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A location-inventory model for large three-level supply chains

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ABSTRACT

We study the location-inventory problem in three-level supply networks. Our model integrates three decisions: the distribution centers location, flows allocation, and shipment sizes. We propose a nonlinear continuous formulation, including transportation, fixed, handling and holding costs, which decomposes into a closed-form equation and a linear program when the DC flows are fixed. We thus develop an iterative heuristic that estimates the DC flows a priori, solves the linear program, and then improves the DC flow estimations. Extensive numerical experiments show that the approach can design large supply networks both effectively and efficiently, and a case study is discussed.

1. Introduction

In the last decades, supply chain management has proved to be a primary lever for companies to lower their costs and improve their overall competitiveness. In particular, the strategic design of the supply network is of crucial importance. It deeply impacts the supply chain planning and eventually the performance of the company. Thus, the facility location problem and its variants have been the focus of much attention from the scientific community. However, the problem is less often approached from a supply chain management perspective (Melo et al., 2009). In particular, while inventory costs may have a significant effect on the cost balance and the positioning of facilities, inventory management considerations are often neglected. Furthermore, the problem remains difficult to solve for large supply chains in reality.

Our research was inspired by the real-life case of a leading European glass manufacturer, mainly producing glass panes for the automotive and construction industries. Its supply chain includes 10 factories and around 500 customers (which can be retailers) throughout Europe. The case presented by the company concerns its reverse logistics network, and more precisely the return flow of reusable items (empty trestles) from the points of consumption to the factories. Currently, empty trestles are directly shipped back to the factories in the same truck that delivered the glass panes to the customer, whereas empty trestles can be folded and are thus less voluminous. The glass producer wishes to assess the advisability of an alternative strategy for the return flow: accumulating empty trestles in regional depots, to return them to factories in trucks that are better utilized. Consequently, inventory management decisions, such as the shipment size, play a central role, and have to be integrated with the location-allocation decisions within a single framework. We are therefore confronted with a fairly classic and difficult problem: the network design and inventory management of a three-level supply chain. In fact, this problem in the reverse logistics context bears a strong resemblance to that in a forward network. Solution methodologies can be

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applied equally well in both contexts, as indicated by Melo et al. (2009). We thus present our methodology in a general fashion, without distinguishing between the forward and reverse cases. Both will subsequently be discussed and exemplified.

Inspired by this real-life case, we study the location of intermediary facilities in a three-level network where factories and customers have fixed locations, and fixed constant production and demand rates. We also want to consider the impact of inventory decisions, and of shipment size in particular. Our approach assists with the making of location-allocation decisions as well as inventory management decisions in an integrated fashion. In other words, the cost function covers transportation and facility fixed costs as well as inventory holding and handling costs, and thus underlines the important trade-off between these costs. The targeted decision level is strategic. We consider a single-period planning horizon and a single product. Furthermore, we allow for direct flows between factories and customers and consider capacitated vehicles. In order to be able to analyze large real-life problems, we develop a continuous optimization formulation (and avoid using integer variables). The latter is shown to decompose when the flows through the DCs are fixed. In this case, the inventory decisions can be computed from a closed-form equation and the location-allocation decisions follow from solving a linear program. Based on this, we then propose an iterative heuristic which, at each iteration, estimates the DC flows, solves a linear program, and then improves the DC flow estimations.

The remainder of the paper is structured as follows. In the next section, we review the related literature. In Section 3, we present the problem and our mathematical modeling. A heuristic method is then proposed to solve it in Section 4. In order to assess the efficiency of the solution procedure, the heuristic is then tested on many different configurations in Section 5. In Section 6, we illustrate the application of the methodology in reverse logistics, to the case of the glass producer, and we discuss the application to forward supply networks. Finally, we conclude in Section 7.

2. Literature review

Our research can be related to several literature streams. First, it pertains to the facility location literature. Facility location models aim at finding the optimal placement of facilities and their links with other layers of the network, so that customer demand is satisfied at minimum cost. Melo et al. (2009) provide a thorough literature review focusing on supply chain management. The interested reader is also referred to the reviews provided by Klose and Drexl (2005) and ReVelle and Eiselt (2005). Our model can be classified as a deterministic single-period model with a single product, applied to a three-level network where the location decisions concern the intermediate layer. Other features are: capacitated vehicles, multiple sourcing, discrete locations, direct shipments from factories to customers, and inventory decisions.

Along with facility location decisions, an important characteristic of our model is that it incorporates inventory control. We rely on the classic economic order quantity (EOQ) control policy, which supposes deterministic demand and continuous review (see the seminal paper by Harris (1915), or Nahmias (2009)). Several EOQ extensions, solving similar continuous lot-sizing problems, have been studied (see the reference book by Axsäter (1980) for example). More specifically, our inventory control policy integrates multiple destinations and multiple sourcing (i.e. a facility may be supplied by several sources). As such, it is close to the EOQ extension known as "Single Resource Multi-Item Inventory Systems" (SRMIS). This EOQ extension considers a single factory that is replenished from multiple sources. The way the replenishments are coordinated impacts the computation of the average inventory at the factory. This problem was shown to be NP-complete by Gallego et al. (1992). The literature has primarily focused on finding the best possible coordination (Page and Paul, 1976; Rosenblatt, 1981; Gallego et al., 1996). In our work, as the problem at hand clearly has a broader scope, we will rely on an approximation of the average inventory at the factories, referred as perfect coordination (see Section 3.3). This approximation was implicitly used by Anily (1991) and Gallego et al. (1992) when they derived lower bounds for the problem. Lange and Semal (2010) discuss perfect coordination in detail and apply it for the allocation and lot sizing problem in a two-level supply chain (no location decision).

The case that motivated this research deals with the reverse network of a glass producer. Reverse logistics is now well established as a significant source of economies, and as an important lever to decrease the environmental impact of the supply chain. Some reference papers are those by Fleischmann et al. (1997) and AkÇali et al. (2009), which review quantitative models for network design, and by Brito et al. (2002) which surveys over 60 case studies. The glass producer case concerns the return flow of reusable items, i.e. empty trestles, which have to be returned to factories to be refilled. One of the first papers to study the problem of reusable items is that by Crainic et al. (1993). It proposes an analysis of the inventory management and shipment planning, but does not deal with network design. Two interesting case studies concern the design of the network for reusable items. Inspired by the case of a Dutch logistics service organization, Kroon and Vrijens (1995) propose a classic facility location model (transportation and fixed costs) to choose the depots in a network designed to return the containers back to their original sender. Quite similarly, Jayaraman et al. (2003) propose a model for the design of reverse distribution networks. Due to the complexity of such mixed integer programs, they focus on the introduction and analysis of an evolved heuristic to solve the proposed model. These two papers concentrate on pure network design (location of depots), while the present work also deals with inventory management.

The main feature of our work is that it integrates supply network design with inventory management. Despite their acknowledged importance, so-called location-inventory models have only appeared quite recently and are still fairly scarce.