

Revision of the Bullwhip Effect

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AN INTRODUCTION TO THE BULLWHIP EFFECT

A supply chain is composed of all the stakeholders and processes involved in satisfying consumer demand: wholesaler, retailer, warehousing, transport and so on. A classic method to understand the internal workings of a supply chain is the much-used beer distribution game that came out of MIT during the sixties. In this game, each player takes on the role of one of the members of the chain (consumer, retailer, wholesaler and manufacturer). The aim is for each of them to coordinate their actions in such a way as to satisfy the demands of the upstream member of the chain at the least possible cost. Sterman (1989) provided evidence of an effect that had already been described by Forrester (1961) whereby initial consumer demand is distorted and amplified as it passes along the chain. This increment is known as the Forrester or Bullwhip effect.

There are a number of levels to a supply chain:

- A **strategic level**, when decisions are taken to define the supply chain network, as, for example, when suppliers, transport routes and manufacturing centres are chosen
- A **tactical level**, when a supply chain programme is defined so as to satisfy real demand. The programme, or plan, is implemented at an *operative level*

Lee et al. (1997) studied the amplification of demand from the retailer to the factory by running a mathematical analysis of how demand is amplified as it passes from one level of the chain to the next. He pinpoints four basic reasons why the effect happens:

1. Interpreting demand signals, forecasting
2. Price variations, special offers
3. Rationing policies, fears of shortages
4. Order planning, batching

Wikner et al. (1992) and Van Ackere et al. (1993) discuss a range of options for reducing the Bullwhip effect, and Towill (1997) provides a summary of them. The main solutions involve information sharing (Fiala, 2004) by members of the chain in order to spark enhanced coordination. Traditional remedies for alleviating the effect involve:

- **Information technology** (Machuca & Barajas, 2004)
- **Efficient customer response (ECR), quick response (QR) and every day low prices (EDLP)**. These techniques are particularly common in the American textile industry.
- **Vendor managed inventory (VMI)**: The supplier controls the client's inventory thereby cutting out one of the stages of decision taking and thus attenuating the Bullwhip effect (Holström, 1997)
- **Collaborative planning, forecasting and replenishment (CPFR)**: this refers to business schemes and processes that are jointly planned by the members of the chain (Ji & Jang 2005)

Information technology and communications (ITC) play a key role in the whole process by enabling fast, fluid information transfer and high levels of interactivity. However, the downside is that this information flow also entails added complexity. Indeed, if poorly managed, it may even be counterproductive, as Disney, Naim and Potter (2002) point out.

TRADITIONAL METHODS TO REDUCE THE BULLWHIP EFFECT

One of the methods that has had an excellent effect in limiting the Bullwhip effect is collaborative planning, forecasting and replenishment (CPFR). The method consists of nine individual steps grouped into triads, and has been developed by VICS (Barratt & Oliveira, 2001; VICS, 2002; Seifert, 2003; Crum & Palmatier, 2004):

- Planning:
 1. Front-end agreement
 2. Joint business plan
- Forecasting:
 3. Sales forecast collaboration
 4. Identifying sales exceptions
 5. Resolving sales exceptions
 6. Order forecast collaboration
 7. Identifying exceptions
 8. Resolving exceptions
- Replenishment:
 9. Order generation.

There is an analysis of a number of real models of CPFR application in Pamela Danese et al. (2004). Disney and Naim (2002) describe several experiments in which CPFR was combined with EPOS (electronic point of sales) to form a hybrid EPOS-CPFR system that cushioned the Bullwhip effect in exchange for sharing information and defining a clear planning and collaboration policy.

TECHNIQUES FOR FORECASTING DEMAND

As far back as 1955, Vassian demonstrated that an ordering policy that minimizes variance of the net inventory over time is:

$$O_t = \hat{D}_t - \text{WIP}_t - \text{NS}_t$$

where \hat{D}_t is estimated demand for period t , WIP is work in progress and NS is net stock. It was demonstrated that inventory variance drifts towards forecasting error variance in the course of the time supplied (Vassian, 1955). In consequence, the more precise our forecasting, the less distortion of demand there will be across the network. There are a considerable number of techniques available to forecast future demand, all of which have been studied in depth. They range from a simple, myopic policy, in which future demand is assumed to be equal to present demand, to classic models like the moving average (Allwood & Lee, 2004), exponential smoothing (Disney et al., 2004) and the minimum mean-square error (Hosoda & Disney, 2004). Other techniques such as Winter's exponential smoothing (Zhao et al., 2002), neural networks and Box-Jenkins models (1970) have also been applied successfully in this field.

There are even forecasting techniques that are tailor-made to diminish the Bullwhip effect, such as that of Ingalls and Foote (2003), based on control theory. They established that forecasting of demand should not vary over time except when errors exceeded certain margins. R.G. Ingalls et al. (2005) employed this control-based forecasting model in such a way that forecasting was not modified from one period to the next, as happens in the most commonly used methods, except in exceptional circumstances. The method provided great stability at the order point, which cushioned the Bullwhip effect a great deal. Ingalls also showed that amplification of demand could be eliminated completely if the average and variance of consumer demand were known precisely. This counterpoises the claim made by Dejonckheere et al. (2003) to the effect that the Bullwhip effect would occur regardless of ordering policies. The major advantage of this method over moving average and exponential smoothing methods is that the order point does not change daily, since demand prediction does not change daily either. It is these fluctuations at the order point and fluctuations in demand that invariably increase the Bullwhip effect when traditional policies are applied.

MODELING DEMAND

The demand signal must be defined in one way or another in order to generate results. Basic, yet by no means less effective methods involve modelling demand assuming a normal, steady distribution, but there are other more intricate methods that can better reflect a real model. For example, Hosoda and Disney (2004) built upon a previous model by Lee (2000) to produce an autoregressive demand model of the order 1 that served to demonstrate that by using an ordering policy that minimised minimum mean-square error (MMSE) in forecasting, orders to the supplier fitted an ARMA model (1,1). They calculated the expressions for amplification of demand as a function of the demand autocorrelation. In a variation on studies that apply the autoregressive model, using predictions to minimise MSE, Zhang (2003) used moving average and exponential smoothing techniques to compare different methods. He observed that the Bullwhip effect disappeared if MMSE was used when demand autocorrelation was lower than 0. In contrast, the other two methods always sparked a Bullwhip effect and were

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