European Journal of Operational Research 271 (2018) 80–96

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Production, Manufacturing and Logistics

Optimal and heuristic policies for assemble-to-order systems with different review periods

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ARTICLE INFO

Article history:
Received 7 April 2017
Accepted 8 May 2018

Keywords:
Supply chain management
Assemble-to-order systems
Ordering policy
Optimal solution
Heuristic

ABSTRACT

We study an assemble-to-order (ATO) system with a single end product assembled from two components. The inventory levels of the components are reviewed periodically. One component is expensive and has a long lead time and short review period, whereas the other component is relatively cheap with a shorter lead time and longer review period. The lead times are deterministic and review periods are determined exogenously. Stochastic customer demand occurs for the end product only and unsatisfied customer demands are backordered. The system incurs holding costs for component inventories and penalty costs for backorders. Assuming an infinite planning horizon, our objective is to identify the optimal component ordering policy to minimize the long-run average cost. Under specific demand distributions we identify the properties of the optimal component ordering policy and observe that the optimal policy has a complex state-dependent structure. Motivated by the complexity of the optimal policy, we introduce a heuristic component ordering policy for more general demand distributions. Given that the heuristic performs well, we use it to measure the effects of various system parameters on the total cost.

1. Introduction

Cost-efficient management of real-world assemble-to-order systems requires coordinated release of multiple components. Lot sizes and lead times of these components are determined by supplier contracts and characteristics of production processes. Timing of the release moments depends on these lot sizes and lead times. Coordination of the release decisions across multiple components is a difficult task. The existing literature overcomes this difficulty through convenient assumptions, such as equal lot sizes (e.g. Svoronos & Zipkin, 1988), equal review periods (e.g. Clark & Scarf, 1960), nested lot sizes (e.g. Chen, 2000) and nested review periods (e.g. Van Houtum, Scheller-Wolf, & Yi, 2007). These assumptions result in larger lot sizes for long-lead-time components. However, in practice, simple and cheap materials typically have large lot sizes and short lead times, while complex and expensive materials usually have small lot sizes and long lead times.

Lot sizes are mainly determined by the trade-off between ordering (or setup) cost and holding costs as dealt with in the classical economic order quantity model. Lead times are mainly determined by material complexity and capital intensity of the processes needed for production. A high material complexity of a component implies that multiple processing steps are needed. The more processing steps, the longer the lead times. Capital-intense production is characterized by high utilization, which naturally translates into long lead times. Thus, in practice long-lead-time items are often more expensive than short-lead-time items. Typical examples of this situation can be observed in high volume electronics and pharmaceutics industry, where key components (e.g. LED screens, active ingredients) have lead times beyond ten weeks, whereas cheap components (e.g. plastic parts, packaging material) have lead times of less than several weeks. Similarly, in capital goods industry, where typically products are assembled to order, expensive items (e.g. wings for airplanes, magnets for medical scanning equipment, lenses for lithography machines) are ordered daily or weekly, while metal and plastic parts may be ordered monthly on average. Thus, we postulate that item lead times are positively correlated with item costs.

The optimal strategy for the coordination of order releases of components in situations where long-lead-time components are ordered more frequently than the ones with short-lead-time is not known to date. This fact and the practical relevance of finding the optimal strategy motivate us to study a supply chain consisting of two components and a single end-product, which is assembled to order. The insights obtained from this basic model give us

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https://doi.org/10.1016/j.ejor.2018.05.013

directions for further research on more complex and realistic supply chain structures.

In this study, we consider an assemble-to-order (ATO) system with two components. One of the components is an expensive one with a long lead time, the other component is cheap and has a short lead time. Stock levels are periodically reviewed and the expensive component is ordered more frequently compared to the other one. It is assumed that the lead times and review periods are given, and the customer demand is stochastic. The target is to find the optimal component ordering policy, which is unknown for such systems to date unknown.

Karaarslan, Kiesmüller, and De Kok (2013) study a similar setting and develop two heuristic inventory control policies. The first heuristic is the pure base-stock policy (PBS), where each component orders up to its base-stock level at every review moment. The second heuristic is the balanced base-stock policy (BBS), where the expensive component has a fixed base-stock level and the cheap component's net stock level is synchronized with the expensive component's net stock level. This policy can only be applied under an *uncertainty period* condition involving the review periods and lead times: the uncertainty period of an item is defined as the sum of its lead time and its review period. The balanced base-stock policy requires that the uncertainty period of the expensive item exceeds that of the cheap item. Note that we assume that the review period of the expensive item is shorter than that of the cheap item.

The PBS and BBS policies have scientific deficiencies. Firstly, for both policies it is not known how well they perform compared to the optimal policy. Secondly, the balanced base-stock policy has a limited application area. The main motivation of this paper is to identify the optimal policy and define a more general heuristic policy that is also applicable to the cases which are not covered by Karaarslan et al. (2013). Using a stochastic dynamic programming formulation, we identify the properties and structure of the optimal policy. The complicated nature of the problem prevents us to solve the dynamic program for general parameter settings. Thus, to solve the problems in a reasonable time, we keep the lead time difference between components equal to one to restrict the state space. It turns out that, even under the state space restriction, the optimal policy is a complex state-dependent policy. Each component's ordering decision is dependent on the inventory position of the other component and two other parameters specific to that component. The ordering pattern for the expensive component can change at different ordering moments during the planning horizon as well.

Given the need to solve the same problem under more general parameter settings, we develop a heuristic ordering policy by using the synchronization principle and reducing the number of parameters per component to one. This policy is called *synchronized base-stock policy* (SBS) (cf. De Kok & Fransoo (2003)). Under this policy, each component has a base-stock level and we order either order up to a base-stock level for each component or we synchronize the component inventory positions. The SBS policy can be applied to any multi-item multi-echelon make-to-stock and assemble-to-order systems with equal review periods and constant lead times. De Kok and Visschers (1999) and De Kok and Fransoo (2003) use discrete event simulation to show effectiveness of SBS policies. In our paper, we build on the notion of SBS policies and extend their application to the situation with non-nested review periods for systems under study.

We derive the long-run average cost function and obtain the optimality equations that need to be satisfied by the optimal base-stock levels. The nature of the optimality equations allows us to numerically compute the optimal base-stock levels. We show that under the optimal SBS policy the non-stockout probability is equal to the newsboy ratio, which is a well-known result for multi-echelon inventory systems with base-stock policies. We also observe that the long-run average cost under the SBS policy is equal to the long-run average cost under the optimal policy for 96.3% of the problems. In a more extensive numerical study, we show how the policy parameters change under different conditions.

The BBS and SBS polices are both applicable to the situation described above. We identify two major differences between the BBS policy and the SBS policy. Firstly, when using the BBS policy, only the cheap component's inventory position is completely synchronized with the expensive component's inventory position at every ordering moment. This policy prevents the situation where a stockout occurs due to the unavailability of the cheap component but an over-supply of the cheap component is possible due to pure synchronization. The SBS policy synchronizes both items to each other and the synchronization decision is taken with respect to a base-stock level. As a result stock-out and over-supply situations can be avoided for both components. Secondly, the BBS policy is a very simple one with only one parameter and it is easy to compute. On the other hand, the SBS policy has a more complex structure. Yet we are able to analytically determine the optimal base-stock levels, and the computational results show that cost optimal solutions for all problems are obtained in less than a second.

We contribute to the literature on ATO systems with different review periods by identifying the structure of the optimal component ordering policy and, inspired by this optimal structure, developing a simple heuristic approach which not only performs extremely well with small percentage cost errors but is also computationally efficient.

The rest of the paper is organized as follows. In Section 2 we present the most recent related literature on ATO systems. In Section 3, we introduce our notation and the optimization problem. Then, in Section 4, using stochastic dynamic programming and numerical experiments, we determine the properties and structure of the optimal policy. We explain the heuristic procedure in Section 5. We conduct a numerical study to test the performance of the heuristic approach with respect to the optimal policy and to measure the effect of various system parameters on the total cost. Our results are summarized in Section 6. We finalize the paper with the summary of the main results and discussion of future research directions in Section 7.

2. Literature review

Apart from Karaarslan et al. (2013) and this paper, assembly and ATO systems with non-nested review periods have not been studied in literature. However, the optimal policy for assembly systems is known for systems with equal and nested review periods. Schmidt and Nahmias (1985) study a two component assembly system with one end item with random demand and equal review periods. They identify the finite-horizon optimal policy for this system by using dynamic programming. Later on, Rosling (1989) shows the optimal policy for assembly systems with equal review periods by restructuring the network as an equivalent serial system. Van Houtum et al. (2007) proves the optimality of base-stock policies for serial systems with nested review periods and this result applies to assembly systems preserving the nested review period structure.

Despite the widespread use of ATO systems, there are very few papers in literature that identify the form of the optimal inventory control policy for ATO systems. In general, the results are limited to certain network structures and parameters, and the optimal inventory control policies for any reasonable objective function are state-dependent. As stated in Song and Zipkin (2003) and Atan, Ahmadi, Stegehuis, de Kok, and Adan (2017), the difficulty with ATO systems in general is the combination of two decisions: inventory replenishment and inventory allocation. The latter situation does not occur in our model since there is only one end item.