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Component commonality under no-holdback allocation rules

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ABSTRACT

We study the value of component commonality in assemble-to-order systems under no-holdback allocation rules. We prove that the total product backorder and on-hand component inventory decrease with probability one as the degree of commonality increases; however, the average cost may not decrease unless a certain cost symmetric condition is imposed.

1. Introduction

ATO systems are an important business model for improving supply chain performance. By eliminating expensive finished-product inventory and carrying only component inventory, ATO systems hold the promise of achieving customization, lower inventory cost and fast response to demand simultaneously. In an ATO system, a product may require a subset of components, and a component can be required by different products. The issues of component commonality and component inventory management (replenishment policy and allocation rule) are critical to the success of an ATO system.

Component commonality is a key enabler of ATO systems. Examples can be found in many industries, such as computers, electronics and automobiles [4]. The value of component commonality has been studied in the operations management literature for decades, with a focus primarily on static models without lead times [16,17]. Recent studies have extended this literature to dynamic inventory systems with lead times [15]. These studies focus on practical but sub-optimal allocation rules because the optimal allocation rules are not known (except for a few special cases, e.g., [3,13]) and only simple and suboptimal allocation rules are implemented in practice.

Because a common component is shared by many products, it allows us to explore the effect of risk pooling in assembly systems. Risk pooling is an important concept in supply chain management [4]: by aggregating demands from different products, we may reduce overall demand uncertainty and improve the cost/effectiveness of the system. In dynamic ATO systems with lead times under heuristic allocation rules, the value of commonality (or risk pooling effect) is more delicate. For example, for a two-product ATO system under a first-come first-serve (FCFS) allocation rule, Song [14] provides a couple of numerical examples to show that component commonality does not lower the total backorder and improve inventory performance. Song and Zhao [15] shows that component commonality does not always generate savings on inventory investment or service-level improvements. In fact, the value of component commonality depends strongly on how the component inventory is managed, e.g., the common component allocation rules, as well as various system parameters such as component costs and lead times. Thus, it is of interest to study the impact of commonality on backorders and inventory performance in ATO systems, but under a class of allocation rules different from FCFS, that is, the no-holdback (NHB) rules.

Song and Zhao [15] first defines the NHB rules. To see how it works, let us compare the FCFS rule with the first-ready first-serve (FRFS) rule (a special case of the NHB rules, see [15]). Under the FCFS rule, demand for each component is fulfilled in exactly the same sequence as it occurs. When a demand arrives, if some of its components are available while others are not, the available components are put aside as committed stock. Under the FRFS rule, however, we do not allocate or commit those available components to the order unless doing so leads to the fulfillment of this order. When a replenishment arrives, we satisfy the oldest backorder for which all required components are available. The FRFS rule is widely used in practice, see, e.g., [12] for an example in Dell Computer Corporation.

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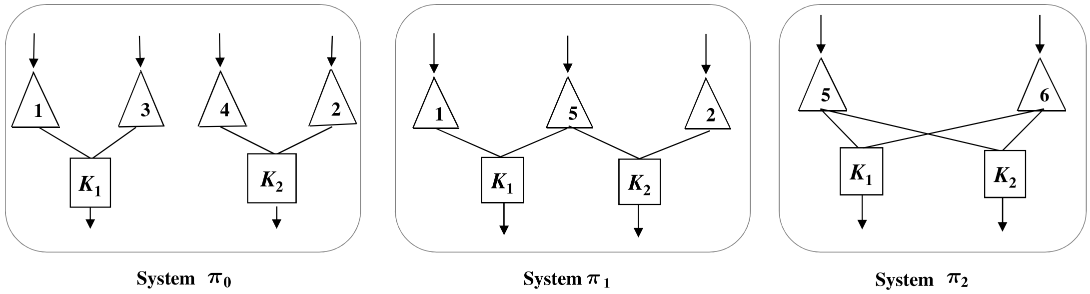

Fig. 1. Two-component ATO systems.

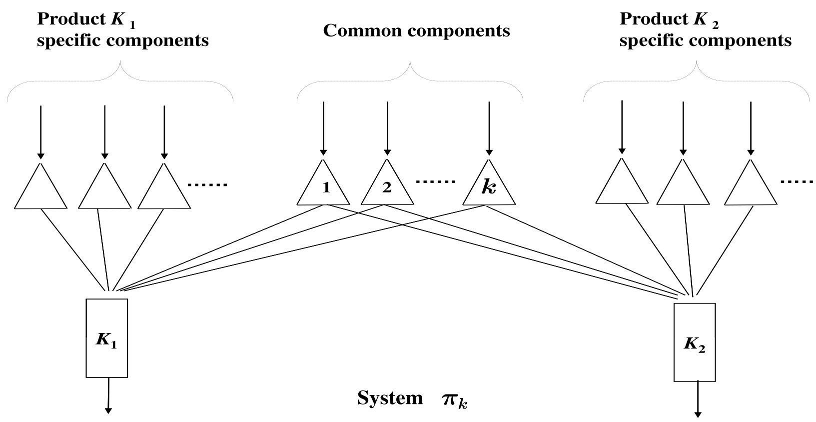

Fig. 2. ATO system with k common components.

Lu et al. [13] studies the NHB rules in continuous-review ATO systems of a general product structure, and identifies conditions on product and cost structure under which the NHB rules outperform all other component allocation rules. Dogru et al. [7] studies the general class of the NHB rules in a two-product system with identical constant lead times. However, both papers do not consider the impact of component commonality. In addition to [15], several other papers study the value of component commonality in dynamic inventory systems with lead times [1,6,14]. They assume continuous-review inventory control and focus on the FCFS rule; although Agrawal and Cohen [1] use a fair-share rule for demand realized in the same period, the paper assumes FCFS for satisfying demand in different time periods.

In the component commonality literature, researchers have employed a representative two-product ATO system in which each product is assembled from two components [2,9] as illustrated in Fig. 1. In system π_0, products are assembled from product-specific components only and there is no common component. In system π_1, the products share the common component 5 that replaces components 3 and 4 in System π_0. In system π_2, the two products share both the common components 5 and 6 where component 6 replaces components 1 and 2 in system π_1.

In this paper, we study the value of component commonality in a generalized version of the aforementioned two-component systems in Fig. 1 with lead times and the NHB rules. Using a sample path analysis, we show that under any NHB rule, both the total product backorder and total on-hand component inventory decrease in any event as the degree of commonality increases. However, the system-wide average cost does not always decrease unless a certain cost symmetric condition is imposed. Finally, we consider systems with general cost structure and conduct a numerical study to quantify the impact of commonality on system-wide average cost and its dependence on various system parameters.

2. The model and preliminary results

We consider a multi-product ATO system with m different components labeled by $i \in \{1, 2, 3, \dots, m\}$. At most one unit of a component is required for each product. Let $\mathcal{K}$ denote the set of products. Each product $K \in \mathcal{K}$ is assembled by the component set $K \subseteq \{1, 2, 3, \dots, m\}$. For each product $K \in \mathcal{K}$, it requires a set of common components $\mathcal{M}$ (which is shared by all products) and a set of product-specific components $K \setminus \mathcal{M}$. If $|\mathcal{M}| = k$, we denote the system by π_k. Fig. 2 provides an example with two products.

In the sequel, we use subscripts to indicate components and superscripts to indicate products. Let $\mathcal{K}_i$ be the product set that requires component i. We assume that the demand process $\{D^K(t), t \geq 0\}$ for product $K \in \mathcal{K}$ follows an arbitrary stochastic or deterministic process which could be dependent or independent of the others, such as ARMA [8] (or a vector ARMA), ARIMA [10], quasi-ARMA [11] and MMFE [5].

The component inventory is controlled by an independent continuous-time base-stock policy with base-stock levels $\mathbf{s} = (s_1, s_2, \dots, s_m)$. Thanks to its simplicity, this class of inventory policies is well adopted in practice and studied in the literature [16]. We note that the base-stock policy is suboptimal in a general assembly system, and refer the reader to [16] for a detailed review of the literature. Without loss of generality, we assume that the initial on-hand inventory of component i equals s_i. For component i, let L_i be the replenishment lead time which is a constant, $I_i(t)$ be the on-hand inventory at time t, and $O_i(t)$ be the outstanding order that is the amount of orders placed but not replenished by t. Because the arrival of each demand requiring component i triggers a replenishment order for this component, we have

$$O_i(t) = \sum_{K \in \mathcal{K}_i} D^K(t - L_i, t), \tag{1}$$

where $D^K(t - L_i, t)$ denotes lead time demand of product K during the time period $(t - L_i, t]$. We assume full backorder for any demand which cannot be satisfied upon arrival. Let $B_i(t)$ be the shortage of component i at time t, and it is expressed as $B_i(t) = [O_i(t) - s_i]^+$, where $[x]^+ := \max\{x, 0\}$. Let $B^K(t)$ be the backorder of product $K \in \mathcal{K}$ at time t. For steady state variables, we omit the parameter t.