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Multi-item dynamic lot-sizing with delayed transportation policy

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ABSTRACT

We optimize ordering and inbound shipment decisions for a manufacturer that sources multiple items from a single supplier. The objective is to satisfy the requirements in the production plan with minimum transportation and inventory holding costs over a multi-period planning horizon. Transportation costs are charged to the manufacturer on a per truck shipment basis. We investigate the option of delaying a less-than-full truckload shipment to the next period, by utilizing the safety stocks as needed. We analyze the impact of delaying shipments on both cost and service levels in stochastic environments through experiments with data from a bus manufacturer. The results indicate that the proposed policy reduces both holding and transportation costs without creating much stock-out risk.

1. Introduction

The importance of coordinating the shipment of parts from suppliers with the production schedule has long been recognized by manufacturing companies, with added emphasis in the context of supply chain management, e.g., Jung and Lee (2010) and Sawik (2009). In this paper, we address the inbound shipment of manufacturing parts to facilitate a production plan. We focus on a multi-item dynamic lot-sizing problem where the cost of shipments from the supplier is charged to the manufacturer. We encountered this problem at a leading coach bus manufacturer in Turkey, and found it to be common with other manufacturers that pay for shipments from the suppliers. The bus manufacturer relies on a Material Requirements Planning (MRP) system to generate the dependent demand for parts and subassemblies over a planning horizon. A majority of the required items are procured from local suppliers that are at most several hours of drive away. The manufacturer prefers to source each item from a single supplier and maintain a long-term relationship with its suppliers. Reduction of the supplier base has been a prevalent trend, as pointed out by Minner (2003), due to benefits such as decreased coordination efforts and more attractive contract terms as a result of large purchasing volume.

A supplier provides several types of items and when the manufacturer places an order that consists of different quantities of multiple items with given due dates, the supplier arranges a shipment plan. The supplier either takes care of the shipment with its own fleet, or as a common practice, utilizes a third party logistics service provider. The parts to be shipped on the same day are packed into trucks and directly shipped to the manufacturer. The transportation cost consists of a fixed cost per truck and a variable cost that depends on the distance traveled, and thus, can be represented by a per truck–per trip cost. Clearly, this cost structure calls for high truck utilizations. However, the bus manufacturer observed that most suppliers ship partial orders, sometimes as frequently as several times in a day, in less-than-full truckloads (LTL shipments). Hence, significant transportation costs accumulate in the long run when all suppliers are considered. As a remedy, the manufacturer wants to control its suppliers' delivery schedules, in addition to its own parts ordering process, to minimize the sum of transportation and inventory holding costs.

We propose and analyze a shipment strategy called the *Delayed Transportation Policy* (DTP) that aims to achieve truck utilization efficiency. The main idea of this strategy is as follows. Manufacturers keep safety stocks as a buffer against demand variability and possible schedule changes. We investigate the option of delaying LTL shipments to the next period by pulling items from the safety stock, considering that the items are ready at the supplier and could be delivered quickly when needed. We find the optimal ordering and transportation schedule under this policy, and without the policy for comparison purposes, by solving Mixed Integer Programming (MIP) models. The models minimize total transportation and inventory holding costs over a multi-period planning horizon, for which time-varying demands of multiple items are given. We analyze the benefits and risks of the proposed policy by computational tests with data from the bus manufacturer.

The remainder of the paper is organized as follows. We review the related literature in Section 2 and present the mathematical models in Section 3. Results of the computational analysis are given in Section 4. Section 5 presents the conclusions.

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2. Literature review

Studies on integrated inventory and transportation planning address problems arising in various stages of retail and manufacturing supply chains. Retail chain models mainly focus on coordinating inventory replenishments with inbound or outbound shipment schedules under stationary demand, whereas studies in joint production and distribution planning vary in terms of production control policies. Our focus in this study is on coordinating inbound parts shipments with the production plan of a manufacturer, where the demand for parts is deterministic and time-varying as in dynamic lot-sizing studies.

An integrated inventory and transportation planning problem arises while supplying a set of retailers, especially in a vendor-managed inventory (VMI) system. Kim and Kim (2000), Bertazzi et al. (2005), Archetti et al. (2007), Lee et al. (2008) and Kang and Kim (2010) address this problem under deterministic demands. In these studies, the objective is to determine both replenishment quantities and a transportation plan that specifies which retailers will be visited by each vehicle over a multi-period planning horizon. Besides these studies, Cetinkaya and Lee (2000, 2002), Axsater (2001), Fry et al. (2001), Kleywegt et al. (2002), Schwarz et al. (2006), Gurbuz et al. (2007) and Cetinkaya et al. (2008) consider supplying a single item with stochastic demand to multiple retailers and analyze coordinated periodic replenishment policies. Both Cachon (2001) and Kiesmuller (2009) study the periodic ordering decisions of a single retailer that sells multiple products with stochastic demand, with the consideration of inbound transportation costs. Cardos and Garcia-Sabater (2006) solve a periodic routing problem for the shipment of multiple items with stochastic demands from a supplier to multiple retailers.

Studies that integrate inventory decisions with inbound or outbound logistics differ in terms of shipment strategies. Gallego and Simchi-Levi (1990) stress the benefits of direct shipping, whereas Hall (1992) argues that multi-stop shipments may provide considerable savings. Since the latter requires items to be collected from multiple suppliers or distributed to multiple buyers, vehicle routes should also be determined (as in Qu et al., 1999; Bertazzi et al., 2005; Cardos and Garcia-Sabater, 2006; Archetti et al., 2007). A recent and comprehensive literature review of combined inventory management and routing, in terms of both industrial needs and theoretical studies, is given by Andersson et al. (2010). On the other hand, many studies analyze the case where the shipment goes directly to its destination. For instance, Yano and Gerchak (1989) and Speranza and Ukovich (1994) consider direct shipments from a vendor that supplies multiple items, where a fixed transportation cost incurs per vehicle per shipment. In our study we also consider a similar situation, but in a multi-period planning horizon.

Studies with joint considerations of production, distribution and inventory planning decisions have been classified in the reviews by Sarmiento and Nagi (1999) and Chen (2004). Recently, Banerjee (2009), Pundoor and Chen (2009) and Sawik (2009) address the problem of coordinating the production schedule with the outbound shipment schedule in a deterministic setting. In these studies, shipments of different products are consolidated and the transportation cost is fixed per shipment. Since we study the sourcing of manufacturing parts, we focus on integrating inbound shipments with the production plan. Studies on this topic differ according to pull or push production strategies. Ben-Khendger and Yano (1994) schedule the delivery of multiple items from a single supplier to a manufacturer in a just-in-time setting. Yano and Gerchak (1989) address how to set transportation contracts and safety stocks, while Hill and Vollmann (1986) study scheduling and routing decisions for vendor pickups, both in a pull production system. In our study, item demands are driven by an MRP system using push strategy and hence a dynamic lot-sizing problem is considered.

Multi-period lot-sizing has been studied extensively in production and inventory management literature since the seminal work of Wagner and Whitin (1958). Its extension to the case of multiple-items that are shipped together has also attracted significant interest, especially in the context of optimizing supply chain operations. The shipment costs are modeled according to the contracts between suppliers and manufacturers. Lee et al. (2002) analyze a dynamic lot-sizing model with pre-shipping and late-shipping options under stepwise shipment costs. They develop an exact polynomial time algorithm. Li et al. (2004) study a lot-sizing problem where the delivery cost is subject to full truckload discounts. Norden and Velde (2005) consider a multi-product lot-sizing problem under a transportation capacity contract that calls for piecewise linearly increasing freight rates. They provide an integer programming formulation and develop a Lagrangian relaxation algorithm to solve it. Lee et al. (2005) analyze a multi-item dynamic lot-sizing problem in which freight costs are proportional to the number of containers used. They propose a heuristic algorithm with an adjustment mechanism based on the properties of the optimal solution.

Several other studies with direct shipments generalize the classical lot-sizing problem by making the fixed ordering cost dependent on the lot-size. Anily and Tzur (2005) study the sourcing of multiple-items from a warehouse or a plant by a retailer. They assume that items of identical size are packed into vehicles that incur a fixed cost per trip. They develop a dynamic programming algorithm that generates an optimal ordering and shipment plan. Consequently, Anily and Tzur (2006) propose a different approach for the same problem. They first generate shipment schedules by a search algorithm and then utilize a shortest-path algorithm to select a schedule among those. Both Rizk et al. (2006) and Ertogral (2008) solve a multi-item uncapacitated dynamic lot-sizing problem with piecewise linear transportation costs by a Lagrangian relaxation procedure. The cost function represents LTL shipments with freight discounts. In contrast, in our study the per truck shipment costs correspond to a step function, as in Anily and Tzur (2005, 2006). The problem we study is similar to the one in Anily and Tzur (2005, 2006), but in finding the number of trucks needed, we do not assume uniform item size. Instead, we calculate the number of pallets required for each item based on its size to get a more realistic estimation of the number of trucks needed. We propose a new shipment strategy and investigate resulting cost savings and possible risks computationally.

In many real-life situations transportation costs of goods are fixed for a finite capacity, based on a truck or a container load. For example, a fixed cost incurs when a truck is deployed whether it is fully utilized or not (Lee, 1986). Banerjee (2009), Kiesmuller (2009), Gurbuz et al. (2007), Cachon (2001), Yano and Gerchak (1989) all consider fixed costs per truck shipment in their models. Van Eijs (1994) considers reduced freight rates when ordering a full-container load instead of a less-than-container load. A discussion of freight rates in practice is given in Swenseth and Godfrey (2002).

When the transportation cost structure calls for full truckload payments, several strategies have been proposed to increase truck capacity utilization. In the commonly studied shipment consolidation strategy, multiple shipments of small quantities are combined into a larger and more economical vehicle load (e.g., Cetinkaya and Lee, 2002; Cetinkaya and Bookbinder, 2003). Gurbuz et al. (2007) propose a replenishment policy in which orders for some retailers may be postponed or expedited so that they can be batched with other retailers' orders, which