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A comparison between individual factories and industrial clusters location in the forest supply chain

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ABSTRACT

A mathematical model for optimal supply chain design and planning is presented in this work. The concept of cluster, where several facilities producing different products are closely located, is introduced and specially considered. In order to analyze facilities integration, discounts on investment and production costs are assumed. In addition, tradeoffs between clusters and individual facilities configurations are assessed. The proposed approach is applied to a forest supply chain, where some production plants use the same raw materials while others compete for the use of byproducts and residuals. Results allow for costs reduction when resources and services are shared by plants within a cluster, where, besides, the effect of production scale on the overall SC is also taken into account.

1. Introduction

A supply chain (SC) is composed of a large number of participants, including production units, suppliers, and customers. In order to satisfy customer needs, products must be produced and distributed on time and in the required quality and quantity. Therefore, several decisions must be addressed in order to achieve an efficient SC coordination.

In particular, the forest SC consists of various members covering various activities such as harvest, transportation, production of several products, and power generation, among others (D'Amours et al., 2009). The heterogeneity of the different involved parts poses interesting challenges for design and planning.

Forest SC is addressed by many works in the literature to propose different contributions towards its efficient operation. Beaudoin et al. (2007) propose mixed integer linear programming (MILP) considering different sources of raw material for lumber production among a set of feasible sawmills with the possibility of selling wood chips to increase mills' profits. Bajgiran et al. (2016) formulate a MILP model and a heuristic algorithm for integrating tactical planning decisions in lumber SC.

The forest industry is characterized by a high byproduct and waste production at different stages. For various reasons, these have not been efficiently used despite having interesting applications. An attractive option for their use is the production of second-generation biofuels, thereby obtaining an environmentally friendly source of energy.

A possible option is to generate pellets. Pellet production has been studied from different perspectives. Economic analyses of its production in different countries were carried out by proposing changes in costs (Trømborg et al., 2013) (Uasuf & Becker, 2011) or different sources of raw materials to determine optimal production scales (Shahrukh et al., 2016). Ethanol is another possible biofuel using forest residues. Several raw materials (Lu et al., 2015) and different processes for their production have been studied (Wei et al., 2009). Costs have been also analyzed to determine the optimal size of biorefineries (Jenkins & Sutherland, 2014).

Several reviews have been conducted on different approaches to biofuel generation in the forest supply chain, including the optimization of economic, social, and environmental aspects (Shabani et al., 2013) (Cambero & Sowlati, 2014).

Alternative approaches and objectives to consider forest supply chain optimization can be found in the literature. Feng et al. (2010)) present a mathematical programming model to design an integrated biorefinery and a forest product supply chain network. Dansereau et al. (2014)) propose a framework for forest biorefineries by optimizing a superstructure to help decision makers identify different supply chain policies for different market conditions. Pettersson et al. (Pettersson et al., 2015) present a model for integrating biofuel production to an existing forest supply chain in Sweden. Rodríguez et al. (Rodríguez et al., 2016) propose a model using disjunctive programming for a case study of Argentine forest industry aimed at determining the optimal SC configuration and considering two different technologies for biofuel production.

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A significant aspect to be considered is integration among involved plants. In the forest industry, there is a strong cooperation and competition relationship among facilities in the use of raw materials, residuals, and byproducts. The same raw material can be used to elaborate several products and different plants can compete for residues and byproducts utilization. In this sense, forming clusters of different plants may be a good option to both optimize resources use and distribution and reduce costs. As regards the forest industry, cluster formation is worth being studied because it supports different integration alternatives among SC members.

There are many factors that favor industrial clusters formation. Porter (1998), in his development of clusters theory, postulates that the benefits are based on economies of scale, availability of human capital, and technology transfer. According to the sources of productivity, benefits and costs of the cluster may be related to: access to inputs and infrastructure, labor and human resources, access to information and performance measures, and complementary products.

There are some published works dealing with industrial clusters formation from different perspectives: SC performance improvement (Yan & Wang, 2008), the economic and industrial development of a region (Zhao et al., 2009), knowledge transfer (Purwaningrum & Evers, 2012), and avoidance of risks in knowledge exchange (Fang et al., 2011).

Tolossa et al. (2013)) present a review of works that integrate the concepts of supply chain management and industrial cluster. Qu et al. (2015)) discuss general operations and configuration policies of cluster supply chains. Nananukul (2013)) proposes a clustering model, where customers are grouped so as not to violate transport capacity restrictions and delivery times, and whose objective is to minimize transport costs. Hackl and Harvey (2013)) propose a framework methodology integrating renewable raw materials into industrial clusters to improve energy efficiency and resource utilization.

Other works deal with the importance of cluster formation to improve competitiveness of members from a conceptual point of view. By means of an empirical study, Canello (2016)) emphasizes that including migrant enterprises within local networks benefits economy and knowledge transfer. Cohen & Marrison (2008)) suggest that clustering of firms improves their performance and cost minimization. In order to minimize total costs, these authors and Rosenthal & Strange (2004)) present a production function affected by agglomeration factors. These factors take into account location and type of those industries that make up a cluster. Kadam et al. (2000)) suggest that the integration of a new ethanol plant with an already existing plant can reduce production costs and minimize capital expenditures by sharing equipment. They include a detailed analysis of cost reductions.

Taking into account the previous analysis found in the literature, it is possible to assert that the different advantages of forming a cluster were studied in depth, in spite of the lack of a systematic approach to determine where and how to compose these clusters. Besides, the advantages of forming a cluster are very varied and depend on each particular case (Kadam et al., 2000, for example).

Forest SC design and planning involve several decisions and coordination requirements due to the various uses of raw materials and the generation of diverse products and byproducts. Taking into account its characteristics, a forest SC is a clear candidate for taking advantage of a cluster configuration. However, specific approaches are required to appropriately evaluate the involved tradeoffs. As previously stated, there are no tools to solve this problem from a quantitative perspective.

Mathematical programming is a useful approach to optimize the operations included in the SC, since it allows simultaneously assessing different integration alternatives while considering all related elements (Corsano & Montagna, 2011; Corsano et al., 2011). The aim of this work is to evaluate the different tradeoffs between the allocation of individual installations and the formation of clusters for the forest industry. Cost reduction is considered according to the quantity and size of grouped plants. In this way, services and resources can be shared by plants in a cluster and, therefore, the production scale and structure of the overall SC can be modified.

The aforementioned problem is addressed by formulating a MILP model for the optimal design and planning of a forest SC to optimize economic performance. The SC involves different facilities that produce various products and byproducts. In addition, several raw material sites are considered, where logs with different characteristics are available and residues are obtained. The model determines location and size of each plant as well as material flows between SC nodes. Although the proposed model includes a detailed formulation considering many production options, the main contribution of this article is the special treatment of the benefits provided by cluster conformation. Specific tradeoffs are assessed using a quantitative perspective. As previously mentioned, the advantages gained by forming clusters have not been explicitly included in similar formulations. Therefore, the proposed approach allows for the correct assessment of its implementation in the forest industry, whose characteristics favor its adoption.

The paper is organized as follows: in the following section, the problem is presented with a description of the involved facilities. In section 3, the mathematical model is formulated. Section 4 shows results and presents the analysis and discussion of the different alternatives and, finally, conclusions are drawn in Section 5.

2. Problem statement

2.1. SC description

A three-echelon SC is considered: forests, which correspond to raw material sites where logs and residues are provided for production; different plants which produce wood, woodboards, pellets, and ethanol; and customer zones whose demands must be fulfilled. Fig. 1 schematizes SC nodes and connections. As well as the remaining elements of the problem, the SC structure can be modified to introduce new alternatives.

At each raw material site, different tree species of various diameters are considered. The harvest produces residues in the forest which are calculated as 38% of cut trees. Sixty per cent of this amount can be used for ethanol and pellet production, while the rest remains in the forest to preserve soil structure and quality.

As previously mentioned, the production facilities considered in this work are: sawmills and woodboard, pellet, and ethanol industries. There are several connections between facilities since some byproducts are used for manufacturing other products, thus generating flows among them. Also, each plant, except for ethanol facilities, generates byproducts that can be used in the same or another plant as a thermal energy source. Pellets can be used for generating thermal energy in all facilities, while ethanol plants can use pellets or acquire liquid fuel from external suppliers to satisfy fuel requirements. Finally, products are distributed to different consumption centers, which have maximum demands for each type of product.

The model poses the optimal allocation of production facilities in order to satisfy customers' requirements using the available forest raw materials. The objective is to maximize the net profit given by incomes from sales minus total SC costs, including investment, operation, raw materials procurement and transport.

Facilities must be located by selecting among a set of locations with different characteristics: close to supply areas, near consumption regions, or intermediate places. The proper allocation of these plants will influence the economic performance of the SC, taking into account that several critical aspects are significantly affected: production scale, distance among nodes, flows among facilities, etc. Plant installation near harvest areas can reduce raw material transportation costs. Small plants in each raw material site usually favor this criterion. If factories are installed in customer areas, raw material transportation cost is increased. The production scale will be influenced by each customer zone's demand, but final products transportation cost is reduced. If plants