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A supply chain as a series of filters or amplifiers of the bullwhip effect

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ABSTRACT

The bullwhip effect refers to the phenomenon of amplification and distortion of demand in a supply chain. By eliminating or controlling this effect, it is possible to increase product profitability reducing useless costs such as stock-out and obsolescence costs. The main focus of this work is to study a single-product serial supply chain in which a control parameter can switch the chain from a series of filters to a series of amplifiers of the bullwhip effect and to analyse how the optimal values of the parameters change when discontinuities in order policy are considered. Furthermore, it is also shown that the bullwhip itself it is not a good index of the chain's performance, because it does not consider the oscillations that occur in the inventories, which also may affect the supply-chain performance.

1. Introduction

The bullwhip effect refers to a phenomenon that occurs in the supply chains when orders to the supplier have a larger variance than the ones from the customers, i.e. demand distortion. This distortion propagates upstream in an amplified form, i.e. variance amplification (Geary et al., 2006).

The first academic description of the bullwhip phenomenon is usually ascribed to Forrester (1961), who explained it as a lack of information exchange between the components of the supply chain and by the existence of non-linear interactions, which were difficult to deal with using managerial intuition. In recent years, several models have been developed for examining different factors that may have an impact on this effect. Metters (1997) tried to identify the magnitude of the problem by establishing an empirical lower bound of the bullwhip effect on profitability. Metters (1997) showed that by eliminating the seasonal bullwhip effect alone, one can increase the product profitability by 10–20%, while decreasing the bullwhip effect due to forecast error it was possible to increase profits by 5–10%. The combined profits by removing seasonality and forecast error, produced an increase in profits around 15–30%. In Chen et al. (2000), the bullwhip effect for a simple supply chain consisting of a single retailer and a single manufacturer was quantified. It was assumed that there is a correlation between the actual demand and its past values while the retailer applies an order policy based only on past demand. Using these assumptions, the impact of forecasting, lead time and information on the bullwhip effect was measured when the variance of the demand increases. Furthermore, Chen et al. (2000) found that, providing customer data information to every stage of the supply chain, the magnitude of the bullwhip effect can be decreased, but still exists when the demand information in each stage is centralised. With the order policy considered, the bullwhip is always bigger than one. The beneficial effects of information sharing and quality of that information in supply chains were examined for reducing the bullwhip effect by Dejonckheere et al. (2004) and Chatfield et al. (2004).

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Following a different approach, Burns and Sivazlian (1979) described a supply chain as a sequence of amplifiers in the frequency domain using the z-transform, whereas Towill et al. (1994, 2003) developed a similar approach using the Laplace transform and filtering the disturbances in the demand signal producing a supply-chain robust with respect to random variation in the demand. Following a systems analysis approach, Chen and Disney (2003) were able of reducing the bullwhip effect by controlling the order policy by using a proportional controller. An improvement in the cost saving due to the reduction of order variance was obtained. Soft computing methods were applied by Carlsson and Fullér (2001) to reduce the bullwhip effect. A policy in which orders were imprecise was applied. Orders were considered as intervals and the actors in the supply chain had to make their orders more precise as the time point of delivery got closer. In that policy crisp orders were replaced by fuzzy numbers. The problem was that the fuzzy system itself was not able learn the membership function therefore a neural network was used to approximate the crisp value. Also in this case, the bullwhip was significantly reduced (Carlsson and Fullér, 2001).

The supply chain was also modelled using Petri nets (Makajic-Nikolic et al., 2004). The authors considered a supply chain as a business process which had to be redesigned assuming that the main cause of the bullwhip effect was the absence of coordination in the management of the supply chain. Petri nets were used as a simulation tool to support a decision-maker in choosing the best-fit scenario and in increasing the coordination. Genetic algorithms (GA) have also been developed to optimise the base-stock levels and reduce the bullwhip effect with the final objective of minimising the sum of holding and shortage costs in the entire serial single-product supply chain (Disney et al., 2000; Sudhir and Chandrasekharan, 2005; Strozzi et al., 2007). The robustness of this approach with respect to changes in the supply line (Sudhir and Chandrasekharan, 2005) as well as in the customer demands (Strozzi et al., 2007) was also assessed.

The objectives of this work are to show how a simple and realistic order policy can reduce or amplify the bullwhip effect and the inventory oscillations in a serial single-product four echelons supply chain, and also to analyse the impact of discontinuities of this order policy on the bullwhip and maximum oscillation surfaces. Moreover, we have also analysed how this order policy may be optimised to reduce the bullwhip and oscillations in the inventories under different customer demands with and without noise.

2. Supply-chain model

In this work, we consider a serial single-product distribution system of four levels similar to the one presented by Sterman (1989) and Mosekilde et al. (1991) in which the actors are the factory, distributor, wholesaler and retailer, see Fig. 1. The customer asks for the goods from to the retailer which, in turns, asks for goods from the wholesaler and so on until the orders reach the factory. In the mean time, the goods are going from the factory down through the chain until they reach the customer.

In order to simplify this production–distribution system several rules were defined by Sterman (1989) and Mosekilde et al. (1991): there is only one inventory at each level; the time delay from passing of orders and shipments from one level to the next is fixed to 1 week (one time period); the production time is taken to be 2 weeks, and it is assumed that the production capacity of the factory has no limit; each week customer orders goods from the retailer, who supplies the requested quantity out of inventory.

The simulation model consists of a high-dimensional iterated map that provides the sequence of operations that each sector should perform. The boxes in Fig. 1 represent the state variables. Each variable has a letter that indicates the respective sector; thus R stands for retailer, W for wholesaler, D for distributor and F for factory. For example, in the wholesaler sector, WINV the wholesaler inventory, WBL the wholesaler backlog of orders and WIS and WOS represent incoming and outcoming shipments, respectively, where WIO is the incoming orders, WED the expected demand and WOP the orders placed by the wholesaler. One time step later, WOP becomes incoming orders to the distributor, DIO. The same notation is employed in the other sectors with the exception of the factory where there is a production rate, FPR, instead of placed orders and where FPD represents the production delay. The exogenous customer order rate is depicted by COR.

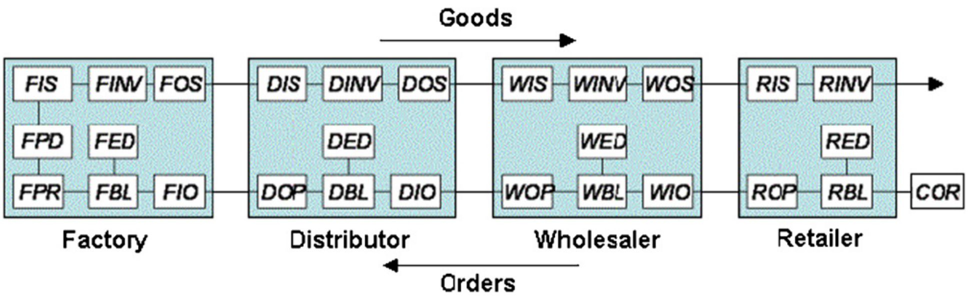

Fig. 1. Basic structure of production–distribution system with state variables and orders flow (left arrow) and goods flow (right arrow) in the supply-chain model.