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Order-up-to-level policy update procedure for a supply chain subject to market demand uncertainty

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ABSTRACT

The planning of a supply chain (SC) subject to market demand uncertainty is challenging in regards to defining update mechanisms that deal with demand variations. This study addresses this challenge and proposes a new reorder point update procedure for order-up-to-level (OUTL) policies in continuous review systems. The new procedure modifies the classical OUTL policy by introducing absorption inventory, a concept that changes reorder points and lot sizes according to demand variations. Results obtained through a discrete event simulation based on real-world data provided by a Brazilian company show that the proposed order policy provides better performance, particularly in terms of bullwhip effect reduction and improved service level.

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1. Introduction

An inventory control policy governs inventory replenishment decisions by specifying when and how many items should be replaced (Rossetti & Chan, 2003). Since 1952 (Simon, 1952), several studies on inventory control policies have analyzed and proposed adequate rules under different operational conditions to help decision makers manage SC inventory (Vassian, 1955). The work of Vassian (1955) and Simon (1952) are considered two pioneering works to the best of our knowledge. According to Holweg and Disney (2005), Simon (1952) produced one of the very first inventory control system investigations using the Laplace transform and Vassian (1955) was one of the first to use the z-transform (Magee, 1958).

Differently from our proposal which considers a dynamic order policy, most of these studies merely focused on static control policies (Silver & Peterson, 1985; Zipkin, 2000) that were formalized by Wilson (1934) based on the work of Harris (1915). In these policies, system parameters are considered fixed over time; for example, the reorder point and ordered quantity (economic lot) are constant along a production period (time between a replenishment order is issued to the previous level and the inventory is updated after the nominal lead time). However, standard static control policies are often inappropriate, as they are not able to properly manage the high variability of market demand (Babai & Dallery, 2009).

As a result, recent studies have been developing dynamic, rather than static, order policies that can better help practitioners in their decision-making process (Aloulou, Dolgui, & Kovalyov, 2014; Babai & Dallery, 2009; Fleischmann, Nunen, & Gräve, 2003; Tako & Robinson, 2012). Dynamic control policies have system parameters that change over time. In these policies, the reorder point and ordered quantity (lot size) are different from one production period to the next (Hadley & Whitin, 1963; Karlin, 1960; Scarf, 1959).

Despite recent efforts to analyze and understand the performance of dynamic order policies (Costantino, Gravio, Shaban, & Tronci, 2015; Disney & Towill, 2002; Lee & Wu, 2006; Mohammaditabar, Ghodsypour, & O'Brien, 2012), there are still gaps in knowledge. Most work has looked at optimization of the replenishment rule measured in terms of holding costs and customer service (Can & Heavey, 2012; Chen & Disney, 2007; Kleijnen, Beers, & Nieuwenhuyse, 2010), but rarely do the investigations shed light on dynamic order policies impact on critical time-varying phenomena like the so-called bullwhip effect. In fact, the adoption of particular order policies may limit or stress the bullwhip effect, thereby modifying SC dynamics. Due to these limitations, it is relevant to further analyze how supply chains adopt these replenishment rules and to design updated dynamic policies

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that can better manage uncertainty, as mentioned in Babai and Dallery (2009), Babai, Syntetos, Dallery, and Nikolopoulos (2009).

Motivated by these considerations, we developed a new dynamic continuous review policy based on the classical OUTL policy and compared the two policies based on the effect they have on SC behavior. More specifically, we proposed a procedure that updates both the reorder point and the quantity ordered according to demand and lead-time indicators. In this study, we simulated a three-echelon supply chain by adopting a discrete event simulation approach based on real-world data provided by a Brazilian company. We measured the SC performance in terms of bullwhip effect, stockout, and customer service level. Key results show that this new policy avoids propagation of uncertainty through SC levels by computing lot sizes with lower variance and by keeping inventories and reorder points slightly higher than those of the classical OUTL policy. Consequently, this new policy mitigates the bullwhip effect, minimizes stockout, and increases the customer service level.

The paper is organized as follows: Section 2 reviews the literature, and Section 3 lays out the proposed dynamic OUTL policy for a SC subject to uncertainty. Section 4 presents the simulation results for a three-echelon supply chain, and Section 5 further discusses these results. Section 6 concludes the paper.

2. Literature review

The most well-known static inventory control policies are continuous review (r, Q) and periodic review (T, S) – see e.g. Hax and Candea (1984), Axsäter (2007), Disney and Lambrecht (2008), among others. In the continuous review policy, r represents the fixed reorder point, and Q is the ordered quantity. In this policy, the protection interval corresponds to the replenishment lead time (Krajewski, Ritzman, & Malhotra, 1999). In the periodic review policy, T represents the review period, and S is the order-up-to level. In this policy, the protection interval corresponds to the replenishment lead time plus the review period (Larsen & Thorstenson, 2008).

There are also variants of static inventory control policies. Among continuous review policies, the most commonly adopted variations are $(s, S), (r, S), (s, Q), (s, nQ)$, and (r, s, Q) (Babai & Dallery, 2009; Chen, 1998; Silver & Peterson, 1985; Tempelmeier & Fischer, 2010), and among periodic review policies, the most used variations are $(T, r, Q), (T, r, S)$, and (T, S) (Babai & Dallery, 2006, 2009).

Research has shown that continuous (r, Q) and periodic review (T, S) policies are not always able to cope with uncertainties in inventory management like variable market demand and stochastic lead time (Babai & Dallery, 2009; Babai et al., 2009). Thus, more recent studies have proposed new order policies, such as reorder point and order quantity, that dynamically modify main inventory control parameters in order to reduce unnecessary costs (Babai & Dallery, 2006, 2009; Babai, Jemai, & Dallery, 2011; Babai et al., 2009).

Among these new order policies, the most adopted continuous review dynamic policies are (r_k, Q) and (r_k, Q_k). Both rules are extensions of policy (r, Q) and are characterized by dynamic reorder point control. Here, k represents a particular period of time with reorder point r_k and order quantity Q_k (Babai & Dallery, 2009; Babai et al., 2009). In policy (r_k, Q), if the inventory position falls below the reorder point r_k, a pre-defined constant quantity Q is ordered at the beginning of period k. However, in policy $(r_k, Q_k), Q_k$ is computed dynamically with an extended method derived from the Silver-Meal heuristic (Babai & Dallery, 2009). The most adopted periodic review dynamic policy is (T, S_k), where S_k represents a replenishment variable level. At the beginning of each review period T, an order of size Q_k is issued to replenish the inventory level up to level S_k (Babai & Dallery, 2009).

Table 1 provides a snowball literature review by including specific and relevant works dealing with the formalization and evaluation of different order policies. We have selected literature on SC static and dynamic inventory control policies from the last three decades, classifying the approaches by methodology (analytical or simulation), order policy (continuous or periodic), number of SC levels, performance metrics (usually inventory cost and service level), the dynamic factor (reorder point and lot size), and the main contribution.

Studies in this literature analyzed supply chains comprising mono-echelon, two-echelon, supply network, and serial inventory systems. The most studied order rule was the continuous review policy while few studies focused on the periodic review. Among the policies, many studies analyzed the benefit order rule optimization has on holding, ordering, shortage costs, lost sales, and total costs. The main methodology was analytical with constant SC parameters and deterministic demand, and the parameters for stochastic demand were known in advance for each period of time over a fixed time horizon. Impact was measured by bullwhip effect, service level, and inventory variance. Few studies looked at uncertainty in demand or time, or dynamic policies that adjust SC parameters using discrete event simulation.

Dynamic order policies are typically modeled in discrete time with known and fixed time intervals and are, therefore, ill-equipped to deal with the reality of uncertainty in time. As such, approaches that take random, rather than fixed, time intervals may serve as more effective models. One example of an effective model is the discrete event system (DES) approach. As illustrated in Kleijnen and Smits (2003), Kleijnen (2005), Tako and Robinson (2012), a discrete event system (DES) can capture individual events like item consumption from inventory or order release. In this case, consumption is a problem best modeled by the DES approach because inventory consumption can occur at random time intervals and demand a random quantity of items (Tako & Robinson, 2012).

Market demands of random phenomena in time and quantity can cause undesirable impacts on SC performance in the form of the bullwhip effect, stockout, or increasing costs (Afzalabadi, Haji, & Haji, 2016; Chen, Drezner, Ryan, & Simchi-Levi, 2000; Lee, Padmanabhan, & Whan, 2004). Several studies have proposed approaches to reduce these variations such as fuzzy logic, time series, system dynamics, and others (Axsäter, 1999; Chaharsooghi, Heydari, & Kamalabadi, 2011; Forrester, 1961; Hsien, 2015; Tempelmeier, 2013; Towill, Evans, & Cheema, 1997). In 2011, Babai et al. (2011) proposed a method to find the optimal OUTL policy based on an analysis of a mono-echelon single product system subject to both stochastic demand and lead time whose inventory was controlled according to an OUTL policy by continuous review. In 2015, Chen and Li (2015) suggested a discrete time control approach, and in 2007 Chen and Disney (2007) offered a myopic OUTL policy that considered stochastic demand. The proposal put forward in this study is classified as a dynamic order policy derived from the continuous review dynamic policy (r_k, Q_k) which captures uncertainty in the market demand but also takes into account DES behavior of inventories.

3. The proposed dynamic OUTL policy

In this section, we propose a new dynamic continuous review policy for a supply chain subject to uncertainty. The classical OUTL policy considers that an order is issued to replace inventory up to a defined level (Chen & Disney, 2007). With this work an update procedure is derived from the classical policy (r, S) using a variable reorder point r^i at the end of each period $i = 1, 2, \ldots$, in a (r^i, S) policy. We use here a superscript i to clarify the difference between r^i

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