Computers & Operations Research 60 (2015) 79–90

Contents lists available at ScienceDirect

Computers & Operations Research

journal homepage: www.elsevier.com/locate/caor

A stochastic programming model for multi-product oriented multi-channel component replenishment

Lu Zhen*, Kai Wang

School of Management, Shanghai University, 99 Shangda Road, Shanghai 200444, China

ARTICLE INFO

Available online 19 February 2015

Keywords:
Component replenishment
Multi-product
Multi-channel
Assemble-to-order

ABSTRACT

Assemble-to-order (ATO) manufacturing companies face decision problems on components replenishment and outsourcing channels adoption. This paper proposes a stochastic programming approach on component replenishment decisions for an ATO contract manufacturer who faces a single period stochastic demand for multiple products made by multiple components. The first stage of the proposed model is to decide the quantities for pre-stocking all types of components. After the confirmation of the demands, the second stage is to decide the quantities of outsourcing components and the outsourcing channels among several candidates for each component. In addition, the assignment of components to the productions of different products, and the decreasing trends of products' prices with respect to their delivery time are considered. For the problem, this paper proposes a stochastic programming model. The nonlinear objective is linearized by some approximation. For solving the model, a local branching based solution method is suggested. Some numerical experiments are performed to investigate the efficiency of the proposed solution method and the effectiveness of the proposed model.

1. Introduction

Manufacturers usually try their best to be competitive in terms of both low cost and short delivery time. For achieving these targets, the manufacturers hope to know the demand information from their clients as early as possible. However, these client companies usually delay their confirmation of order quantities so as to mitigate market fluctuations. For the manufacturers, they also need to outsource some components from suppliers; and the long lead time of outsourcing components will influence their competences for delivering products in a timely manner. Therefore, many manufacturers usually outsource and keep a certain level of component inventory in advance before the demands are confirmed in their clients' orders. In this way, the manufacturers can obtain higher profits through a timely response in delivering products.

According to the above backgrounds, this paper studies a decision problem on component replenishment for an ATO contract manufacturer who faces a single period stochastic demand for multiple products made by multiple components. A two-stage stochastic programming model is proposed. The first stage decision is before the confirmation of the order demands for products. The manufacturer needs to decide the proper quantities for pre-stocking all types of components. The second stage decision is after the confirmation of the demands. If some of the pre-stocked components are below the required quantities for assembling the products needed by clients, the manufacturer needs to decide both the quantities of outsourcing components and the outsourcing suppliers among several candidates for each needed component. In addition, when the outsourced components are delivered, how to assign them to the productions of different products is another issue in the second stage decision. The decreasing trends of products' prices with respect to their delivery time are considered in the objective of this decision problem, which is to maximize the expected profit of the manufacturer. By using the stochastic programming methodology, this paper proposes a decision model with nonlinear objective, which is linearized by outer-approximation. For solving the model, a local branching based solution method is suggested. Some numerical experiments are performed to investigate the efficiency of the proposed solution method and the effectiveness of the proposed model.

The remainder of this paper is organized as follows. Section 2 is the literature review. Problem backgrounds of this problem are elaborated in Section 3. Then a mathematical model and some analysis on the model are given in Section 4. For solving the model, Section 5 addresses a solution approach. Section 6 lists results of numerical experiments. Then some closing remarks are given in the last section.

* Corresponding author. Tel.: +86 21 66134237.
E-mail address: lzhen@shu.edu.cn (L. Zhen).

http://dx.doi.org/10.1016/j.cor.2015.02.006
0305-0548/

2. Related works

This study is related to the ATO systems. For a comprehensive overview on ATO related studies, readers can see the review work given by Song and Zipkin [14]. Here some closely related studies are discussed as follows. Fu et al. [6] proposed some profit-maximization models on inventory, production and outsourcing decisions in ATO systems. Some structural properties of optimal solutions were investigated. Hsu et al. [9] studied how to determine the inventory quantities for components in an ATO system, which assumes that demand is uncertain, there are multiple partial shipments, the price for the final product and the costs of components depend on their delivery time. Different from the above work, Hsu et al. [10] considered the situation where the manufacturer needs to deliver the full order quantity in one single shipment. This full-shipment delivery way is appropriate in some cases because of the economy of scale in transportation. The performance differences between the full-shipment mode and the multiple partial shipments mode were also investigated through experiments. Fu et al. [7] considered the situation that components can be ordered early at normal prices before the demand is revealed, or they can be replenished later at higher prices due to expediting. Xiao et al. [15] considered emergency replenishment of components for a single-product, single-period ATO system under uncertain assembly-in-advance capacity and operations. Based on the studies by Hsu et al. [9], Fu et al. [7], and Yao et al. [16] studied a component replenishment problem by extending the previous models from single channel settings (i.e., 'regular' purchase channel in Hsu et al. [9], and 'expediting' channel in Fu et al. [7]) to dual channels settings. Yao et al. developed some structural properties of the optimal solutions and used them to solve their problem analytically. Karaarslan et al. [11] analyzed an ATO system of one product and two components under two different policies, and then investigated the optimal policy designs for minimizing the holding and backorder costs. Recently, the pricing strategies in the ATO systems also attracted attentions from academia. Fang et al. [4] developed a Stackelberg game based model to determine a manufacturer's pricing policy for their suppliers' consignment inventories. Shao and Ji [13] studied strategic pricing decisions of a decentralized ATO system under price-sensitive demands, and investigated the effects of sourcing structure on system performance. This paper is oriented to multi-product ATO systems, which have also been studied by other scholars in recent years. El Hafsi et al. [3] studied an ATO system, in which multiple products are made by a set of multiple distinct components, and investigated some optimal policies for components' inventory control. El Hafsi [2] also investigated the optimal production and inventory allocation policies for the ATO system. Some comparative experiments between the proposed optimal policy and the first-come first-serve policy were performed to validate its benefits. Ko et al. [12] studied an ATO system that uses a base-stock policy and derived some closed-form formulae for approximating the lead-time distributions in equilibrium. The above mentioned studies are mainly about the single-level ATO systems. For a multi-level ATO system, Hnaien et al. [8] investigated its optimal inventory control decisions under uncertain lead time, and proposed two genetic algorithms based multi-objective models.

Among the above studies, the work by Yao et al. [16] is closely related to this study. Both of them are about component replenishment for ATO systems under single-period stochastic demands and the decreasing trends of final products' prices with respect to their delivery time. However, the differences from Yao et al. [16]'s study mainly include:

(1) This study extends the previous model in Yao et al. [16] from a single-product setting to a multi-product setting, in which some components may shared by different products. This change makes the decisions in the second stage more complex because the allocation of components to products also becomes decision variables.
(2) The products' prices depend on their delivery time, but the assembly time is assumed to be zero in the previous model. This study considers the assembly time, which depends on the batch size of the assembled products. This change further complicates the revenue objective function, which becomes significantly nonlinear. Thus this study needs to employ some approximation method to handle the nonlinear objective.
(3) The properties of the optimal solution in the previous study are mainly derived by using the newsvendor model. However, these properties do not apply in this study because the consideration on the above mentioned realistic factors makes the problem intractable for using the newsvendor model again. Thus this study formulates a stochastic programming model to consider the uncertain demands of products.

3. Problem backgrounds

We suppose there is an ATO manufacturer who is about to receive orders for n different products. This study considers that multiple final products share multiple components. More specifically, these n different products are assembled by some of m different components. According to the BOM (bill of material) information of the products, the relationship between a product (e.g., A_i) and a component (e.g., B_j) is deterministic and denoted by $u_{i,j}$, which reflects the number of components B_j contained in one product A_i. Fig. 1 shows the BOM information in multi-product oriented ATO system.

The quantity of each product required by customers will be confirmed in the orders at the time 0. For each product A_i, its unit price, denoted by $p_i(t)$, is a decreasing function of the delivery time t. Thus the contract manufacturer needs to assemble and deliver the products as soon as possible. The manufacturer usually outsources some components in advance so that the customers can accept the first batch, which may be partial delivery of the entire orders, in a fast way. In this case the first batch of final products can be sold at some high prices. If the confirmed orders' demands are not met with the pre-stocked components, the manufacturer has the opportunity to procure additional components through various suppliers who offer

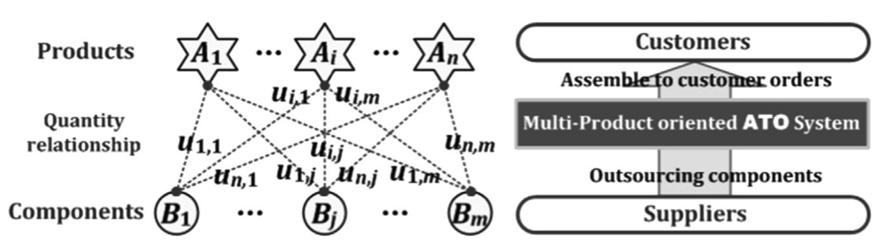

Fig. 1. BOM information in multi-product oriented ATO system.