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Integrated production and logistics planning: Contract manufacturing and choice of air/surface transportation

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ABSTRACT

We study the operational problem of a make-to-order contract manufacturer seeking to integrate production scheduling and transportation planning for improved performance under commit-to-delivery model. The manufacturer produces customer orders on a set of unrelated parallel lines/processors, accounting for release dates and sequence dependent setup times. A set of shipping options with different costs and transit times is available for order delivery through the third party logistics service providers. The objective is to manufacture and deliver multiple customer orders by selecting from the available shipping options, before preset due dates to minimize total cost of fulfilling orders, including tardiness penalties. We model the problem as a mixed integer programming model and provide a novel decomposition scheme to solve the problem. An exact dynamic programming model and a heuristics approach are presented to solve the subproblems. The performance of the solution algorithm is tested through a set of experimental studies and results are presented. The algorithm is shown to efficiently solve the test cases, even the complex instances, to near optimality.

1. Introduction

Consumers are increasingly seeking newer products with more features. To remain on the leading edge of the ever more demanding marketplace, companies are under constant pressure to shorten their product lifecycles and introduce new products with competitive prices at a faster pace. This market pressure inevitably propagates upstream in the supply chains to higher tier suppliers.

Production and logistics operations are critical to the success of supply chains in most manufacturing industries. Manufacturers' survival in today's competitive market relies heavily on the coordination of the manufacturing and distribution operations, in addition to how well each are executed. Better asset utilization enables the manufacturers to reduce their marginal costs and hence become more competitive; on the other hand, using faster yet economical transportation options decreases lead times while keeping logistics expenditures low. In this research, we integrate the production scheduling and logistics planning of a manufacturer with the objective of maintaining a customer service level at a minimum cost, and provide a novel solution approach.

Our research stems from the integrated production scheduling and logistics planning problem of contract manufacturers (CMs). A CM is a specialized outside supplier that provides manufacturing services under contract for a limited set of products. Supplying similar products to a set of different customers allows CMs to benefit from the economies of scale and enables them to invest in automation and specialization, thus, reducing the marginal cost of production. It is argued that this business model allows companies to focus on their core competencies (e.g. product development and design) while outsourcing part of their manufacturing to CMs to reduce cost and possibly attaining better quality. CMs play a key role in industries such as computer electronics, aerospace, defense, energy, pharmaceuticals, medical equipment, and automobile manufacturing (Han, Porterfield, & Li 2012). CMs, essentially, compete on lower production cost and shorter lead-times that reemphasize the significance of integrated production and logistics planning.

We consider the integrated make-to-order production scheduling and logistics planning problem of a CM serving a given set of customer orders. The CM has multiple parallel processors (i.e., production lines which can be located in the same plant or different plants) and can produce each order on any one of the processors. Orders require different processing times on different processors. The processing of an order cannot be split between multiple processors and cannot start before receiving all the needed raw material. Moreover,

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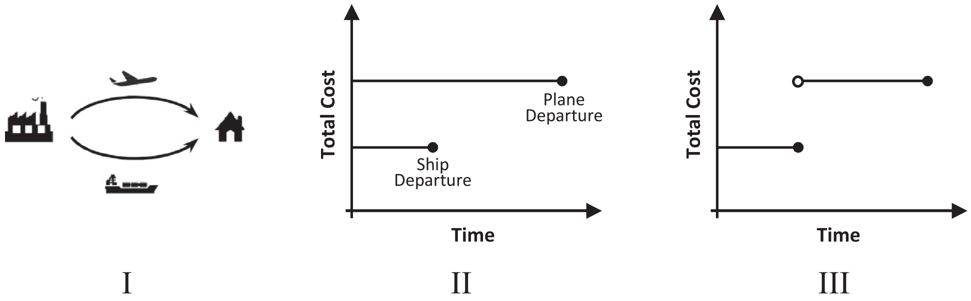

Fig. 1. Time-dependent logistic function (III) based on cost and variability of shipping options (II) for an illustrative transportation network (I).

switching from the completion of an order to the start of the next one on the same processor requires setup and retooling. The cost and duration of this transition are dependent on the order sequence. All orders must be processed and delivered to the customer on or before a predefined due date to avoid service level penalties. While there is no earliness penalty, delivery tardiness is penalized in stages; e.g., a fixed penalty for the first week delay and additional daily penalties thereafter.

CMs often utilize third parties for their logistics and distribution needs. In fact, almost 80 percent of firms rely on third party service providers for their transportation and other logistics operations (Langley, 2014). By outsourcing transportation, CMs are constrained with the carriers' shipment schedules. On the other hand, carriers commonly offer multiple shipping options with varying costs and lead-times for CMs to choose from. The integration of production and transportation planning allows the CM to trade-off between these shipping options to reduce the overall cost of fulfilling orders. For instance, early completion of an order can be capitalized on by choosing a cheaper but slower surface transportation, while tardiness penalty can be avoided in case of late completion of an order by utilizing more expensive but faster air transportation. The CM business model considered in this research is known as *commit-to-deliver*, where the manufacturer takes the responsibility of delivering goods. This arrangement contrasts with the *commit-to-ship* model where the manufacturer is only responsible to complete and ship the goods by a given due date (Stecke & Zhao, 2007). In the commit-to-ship model, the customer chooses and pays for the transportation option, hence controls the delivery time. The commit-to-deliver model with integrated production and logistics planning is shown to benefit both the manufacturers and the customers by increasing the manufacturer's profit, reducing lead-time variability, and improving customer service level (Stecke & Zhao, 2007).

Under commit-to-deliver model, the availability of multiple carriers allows the manufacturer to compare shipping fees and lead-times. Longer shipping times lead to later deliveries, which in turn may result in tardiness penalties. The availability of shipping options is time dependent since many carriers have predetermined cut-off times that shippers have to abide by. Multiplicity of shipping options with different cut-off times, delivery lead-times and total costs (e.g., shipping fees and late delivery penalties) results in a time-dependent logistics cost function for each order. Characterization of the time-dependent logistics cost function is achieved by selecting the dominant shipping option(s) among all feasible options for any given manufacturing completion time of an order. Fig. 1 illustrates the relationship between shipping options and a time-dependent logistic cost function for an illustrative single-leg transportation network.

In this example, the manufacturer can directly ship an order to a customer via air or water mode. Water transportation is cheaper but slower; in contrast, air transportation is fast but far more expensive. Delivery time of each transportation option can be determined based on the scheduled departure time of the ship or flight and their respective lead-times. Thus, the total cost of each option can be calculated based on the shipping cost and the service-level cost as determined by delivery time and order due date. Accordingly, for a given mode of shipping, even with identical transportation fees, any difference in the carriers scheduled departure times may result in different delivery times and total costs. For this illustrative example, let us assume that the CM is considering only one option from each mode to deliver a customer order. Based on the delivery time (thus the penalties) and shipping fees, the total logistics cost of each option is calculated. Water mode option has a lower total cost, but is available for a limited time, after which the more expensive air mode option remains as the only available option. Consequently, if the manufacturer can complete the order before the ship departure time, the cheaper water option would be the best choice. Otherwise, air transportation with the higher cost must be used. Hence, the logistic cost function takes the form of a time-dependent step function with jump points at options' scheduled departure times.

In practice, however, customer orders are delivered through a complex scheduled transportation network that often involves multimodal transportation with transshipment nodes. Indeed, the attributes of cargo such as its quantity, product type, weight, volume, handling restrictions, and security concerns affect the routing and mode selection decisions in its transportation planning. For instance, if a mode is not capable of transporting a given cargo (e.g., dangerous goods on a mixed passenger-cargo flight), it would not be reasonable to further consider this mode as an option and thus should be ignored. Similarly large-sized products would cost more to transport and will be subject to various dimension and capacity restrictions. This interplay between the transportation options and cargo characteristics (quantity, weight, product type, etc.) are captured through the time-dependent logistics cost function which is an input to our problem. Therefore, selecting the best routing option and estimating the delivery time and shipping cost require a careful evaluation of the routing options. Azadian, Murat, and Chinnam (2012) study the routing of a single cargo shipment in a transportation network with transshipment points under both deterministic and stochastic settings by considering customer service level, capacity availability, and delays. They study the application of this problem in air-cargo shipping. In their problem, the shipper has multiple carrier options at the origin airport as well as at the mid-way transition airports. The objective is to route the cargo through a set of interconnecting flights from origin to destination to minimize cost, including the delivery tardiness penalties. They developed a recursive dynamic programming solution algorithm that calculates the expected cost of different routing policies and identifies the best policy based on the cargo loading times at the origin and intermediate airports. Their logistic cost function, which accounts for both transportation costs and delivery delay penalties, is shown to be non-decreasing time-dependent function that can be modeled as a regular step function in the deterministic setting. Similar to the problem of routing of a single air cargo in Azadian et al. (2012), where the logistics cost depends on the