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# SPC forecasting system to mitigate the bullwhip effect and inventory variance in supply chains

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ABSTRACT

Demand signal processing contributes significantly to the bullwhip effect and inventory instability in supply chains. Most previous studies have been attempting to evaluate the impact of available traditional forecasting methods on the bullwhip effect. Recently, some researchers have employed SPC control charts for developing forecasting and inventory control systems that can regulate the reaction to short-run fluctuations in demand. This paper evaluates a SPC forecasting system denoted as SPC-FS that utilizes a control chart approach integrated with a set of simple decision rules to counteract the bullwhip effect whilst keeping a competitive inventory performance. The performance of SPC-FS is evaluated and compared with moving average and exponential smoothing in a four-echelon supply chain employs the order-up-to (OUT) inventory policy, through a simulation study. The results show that SPC-FS is superior to the other traditional forecasting methods in terms of bullwhip effect and inventory variance under different operational settings. The results confirm the previous researches that the moving average achieves a lower bullwhip effect than the exponential smoothing, and we further extend this conclusion to the inventory variance.

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## 1. Introduction

The orders variability often increases as one moves up the supply chain. This phenomenon is recognized as the bullwhip effect and has been observed in many industries (Klug, 2013; Lee, Padmanabhan, & Whang, 1997a; Zotteri, 2012). The bullwhip effect can cause large consequences in supply chains such as stock outs, low service level, and extra transportation and capacity costs. Lee et al. (1997a), Lee, Padmanabhan, and Whang (1997b) identified five operational causes of the bullwhip effect: demand signal processing, lead-time, order batching, price fluctuations and rationing and shortage gaming. Of our particular interest is the demand signal processing which represents the practice of dynamically estimating the demand forecasts and subsequently updating the parameters of the inventory control policies (Dejonckheere, Disney, Lambrecht, & Towill, 2004). By doing that, short-run fluctuations maybe overreacted because of forecast updating causing order variability amplification across the supply chain. Extensive research has investigated the impact of the above-mentioned causes utilizing three modeling approaches: statistical modeling, simulation modeling and control theoretic approach, showing that the bullwhip effect can be mitigated by selecting the proper forecasting method (Chandra & Grabis, 2005; Chen, Drezner, Ryan, & Simchi-Levi, 2000; Chen, Ryan, & Simchi-Levi, 2000; Jaipuria & Mahapatra, 2014; Li, Disney, & Gaalman, 2014), proper ordering policy and smoothing (Costantino, Di Gravio, Shaban, & Tronci, 2014a; Costantino, Di Gravio, Shaban, & Tronci, 2014b; Costantino, Di Gravio, Shaban, & Tronci, 2014e; Dejonckheere, Disney, Lambrecht, & Towill, 2003; Dejonckheere et al., 2004; Wright & Yuan, 2008), reducing the lead-time (Chen, Drezner, et al., 2000; Chen, Ryan, et al., 2000; Ciancimino, Cannella, Bruccoleri, & Framinan, 2012) and increasing the collaboration level (Babai, Ali, Boylan, & Syntetos, 2013; Cho & Lee, 2013; Ciancimino et al., 2012; Costantino, Di Gravio, Shaban, & Tronci, 2014d, 2014e).

In particular, previous researches have attempted to quantify the contribution of various forecasting methods to the bullwhip effect. The periodic review order-up-to (R, S) policy (OUT) is widely applied in practice and therefore most previous studies have adopted it to investigate the impact of the available traditional forecasting methods on the bullwhip effect (Li et al., 2014). In this

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policy, the order is generated to recover the gap between the target and current levels of inventory position, where the target level is dynamically updated with demand forecast every review period. Chen, Drezner, et al. (2000) have quantified statistically the bullwhip effect in a two-stage supply chain (single supply chain consisting of a demand point (customer), a stocking point (retailer), and an outside supplier/manufacturer) employs OUT with moving average (MA) and experiencing autoregressive AR(1) demand process. They have further extended this analysis to the exponential smoothing (ES) showing that, if both methods are set to achieve the same forecasting accuracy, then ES produces higher bullwhip effect (Chen, Ryan, et al., 2000). Dejonckheere et al. (2003, 2004) have confirmed these results through a control theoretic approach. Zhang (2004) has found statistically that the bullwhip effect measures under MA, ES and minimum mean-squared error (MMSE) have distinct properties in relation to lead-time and demand parameters. Ma, Wang, Che, Huang, and Xu (2013) derived bullwhip effect and inventory variance for MMSE, MA and ES under price sensitive demand. Li et al. (2014) quantified and compared the bullwhip effect under Naïve, MA, ES, Holts method and dampened trend method. Further related research on the effect of traditional forecasting methods can be found in Bandyopadhyay and Bhattacharya (2013), Bayraktar, Lenny Koh, Gunasekaran, Sari, and Tatoglu (2008), Kelepouris, Miliotis, and Pramatari (2008) and Wright and Yuan (2008). Table 1 summarizes the related literature to this study.

The majority of the previous studies have been focusing only on characterizing the impact of the available traditional forecasting methods (time series models) on the bullwhip effect with limited ideas for novel forecasting systems (see also, Table 1). However, most recently, some researchers have attempted to develop improved forecasting systems based on artificial intelligence techniques (AI) and compared them against the traditional methods in terms of bullwhip effect measures (Campuzano-Bolarín, Mula, & Peidro, 2013; Jaipuria & Mahapatra, 2014). Although implementing artificial intelligence methods may improve forecasting performance, they have limited usage, require advanced level of knowledge, and practitioners always prefer easy-to-use management tools. Table 1 also indicates limited research has been focusing on both the bullwhip effect and inventory variance while evaluating the available forecasting methods (Hussain, Shome, & Lee, 2012; Ma et al., 2013). In supply chains, both downstream and upstream echelons have different interests in forecast updating where upstream echelons desire forecasting method chosen by the downstream echelons to smooth the bullwhip effect while the downstream echelons has an interest in minimizing inventory variance (Ma et al., 2013). In general, there is a lack of studies that have attempted to develop bullwhip effect solutions without major implementation effort (Chandra & Grabis, 2005). This is the main objective of this research as we attempt to present and evaluate an easy-to-implement forecasting system that can counteract the bullwhip effect without affecting inventory performance.

The classical forecasting approach looks at demand forecasting and inventory management as two independent stages without interactions, which may cause a sub-optimal performance of the whole system (Babai et al., 2013). In inventory systems (e.g., OUT), the target inventory level is dynamically updated with demand forecast (over the lead-time) leading to variation in replenishment orders that induces the bullwhip effect, however, maintaining a fixed target level or reducing its variability would mitigate or eliminate the bullwhip effect, respectively. In traditional forecasting systems such as MA and ES, that are commonly used in practice, the sensitivity to demand changes can only be controlled through a single smoothing dimension. They are rigid systems to allow controlling the trade-off between responsiveness (following the demand changes very closely) to keep desired service level and mitigating the bullwhip effect through avoiding over/under-reaction to demand changes (Dejonckheere et al., 2003, 2004). Therefore, forecasting should be protected from the over/under-reaction to short-run fluctuations in demand/incoming order without affecting inventory performance (Jaipuria & Mahapatra, 2014). This protection can be achieved by embedding a simple monitoring tool to the forecasting system such as control charts to regulate forecasting sensitivity to demand changes (Costantino et al., 2014e). Control charts have recently been employed successfully to develop easy-to-implement forecasting and inventory control systems for dynamic environments like supply chains as can be found in Pfohl, Cullmann, and Stölzle (1999), Lee and Wu (2006), Cheng and Chou (2008), Kurano, McKay, and Black (2014) and Costantino et al. (2014a, 2014b, 2014e).

In particular, Cheng and Chou (2008) contributed in ESWA with an integrated inventory control system that employs the ARMA and Shewart control charts with the western electric rules, to determine the time and the quantity to order. However, their inventory system produces replenishment order without differentiating between forecasting and inventory control. Costantino et al. (2014a, 2014b, 2014e) have alternatively developed and evaluated novel inventory control systems that differentiate between forecasting and inventory position control in which two control charts are integrated to estimate expected demand and adjust inventory position (net inventory level + supply line inventory), respectively. The first control chart represents a simple and easy-to-implement forecasting mechanism to estimate the expected demand based on the current variation of the incoming orders/demand through a set of decision rules without over/under-reaction to demand changes. The second control chart is employed to control the inventory position whilst allowing order smoothing. They evaluated this inventory control system in a multi-echelon supply chain through simulation and found that it is superior to the OUT policy integrated with MA under various operational settings. They have reported that their forecasting system, we denote as SPC-FS, can achieve a higher ordering and inventory stability than MA but indicated that further investigations are still needed. Specifically, their research was mainly focused on the performance of the inventory replenishment policy as a whole and therefore the effectiveness of SPC-FS has not been extensively characterized.

This research focuses mainly on the forecasting part of their proposed system by integrating SPC-FS with OUT ordering system and comparing its forecasting performance with other common forecasting systems, i.e., MA and ES. This inventory system (SPC-FS + OUT) works as an expert system since it combines novel forecasting system (SPC-FS) and traditional ordering policy (OUT) and SPC-FS's rules can be tuned based on practitioners knowledge. The MA and ES are selected as benchmark because of their popularity in practice and literature (see, Table 1). The popularity of MA and ES in practice can generally be attributed to their ease of use, flexibility, and robustness in dealing with non-linear demand processes subject to the proper selection of their parameters (Costantino et al., 2014d; Silver, Peterson, & Pyke, 2000). "Empirical research by Makridakis et al. (1982) has shown simple exponential smoothing to be a good choice for one-period-ahead forecasting. It was the preferred option from among 24 other commonly used time series methods compared under a variety of accuracy measures and theoretical models for the process underlying the observed time series" (Disney, Farasyn, Lambrecht, Towill, & de Velde, 2006). However, bullwhip effect research have shown that MA produces lower bullwhip effect than ES, proving that forecasting accuracy is different from forecasting performance in inventory systems (Babai et al., 2013). The parameters of MA and ES can also be adjusted to achieve the same forecasting accuracy and thus they are very appropriate to conduct direct comparisons with SPC-FS which can be considered a modified version of MA but

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