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ScienceDirect
Int. J. Production Economics 113 (2008) 587–597
international journal of production economics
www.elsevier.com/locate/ijpe

# Mitigating the bullwhip effect by ordering policies and forecasting methods

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Received 1 December 2006; accepted 18 October 2007
Available online 10 March 2008

**Abstract**

The ''bullwhip'' effect, in which order variability increases as one moves up the supply chain, has been observed in a range of industries, modeled by several authors and various remedies suggested. This paper provides a simulation of the effect of improved forecasting methods, and finds that Holt's and Brown's methods substantially mitigate the bullwhip effect across a range of performance metrics. The end result is to identify ordering policies that perform particularly well in combination with these forecasting methods and indicate how they can be implemented in practice.


*Keywords:* Supply chain management; Bullwhip effect; Forecasting; Ordering policy; Simulation model.

## 1. Introduction

The ''bullwhip effect'', is an important phenomenon in supply chain management, in which the order variability increases as one moves up the supply chain. It has been observed in the commercial operations of Campbell's Soup (Fisher et al., 1997), HP and Proctor & Gamble (Lee et al., 1997), a clothing supply chain (Disney and Towill, 2003a), and Glosuch (McCullen and Towill, 2000). The bullwhip effect causes instability in the supply chain, since a small change in orders received by a retailer can result in larger changes in the resulting orders received by a factory. It costs money, wastes resources and results in a loss of market share.

The causes of the bullwhip effect can be divided into two groups: time lags and planning and behavioral aspects (Nienhaus et al., 2003). In the first group, the remedy options include compressed time delays (Blackburn, 1991), reduced lead time (Metters (1997); Lee et al., 1997), echelon elimination and cycle time compression (McCullen and Towill, 2000). In the second group, five major causes of the bullwhip effect are identified by Lee et al. (1997): lead time, demand signal processing, order batching, price fluctuations, and rationing and shortage gaming (flywheel effect). Of these Disney and Towill (2003b) consider lead time and demand signal processing to be of particular importance. Remedies include synchronizing capacities and lead times (Lee et al., 1997; Towill, 1997), increased coordination among companies (Metters, 1997), vendor-managed inventory (Disney and Towill, 2003b) and including demand variability in pricing decisions (Naish, 1994).

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0925-5273/$ - see front matter 
doi:10.1016/j.ijpe.2007.10.022

In terms of management science techniques, Yao and Dong-Qing (2001) indicates that demand forecasting and ordering policies are two key methods of controlling the bullwhip effect and Paik and Seung-Kuk (2003), in a statistical study, identified demand forecasting as one of the significant variables for bullwhip control. Miyaoka and Hausman (2004) also found that improved forecasting could reduce fluctuations in manufacturing production levels.

Based on this research, we focus on two factors: demand forecasting and ordering policies. Moving average and single exponential smoothing methods have been used by Graves (1999) and Chen et al. (2000a, b). The first aim of the current paper is to use more sophisticated forecasting methods, including Holt's method and Brown's double-exponential smoothing, DES, method.

Most authors use ''order up-to'' policy, including Chen et al. (2000a, b) and Lee et al. (2004). Order rate is decided by requisitions received from the upstream trading partner, the gap between desired and actual inventory, and delay in inventory. By changing the definition of desired and actual inventory, Kohli (2005) gave a new equation for ordering policy including lead time, safety stock, and order frequency, and Sterman (1989) applied generic stock acquisition and an ordering heuristic in his model.

The present paper is based on modifications to Sterman's model to study how different ordering policies and forecasting techniques, either separately or in combination, can control the bullwhip effect. We identify a range of ordering policies for which the bullwhip effect can be alleviated by using either Holt's or Brown's forecasting method.

The remainder of the paper is organized as follows. Section 2 describes the basic model and how we have extended it to incorporate Holt's and Brown's forecasting methods. Section 3 describes the simulation methodology and the metrics used to measure the extent of the bullwhip effect. It also presents the results, identifying which ordering policies can benefit from Holt's and Brown's forecasting procedures. Section 4 describes how these results can be used in practice to alleviate the harmful effects of the bullwhip effect in supply chain management.

## 2. Methods and models

Our model is based on the four-stage supply chain, shown in Fig. 1. Orders for goods propagate upstream from left to right, and goods are shipped, downstream, in an opposite direction. We use a Basic Model (BM) based on Sterman's model, with a customer and four trading partners: retailer, wholesaler, distributor, and factory. Each trading partner has its own stock management system and ordering decision system. Extending the BM, we build three other models: BM using moving average forecasting (BM + MA), BM using Holt's forecasting (BM + Holt's), and BM using DES or Brown's forecasting (BM + Brown's).

Fig. 2 shows the flow relationships between two trading partners. The order decision system comes from expected demand ($ED_t$), adjustment of stock ($AS_t$), and adjustment of supply line ($ASL_t$). Orders ($O_t$) increase the supply line while shipment received ($SR_t$) decreases the supply line. Goods flow out of stock to decrease inventory while shipment received ($SR_t$) flows into the stock to increase inventory.

### 2.1. *Bullwhip model for retailer, wholesaler, and distributor*

Since the business process model for the factory is different from other trading partners, the model for retailer, wholesaler, and distributor is described first. In Section 2.1.1, a basic conceptual model is defined and in Section 2.1.2 we modify it to give a computationally efficient formulation.

#### 2.1.1. *Basic conceptual model definition*

The equations in Tables 1 and 2 formalize heuristics based on the Sterman's model (Sterman, 1989).

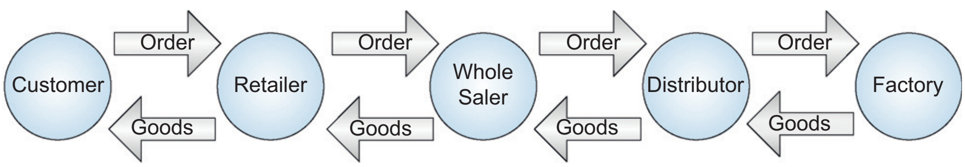


Fig. 1. Production–distribution system.