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Project scheduling in optimizing integrated supply chain operations

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ABSTRACT

A Supply Chain (SC) requires undertaking considerable number of activities covering the flow of information and goods among multiple production and distribution cells over several tiers. The successful implementation of a SC hinges on the optimum integration and synchronization of these activities.

In this paper, we formulate an integrated SC as a project network (PN) with activities covering: sending and receiving orders, processing these orders as well as sending and receiving of shipments and their precedence. This PN is also modeled as a Mixed Integer Program (MIP) that captures various trade-offs including stationary and transient inventory holding costs, crashing cost of the processing activities, shipping cost, and penalty for late delivery of customer orders. The SC activities are synchronized using the MIP to ensure proper coordination among all the SC cells. The solution provides the optimal: cycle time(s), shipping modes, processing times, and the due dates for all SC cells at minimum cost.

The computational work for optimizing SCs of an illustrative example as wells as an applied case for the production and distribution of automotive batteries demonstrated that the proposed approach is of merit in efficiently optimizing integrated SCs.

1. Introduction

Despite the popularity of the terms Supply Chain (SC) and SC Management (SCM), both in academia and practice, there remains considerable confusion as to their meaning, Mentzer et al. (2001). Some authors define SCM in operational terms involving the flow of materials and products, some view it as a management philosophy, and some view it in terms of a management process, Tyndall et al. (1998). The most common definition of the term SC is "A system of suppliers, manufacturers, distributors, retailers and customers where material flows downstream from suppliers to customers and information flows in both directions", Ganeshan et al. (1998). Chopra and Meindl (2010) state that: "SC conjures up images of product or supply moving from suppliers to manufacturers to distributers to retailers to customers along a chain." They also state that most SCs are networks, and recommend using the term "supply network." Naturally cash flows are based on the flow of goods and information. An effective SC must ensure that the required product quantity is delivered to the customer on time at minimum cost. Clearly, the main objective of SCM, "is the design and management of seamless, value-added processes across organizational boundaries to meet real needs of the end customer," Akkermanns et al. (1999). Similarly, Simchi-Levi et al. (2008) define SCM as, "a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores so that the merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system wide costs while satisfying service level requirements."

As the above definitions imply, a SC involves the integration of the activities that procure material, transform them into intermediate goods or final products, and then deliver them to distributors and/or customers. These activities cut across various functions in an organization and also over multiple organizations. Ideally, effective collaboration should take place among the various activities within the inbound and outbound sides of the producer. However research has shown that effective collaboration most often occurs within the producer's most important first-tier customers or suppliers. Fawcett and Magnan (2002) show that over 95% of collaborative efforts focus on the first-tier. Furthermore, according to Poirier (1999) and Blackwell (1997) distributors and marketers (outbound/distribution side) see the world differently from the suppliers (inbound/production side). Consequently there is a need for a SC management tool that integrates the entire supply chain, and then optimizes over the integrated SC to guarantee its competitive advantage.

The primary objective of this paper is to develop a managerial tool that can be used to integrate all tiers of the SC and optimizes over all the activities of the chain. We first show that the integrated

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supply chain (ISC) can be modeled as a project network (PN). The project captures all the activities involved in the ISC for multi-component family of products regardless the number of tiers in the ISC. Second, the PN is formulated as a mixed integer program (MIP). The optimal solution of the MIP provides the duration for all processing and shipping/distribution activities, and the schedule of orders. It also allows for deriving the cycle time–cost curve; hence providing the manager with a menu of cycle times and costs to select from; see Klibi et al. (2010).

The paper is organized as follows. Section two provides the problem definition followed by the literature search in Section 3. The basic concepts for modeling the ISC as a PN are given in Section 4. Section 5 states the MIP formulation of the ISC and its solution. Section 6 provides the computational work including an illustrative example, and a real life SC for the production and distribution of automotive batteries. The concluding remarks are provided in Section 7.

2. Problem definition

The problem deals with a SC for products provided by multiple suppliers (e.g. manufacturers or vendors) cells in the same tier or over a hierarchy of several tiers. A product may consist of several components. The types of cells in a SC include customers or distributors in the top tier, manufacturers, sub-assemblers or suppliers as intermediate tiers, and vendors at the bottom tier. The top tier includes customers receiving products from major suppliers who in turn receive components from cells at lower tiers. Suppliers may receive components from sub-suppliers and the chain of supply continues until its bottom tier. Major suppliers or manufacturers receive orders from customers for fixed quantities of different products over a predetermined planning horizon. The orders are received up to a given deadline for delivery within this planning horizon. An order for a product specifies the quantity and the delivery due date. A penalty is incurred if the customer receives its order after the due date. The SC includes orders of multiple products that may share common components. The time and cost of processing each component in a cell are based on the rate and capacity of processing in that cell. The cost of processing in a cell is a continuous linear function of the processing time. Processing duration varies between normal and shortest (crashed) durations, where the peak cost is incurred at the shortest duration. The capacity for processing in a given cell would vary between the normal and the crash time capacities. Components may be shipped using one of several transportation modes. The duration and cost of shipping is dependent upon the selected mode and the quantity to be shipped using that mode. Inventory holding costs are incurred when components are stored in the supplier cell or the receiving customer cell as well as during transit from supplier to customer. Once all orders are received, suppliers would like to: schedule and synchronize all activities required to complete and deliver these orders, determine the expected delivery times, and optimize the related costs.

The establishment of deadlines for each customer in the ISC and for any of its tiers while minimizing the total cost is a challenging problem. First, the ISC involves different types of activities. Transportation activities have discrete durations and costs, while others have continuous or constant durations. Second, managing the ISC to satisfy a given due date while minimizing the total cost may require crashing some activities, determining inventory policies, and selecting the distribution channels. Third, the ISC must balance the ability to satisfy customer needs, or market changes at minimum cost.

Formulating and optimizing the corresponding supply chain becomes a challenging task, particularly when considering the issues of inventory, processing operations, and shipping policies within the ISC. On the inbound side, it consists of multi-stage inventory belonging to raw material and work-in-process where the product earns value as it moves upstream, while on the outbound side, it consists of multi-echelon inventory belonging to the finished product that exchanges hands within the various distribution channels, but at extra time and cost. Similarly crashing processing activities, or expediting the shipping activities to meet certain due dates leads to considerable trade-offs. To illustrate, consider the two cycle time (CT) extremes, namely: the longest and shortest ISC CTs. The longest CT is obtained by processing each activity and shipping each lot at its longest duration which would result in low processing and shipping costs, but high inventory costs. It may also result in unsatisfied customers due to late delivery. On the other hand, the shortest CT is realized by crashing processing and shipping activities using the fastest mode leading to high processing and shipping costs, but low inventory costs. Due to these trade-offs, it would be hard to identify whether any of the two extremes, or any operating policy in between, provide the minimum cost for a desirable CT or customer due date.

3. Literature review

Research in the operational side of SCM is considerable as reflected in the recent review papers and handbooks such as Chen (2010), Klibi et al. (2010), Guide et al. (2009), Bilgen and Ozkarahan (2004), Simchi-Levi et al. (2004), Ganeshan et al. (1998), and Geoffrion and Powers (1995). Chen (2010) for instance shows that in make-to-order SC production and distribution, functions are intimately linked and must be scheduled jointly. In this review the author also reports that research integrating production scheduling and outbound distribution is relatively recent, but growing rapidly. Klibi et al. (2010) provide a review of papers dealing with SC design under uncertainty. Bilgen and Ozkarahan (2004) provide a review of papers dealing with the integration between strategic, tactical and operational issues; and Guide et al. (2009) discusses the evolution of closed loop SC research.

Examination of literature shows that while many recent publications dealt with the integration of production and distribution functions in SC, none of these papers dealt with the problem defined above. See for instance Nagurney (2010), Bard and Nananukul (2009), Samaranayake and Toncich (2007), Stecke and Zhao (2007), Chen and Vairktarakis (2005), Hall and Potts (2005), Kaminsky and Simchi-Levi (2003), and Thomas and Griffin (1996). Samaranayake and Toncich (2007) integrated enterprise resource planning and SCM systems for planning and operation; where Nagurney (2010) developed a framework for design and redesign of SC to integrate production and distribution using variational inequalities. Kaminsky and Simchi-Levi (2003) dealt with the transportation issues in a two stage manufacturing SC; and Bard and Nananukul (2009) dealt with vehicle routing in a SC consisting of a single facility serving multi-customers with varying demands over a finite planning horizon. Stecke and Zhao (2007) focused on the integration of these functions in a make-to-order SC. None of these publications applied the methods of project management for managing the ISC, or dealt with large size (several tier) supply chains.

Network models have been used extensively in the optimization of manufacturing and distribution systems; see Chen (2010), Ettl et al. (2000), and Geoffrion and Powers (1995). Networks were used in the design of multi-echelon supply chains. Graves and Williams (2005) used spanning trees in the configuration of the SC for a new product. The spanning tree consists of the essential functions of the process within the SC. Within this representation demand at each stage follows a one-to-one replenishment policy;