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Crossover aware base stock decisions for service-driven systems

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ABSTRACT

We investigate the impact of order crossover on a periodic, order-up-to (R,S) inventory system where attaining a target service level is the focus. We first address two crossover related assumptions and then explore five methods of including crossover information into the process of determining the order-up-to level (*S*). We develop a hybrid discrete-event/continuous simulation model and perform a full-factorial simulation study under various conditions of target service level, demand variance, and lead-time variance. We find the method used to include crossover information into the decision significantly impacts service performance and that methods based on effective lead-time observations perform best.

1. Introduction

1.1. Motivation

Order crossover, when orders arrive in a sequence different from that in which they were originally placed, is increasingly likely to occur in modern supply chains (Riezebos, 2006; Srinivansan et al., 2011). Crossover can be caused by a number of factors, such as extended transportation delays, orders filled from different geographic regions, supplier stockouts, the use of multiple transportation modes, and the use of emergency or expedited orders. The reasons for increased chances of order crossover are numerous, including the pressure to reduce the time before a replenishment need is detected, substantially shorter administrative processing times, the use of alternative or multiple suppliers, shorter throughput time at suppliers, the use of multiple transportation modes by suppliers, and the trend toward more frequent orders of smaller sizes (Riezebos, 2006; Srinivansan et al., 2011).

In practice, many inventory systems are driven by service goals. Focus on service performance has become critical in recent years due in part to a trend in supply chain operations that is a variant of the oft-cited “Amazon Effect”, which we refer to as the “Amazon Service Effect”. The Amazon Service Effect refers specifically to the elevated service expectations of customers, both retail and commercial, based on their interactions with Amazon.com. In essence, customer experiences with Amazon, in areas such as speed of delivery, have become service expectations for interactions with other companies (Konzak, 2013; Parry, 2014; Baskin, 2017). Increased service expectations cause firms to focus more directly on service levels. Many of the changes in order placement and fulfillment strategies implemented to focus on service performance, such as a greater number of smaller (volume-wise) orders and the use of several transportation modes, create conditions that increase the likelihood of order crossover.

Recent research has shown that significantly larger inventory costs will be incurred by using “crossover unaware” replenishment policies, policies that do not take crossover into account, even when order crossover is rare (Hayya et al., 2009, 2011a; Riezebos and

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Gaalman, 2009; Srinivansan et al., 2011). However, there is almost no work on service-focused implications. The growing prevalence of order crossover, coupled with the increasing importance of service performance, in modern supply chains calls for further investigation of "crossover aware" service-driven inventory management by the research community.

1.2. Investigation

We investigate several methods for incorporating order crossover information into a service-focused, periodic, order-up-to (R,S) policy. The challenge is to represent the impact crossover has on the stream of incoming (filled) replenishment orders. We account for this impact by utilizing the "effective lead time" (ELT) approach developed by Hayya et al. (2008). We depart from the majority of the crossover literature by using a desired P_1 service level, also known as the cycle stockout level (CSL), to set the order-up-to level (S), instead of focusing on cost minimization. We develop a hybrid discrete-event/continuous simulation model that accurately represents the step-by-step activities of the inventory system and explicitly records the effective lead-time demand and protection period demand values using a unique representation. In total, we investigate five approaches to including crossover information under various conditions of lead-time variance, demand variance, and target service level and compare the results to benchmarks generated via simulation-optimization.

1.3. Contribution

We address three questions:

1) Does order crossover impact performance of service-focused inventory systems as it does with cost-focused systems?
2) Is R + ELT the appropriate protection period for periodic order up to (R,S) inventory systems under crossover conditions?
3) Does the method used to include crossover information into the decision process impact system performance?

We add to the order crossover knowledge-base on a number of fronts. The first two questions focus on assumptions that have not been fully addressed in the literature. The third question forms the core of the investigation and addresses the issue of how crossover information is incorporated into the inventory decision process. This facet of order crossover is, at this time, an unexplored issue. Our investigation addresses these issues under a variety of environmental conditions, exploring multiple levels of lead-time variance, demand variance, and service level targets in addition to the various crossover inclusion methods. In addition, the design of the hybrid discrete-event/continuous simulation model we employ extends the current state-of-the art and allows us to capture and analyze details that are not possible with more aggregate modeling approaches. The model design also allows us to remove modeling assumptions, such as a restriction to integer-valued lead-times, which were necessary in previous research models.

2. Background

2.1. Order crossover

Order crossover occurs when orders do not arrive in the same series in which they were placed, and are thus out of sequence. An important consequence of order crossover is that it distorts the incoming stream of filled orders, also known as replenishment arrivals, because the "realized" lead-time is impacted, often substantially. Knowledge of lead-time and lead-time demand characteristics is an important part of the design of many inventory systems, so such distortions can have important and costly effects. Classical inventory methods, such as those used for the (R, S) policy we study, typically set safety stock levels by characterizing the lead-time demand distribution. However, the lead-time demand distribution is impacted by order crossover, primarily through reduced variance of the true "realized" lead times. Given the potential cost and performance implications, modern supply chain managers have significant incentive to take order crossover into account when managing inventory.

2.2. Inventory management under order crossover

He (1992) identifies the initial work on order crossover as being due to Takacs (1956, 1959), with work soon afterward by Scarf (1958), Galliher et al. (1959), Finch (1961), and Agin (1966). Zalkind (1976, 1978) marks the beginning of the "modern" era of order crossover research, with his focus on characterizing the number of outstanding orders (often denoted by *N*) as a means of assessing the tendency for orders to crossover. Zalkind (1976), and later Robinson et al. (2001), show that the variance of the "shortfall" distribution (the amount by which the inventory position is below the order-up-to level) is less than the variance of the lead-time demand distribution and that basing an inventory policy on the shortfall distribution is more accurate. Hayya et al. (2008) similarly show that the variance of the effective lead time is less than the variance of the "parent" lead time and thus the variance of the effective lead-time demand is less than the parent lead-time demand. Zalkind (1978) show that the distribution of the number of outstanding orders (*N*) can be used to determine the shortfall distribution characteristics and present a procedure for determining the optimal order-up-to level for a periodic, order-up-to policy that uses the distribution of the *N* to find the shortfall distribution. Bradley and Robinson (2005) and Robinson and Bradley (2008) develop and then refine an approximation of the shortfall distribution, developing a bound on the variance of the number of orders outstanding (*N*).

Liberatore (1979) added to the literature by focusing on the idea of non-interchangeability, which was further extended by several