complex task when several parameters and constraints are taken into account at the same time, such as species needed to obtain the final product expected, the freshness of the fiber required to ensure a certain level of quality, and even the demand to prioritize (chips or lumber demand for sawmills, regular or high-quality paper for a paper mill) to maximize value and profit (Van Horne et al., 2006; Bredström et al., 2004). Furthermore, a collaboration approach such as Vendor Managed Inventory (VMI) could be implemented to facilitate the production of high-quality products and improve the profitability of each supply chain member.

In this article, we use mixed-integer programming models to demonstrate that when sawmills and pulp and paper operations are

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coordinated, the right timber can be allocated to the right sawmill, while the right chip quality can be supplied to the paper mill, leading to improved supply chain profitability. In particular, we first develop two mathematical models that reflect the key planning decisions faced by the forest products companies; one model describing operations of four sawmills (harvesting, production, inventory, transportation, and demand satisfaction) and another one encompassing operations of a pulp and paper mill (supply, production, inventory, and demand satisfaction). Using these models, we compare three different logistics approaches that could be used by these companies: (1) a Make-To-Order (MTO) mode where the pulp and paper mill decides on the quantity and quality of wood chips to order, (2) a VMI scheme in which sawmills decide when and what quantity of chips they will supply to the paper mill, based on an expected service level, and (3) a centralized approach, based on the model of Alayet et al. (2016), in which all the planning decisions are driven by a single decision center. We then measure and compare the benefits of each approach for each stakeholder as well as for the whole supply chain, based on eight scenarios. Each scenario encompasses the possibility to satisfy or not the paper and lumber demand (i.e. demand constraints) as well as to change or not the production yield (i.e. the ratio of chips and lumber obtained from logs). Results highlight the importance of prioritizing certain demand or adapting the production yield depending on the business context. Furthermore they confirm that a logistics approach like VMI may ensure greater coordination between the forest products companies, decrease the inventory cost while reducing the age of the wood fiber kept in stock. To the best of our knowledge, no previous research has combined both a VMI technique and the management of fiber freshness to improve product quality and profitability of lumber and pulp and paper operations. Furthermore, such an approach could contribute to improving the economic situation of different but complementary forest products companies.

While a collaboration scheme for the context considered in the study seems promising, its implementation remains a challenge, especially for a supply chain encompassing multiple operations and various independent stakeholders. A more complex supply chain involves higher costs for managing the relationship and ensuring the respect of the policies, rules, and plans established. It may also involve issues related to the complexity of carrying out joint activities, information sharing and security, lack of trust among partners, divergent/incompatible business objectives and culture, financial risk, etc. (Lehoux et al., 2010; Ramanathan et al., 2011; Jeng, 2015). As pointed out by Lehoux et al. (2014), supply chain members must be ready to put the time and effort needed to ensure its success.

This paper is organized as follows: Section 2 presents a brief literature review on the concepts of supply chains and coordination mechanisms. Section 3 describes the case proposed, the problem to be solved, and the methodology followed. The mathematical models are explained in Section 4, while Section 5 focuses on the results and their analysis. Finally, the conclusion and suggestions for future work are presented in Section 6.

Literature review

According to Lummus and Robert (1999), a supply chain is a network of entities through which material flows. These entities may include suppliers, carriers, manufacturing sites, distribution centers, retailers, and customers. In this context, supply chain management (SCM) is adopted to synchronize and manage the flows of materials and information between network entities. In particular, it aims to design, implement, and monitor systems in order to improve business logistics networks as well as the interactions between network activities (Mahmood et al., 2003). SCM complexity stems from its structure composed of many activities over several independent subsystems which poses interesting challenges (Arshinder et al., 2008). To cope with this complexity, planning approaches for supply chain operations need to implicate coordination between its components.

According to Malone and Crowston (1994), "Coordination is managing dependencies between activities". Romano (2003) indicates that coordination mechanisms constitute a decision-making process that allows selecting, among the different feasible solutions, the most appropriate actions to achieve the overall goal of SCM. Fiala (2007) identified two types of coordination between suppliers and customers, centralized coordination and decentralized coordination. Decentralized coordination is characterized by the decision-making power dispersed among the numerous supply chain entities. Centralized coordination represents the classic prototype of "perfect collaboration" in logistics networks (Lehoux et al., 2014). Indeed, the decision-making policy is centralized when all decision-making powers are entrusted to one entity of the supply chain (Fiala, 2007; Mintzberg, 1982). The decision makers integrate all factors that synchronize and coordinate the various resources and entities and are in a good position to conduct benchmarking analyses (Fiala, 2007). Li and Wang (2007) examined the coordination mechanisms of supply chain systems. They highlighted the aspects and factors required to coordinate centralized and decentralized supply chains in the context of deterministic and stochastic demands. They suggested maintaining both interest and participation of all supply chain stakeholders through the use of information technology and useful real-time data sharing so as to optimize system performance.

In this regard, Pülzl and Lazdinis (2011) explored the potential of an Open Method of Coordination (OMC) for the forest sector in the European Union. They described their OMC concept as "... a way of encouraging co-operation, the exchange of best practice and agreeing on common targets and guidelines for Member States, sometimes backed up by national action plans.̈(European Commission, 2001). The purpose of their study was to find solutions for facilitating coordination between twenty-seven Member States and the European Commission. For their part, Rizk et al. (2006) discussed the case of the pulp and paper industry in which they examined different issues related to coordination between paper processing and its distribution. The objective was to plan processing activities, deliveries, and inventory levels for a variety of finished and intermediate paper products. Gaudreault et al. (2009) studied the coordination of independent facilities offering sawmilling products to customers. In their study, the coordination dealt with production planning, activity scheduling, and transportation selection in order to maximize customer satisfaction. Lehoux et al. (2010) presented an analysis of key factors to facilitate coordination between a pulp and paper producer and its wholesaler. Their analysis showed that keeping a supply chain profitable necessarily involves the implementation of a coordinated planning approach. Farnia et al. (2014) showed the importance of coordination when buying wood through an auction system. In particular, they compared two 'time-based lumber combinatorial auction' systems with and without coordination. The analysis demonstrated the positive impact of coordination on wood fiber management as well as on the harvesting and transportation costs when multiple products must be delivered in several places. More recently, Kimmich and Fischbacher (2016) analyzed the wood harvesting and merchandising process for the public forest in Switzerland. They considered many economic factors that could affect the forest products supply chain such as prices, trust between sellers and buyers, risk, lead time, etc. They highlighted that a more efficient management of those factors as well as a greater coordination between supply chain partners could certainly improve supply chain profitability while creating higher value. Alayet et al. (2016) modeled logistics activi-