The Bullwhip Effect—Exploring Causes and Counter Strategies

Supply Chain Management

This article is based on Hewlett-Packard Company’s Strategic Planning and Modeling’s use of the Stanford University white paper "The Paralyzing Curse of the Bullwhip Effect in a Supply Chain" by Hau L. Lee, Paddy Padmanabhan and Seungjin Whang (March 1, 1995). An in-depth article has been published in Sloan Management Review (1997) by the same authors. [The Bullwhip Effect in Supply Chains (1997) - H.L. Lee, V. Padmanabhan, S. Wang; Sloan Management Review]

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The Bullwhip Effect

Demand information in a supply chain is often altered when transferred from one part or node of the supply chain to another. Such changes as delays, amplification, and distortion of demand signals are known as the bullwhip effect. They lead to tremendous inefficiencies in a supply chain like excessive inventory investment, poor customer service, lost revenues, misguided capacity plans and ineffective transportation and production schedules. These inefficiencies could potentially induce significant costs. This article discusses causes of the Bullwhip effect and some strategies to mitigate its results.

P&G coins the term Bullwhip effect in its diaper supply chain

When logistics executives at Procter and Gamble (P&G) were examining the order patterns of Pampers

The Beer Game
disposable diapers, they observed larger variations in the orders than in the sales. The diaper sales at retail stores showed fluctuations, but those variations were not excessive. However, the orders placed on P&G by the distributors showed a much greater degree of variability. Interestingly, when they looked at the orders P&G placed on their suppliers, they discovered that the swings and variability were even greater. At first glance, this did not make sense to the executives. While consumption of diapers by babies is fairly steady and demographics do not significantly change over time, the demand order variation increases as one moves up the supply chain. P&G started calling such a phenomenon the "bullwhip" effect. In some industry segments, the bullwhip effect is also known as the "whip-lash" or the "whip-saw" effect.

**Hewlett-Packard Company (HP) observes delays, amplification and distortion of the demand signal in its printer supply chain**

When HP examined the sales of its printers and print cartridges at a major reseller, they found that the same Bullwhip phenomenon could be seen. However, the orders placed on HP by this reseller have much bigger swings and variations than P&G observed. Orders placed on HP's integrated circuit division by its printer unit exhibited even greater variation (see Figure 1).

What happens when a supply chain is plagued by the bullwhip effect that distorts its demand information as it is transmitted up the chain? Common symptoms of such variations could be excessive inventory, poor product forecasts, insufficient or excessive capacities and other causes of poor product unavailability. Excessive revisions of production plans, and high corrective costs such as expedite shipments and overtimes are additional symptoms that should be noted.
Figure 1

The Bullwhip effect as observed in HP’s retail supply chain. Top: demand signal delay, amplification, and distortion for a HP product with a long life-cycle. Bottom: the Bullwhip effect during a product rollover. Note the large spike at the beginning of life to fill the retailer’s pipeline-reflecting a "one to show, one to go, one in reserve" shelf replenishment policy.

Perhaps the best illustration of the bullwhip effect in a supply chain is the well-known "Beer Game". Players of the game try to minimize inventory while keeping their customers supplied. The supply chain simulated by the game consists of four nodes—a retailer, a wholesaler, a distributor, and a factory. The participants play the role of one of these nodes. They make ordering decisions to meet demand of their immediate customer at the lowest possible cost. The decisions are based on the incoming orders from the immediate downstream player, their local inventory position, and the delivery performance of their immediate supplier. Consumer orders are simulated by cards and the factory player plans production for each week. Apart from orders received from their immediate customers, no communication among the participants (nodes) is allowed. The game has been played thousands of times and each time similar outcomes occur. The variability of an upstream site is always greater than those of a downstream site. This game offers a simple and yet powerful illustration of the bullwhip effect. The delay, amplification, and distortion of demand signal variability can be attributed to independent decision making of the players involved. Is this irrational or rational decision making? Most players provide a rational evaluation of events and decisions when interviewed immediately after the game.

Causes of the Bullwhip Effect

We believe that the bullwhip effect is a consequence of rational behavior of the decision-makers under the imposed supply chain structure and processes. This implies that companies desiring to gain control of the bullwhip effect have to look at the supply chain structure and related processes.

Hau Lee et al. identify four major causes of the bullwhip effect: 1. Demand forecast updating—consecutive use of immediate downstream order data to analyze trends of market (end-user) demand. 2. Order batching—periodic ordering on suppliers to fulfill continuous demand. 3. Price fluctuation—pricing induced over-ordering and consecutive order hiatus. 4. Shortage gaming—order distortion in anticipation or as a result of shortages.

Each of the four forces in concert with supply chain structure, associated processes and rational decision making
by order managers in a supply chain create the bullwhip effect. Understanding the causes of the bullwhip effect aids the design and development of strategies to counter the effect.

**Demand Forecast Updating**

The beer game outcomes are the result of many behavioral factors. Perception plays a key role in interpreting the demand signal the players observe. They create a mental model of the supply chain functioning and the demand patterns they observe. This mental picture influences their decision-making. Everytime a downstream customer (node or entity) places an order, the upstream manager processes that piece of information as a signal about the future demand for the product. Based on this signal, the upstream manager often readjusts the future demand expectation. This, in turn, changes the orders they place onto their supplier. This is similar to the common real-life situation where every entity in a supply chain does its own forecasting for product scheduling, capacity planning, inventory management, and part procurement. This forecast is often based on the order history of the entities' immediate customers. Lee et al. contend that demand signal processing by consecutive entities up the supply chain is a major contributor to the bullwhip effect.

**Order Batching**

A simple illustration of order batching is a consumer's shopping behavior for diapers. Most likely you do not buy on a continuous replacement basis, but in stead aggregate usage into larger purchase quantities. You accumulate your diaper and other grocery requirements based on your desired frequency of your store visits. You are buying in "batches". This distorts the actual (diaper) consumption pattern and this distortion is further magnified when your store visits are highly irregular or you buy at different stores.

In a supply chain, each organization places orders on an upstream organization using some inventory replenishment mechanism. As demand depletes inventory, a company or supply chain entity may not order continuously, but accumulate inventory replenishment requirements from its supplier. Such batching behavior leads to the bullwhip effect.

Two forms of order batching can be traced: periodic ordering-ordering on a periodic cycle-and order pushing-order surges through sales incentives like quota. Reasons for periodic ordering can be the supplier's capability of handling frequent ordering, costs and time requirements of order processing or purchase order generation. Ordering systems and processes in place, for example MRP or DRP systems, can also be influencers. As order cycles of disparate customers tend to randomly overlap, the result is a more erratic demand pattern than the actual demand seen by the customers-hence the Bullwhip effect.

One common obstacle for ordering more frequently is transportation. There are substantial differences in the full truckload (FTL) and less-than-truckload rates, creating a strong motive for a company to order full truckloads from a supplier. In addition, some suppliers give discounts or rebates for FTL orders. If such FTL orders are large with respect to the average demand the direct linkage between demand and ordering is distorted. This, in turn, induces more erratic order patterns up the chain.
Price Fluctuation

Promotions can also be an incentive for buying more than the demand requirements. For example, you buy more diapers than you need to cover your baby's diaper requirements in between store visits because of a discount. You make a forward buy. This distorts the demand signal. Retailers and their distributors, in turn, exhibit similar behavior. It has been estimated that 80% of the transactions from manufacturers to distributors in the grocery industry were made under some "forward buy" arrangement (see the Kurt Salmon Associates Report, 1993). Forward buy is a result of price fluctuations in the market place. It has become a common practice for manufacturers and distributors to run special promotions like price discounts, quantity discounts, coupons, and rebates periodically. All these promotions resulted in some form of price fluctuations, which incent immediate customers to buy more than required or to wait on a favorable price before reordering or buying. Additionally, manufacturers offer trade deals to the distributors/wholesalers, which can be viewed as an indirect form of price discounts.

In 1991, the amount of money that companies spent based on trade deals and promotions constituted 55% and 25% of the companies' total marketing budget. When price fluctuation based buying behavior becomes common practice it makes forecasting based on order patterns especially difficult, as the buying pattern of the customer does not reflect the consumption pattern of that customer. The result is that the variation of the buying quantities is much bigger than the variation of consumption.

Forward buying can be a rational decision when price fluctuation, like high-low pricing, is part of the market dynamics. If the cost of holding inventory is less than the price difference, then buying more than required for the current order period is the right "local" decision. But, it is not the right decision from a supply chain perspective. In fact, the high-low-pricing phenomenon has induced a stream of research on how companies should order in an optimal way to take advantage of the low price opportunities. This yields benefits for one player in the supply chain, but creates the Bullwhip and increased costs upstream.

Shortage Gaming

When the demand for a product exceeds its supply, a manufacturer often applies some rationing scheme to allocate the product to its customers. If the allocated amount is proportional or perceived to be proportional to the amount ordered, customers would order more than needed to ensure "sufficient" product allocation. This over-ordering behavior can also be observed in the Beer game when immediate suppliers fail to meet demand for a number of order cycles. Outside the Beer game, where orders cannot be cancelled, one often sees order cancellations when the supply constraints are lifted.

The effect of shortage gaming is that the orders placed by the customers may provide very little information about the actual demand for the product. This can be particularly challenging to manufacturers for newly introduced products. Then this would result in misguided investments in capacity and inventory. Examples over-ordering with significant impact have occurred for DRAM, Apple Macintosh computers, IBM Aptiva Computers, HP printers, and Motorola cellphones. HP, for example, could not meet the demand for its LaserJet III model printer, and the product was put on allocation. Orders for the printers surged many-fold. But HP management could not determine whether the orders were genuine reflections of the real market demand, or simply "phantom" orders to get better allocation of the product. When the supply of the LaserJets became less constrained, HP saw many resellers cancel their orders. HP spent millions of dollars on excess inventory and in unnecessary capacity as a result of shortage gaming.
Countering the Bullwhip effect

Lee et al. present a framework (Table I) to change the supply chain structure and processes to counter the Bullwhip effect. They focus on three areas of supply chain improvement—information sharing, alignment, and operational efficiency. Information sharing focuses on communicating consumption and inventory information throughout the chain. Understanding the impact of this sharing and looking for improvements in the information flow is also part of this improvement opportunity. Alignment focuses on policies and processes of pricing, transportation, inventory planning and ownership, between the upstream and downstream sites in a supply chain. Finally, operational efficiency refers to activities that result in operational performance improvements such as costs and lead-time.

Table 1: A Framework for countering the Bullwhip effect [Lee et al. (1995)].

<table>
<thead>
<tr>
<th>Initatives to address the causes of the Bullwhip Effect</th>
<th>Information Sharing</th>
<th>Alignment</th>
<th>Operational Efficiency</th>
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<tr>
<td>Demand forecast updating</td>
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<td>Vendor Managed Inventory</td>
<td>Lead-time reduction</td>
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<td>Point-of-Sale data</td>
<td>Discount for information sharing</td>
<td>Echelon-based inventory control</td>
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<td>Electronic Data Interchange (EDI)</td>
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<tr>
<td>Order batching</td>
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<td>Price fluctuations</td>
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<td>Shortage gaming</td>
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<td></td>
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<td>Inventory consignment</td>
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Avoid Multiple Demand Forecast Updates

Every member of a supply chain conducts forecasting in connection with their planning activities (e.g., manufacturer for production, wholesaler for logistics planning, etc.). The bullwhip effect is created when
supply chain members undertake forecasting solely with the demand input from their immediate downstream member(s). The demand input from the immediate downstream member(s), of course, is a result of a forecasting exercise undertaken by that member, using as input from its downstream member(s). This serial processing of consumption data is what we have described as a major cause of the bullwhip effect. A better understanding of the dynamics within the supply chain can then lead to significant improvements and mitigation of Bullwhip.

An alternative to serial forecasting involves simultaneous availability of consumer demand data to all supply chain sites. This simple change in demand data transfer allows parallel forecasting and avoids the amplification that results from a multi-stage forecasting process. It also has the added benefit of eliminating the delays inherent in a multi-stage system.

In the computer industry we are beginning to see more and more manufacturers requesting sell-through data from their resellers. These are data on the withdrawal of stocks from the resellers' central warehouse. Although they are not the same as point-of-sale (POS) data at the resellers' stores, they represent a significant improvement over the previous situation, when the manufacturers had no visibility of what goes on in the supply chain once the products left their shipping point. Companies like IBM, HP and Apple are all requiring sell-through data as part of the commitments from resellers in their contracting.

Of course, the upstream sites would be even better off when POS data are available. The grocery industry seems to be taking the lead on this development. The increasing penetration of electronic data interchanges (EDI) among the players in the grocery supply chain (67% of manufacturers, 65% of distributors and 40% of wholesalers) will undoubtedly facilitate information transmission and sharing among chain members. Sometimes monetary inducements are offered to the downstream members for information transmission.

Even if multiple organizations in a supply chain are using the same source demand data to perform forecast updates, the differences in forecasting methods and buying practices could still lead to unnecessary fluctuations in the order data placed on the upstream site. A more radical approach is to let the upstream site be the controller of replenishments from all upstream to downstream sites. The upstream site is given access to the demand and inventory information at the downstream site, and would do the necessary forecasting update and replenishment functions for the downstream site. The downstream site becomes a passive partner in the supply chain.

This practice is becoming prevalent in various industries. In the consumer product industry, such a practice is known as VMI (Vendor Managed Inventory) or CRP (Continuous Replenishment Program). Dell Computers has been selling its computer products directly to the consumers for years without going through the distribution channel and hence has avoided one layer of the supply chain that contributes to the bullwhip effect.

**Order batching**

Since order batching contributes to the bullwhip effect, companies need to devise strategies to eliminate the need for batching. These strategies should lead to smaller order sizes or more frequent replenishments. The larger order sizes and low order frequencies are often the result of relatively high ordering and replenishment costs. Cost contributors are the paper work and the processes involved.
Improving, streamlining, and standardization of processes and elimination of paperwork can lower these costs and allow for more frequent ordering in smaller order sizes. P&G, for example, has introduced standardized ordering terms across all business units to simplify the ordering process and dramatically cut down on the number of invoices required (Millstein, 1994). Transportation economics often outweigh even significant decreases in order costs. Smaller order sizes can become economical for the entities involved when different products from the same manufacturer are combined or when different entities combine different shipments to locations in proximity to one another. Third party logistics providers can be enablers when these neighboring entities are competitors. Financial discounts for ordering shipments of mixed stock keeping units (SKUs) can help achieve this. P&G gives such discounts to distributors. Of course this requires changes to the manufacturers processes and capabilities, like the ability to create mixed SKU pallets. Third party logistics providers combining shipments can be especially appealing to small customers whose volumes do not justify frequent full truckload replenishments independently.

Stabilize prices

The manufacturer can reduce the incentives for retail forward buying by moving towards a more uniform wholesale pricing policy. The grocery-industry is leading this shift with major manufacturers such as P&G, Kraft, and Pillsbury moving to the Every Day Low Price or Value Pricing strategy. P&G's Value Pricing seems to have worked wonderfully. From 1991 to 1994, P&G has reduced its list prices by 12% to 24%, and aggressively slashed the promotions it offered to trade customers. In 1994, P&G reported its highest profit margins in 21 years, and boosted increases in market shares (Schiller, 1994).

From an operational perspective, the use of initiatives such as continuous replenishment programs together with a rationalized pricing policy can help to control forward buying behavior. The move by manufacturers to use computer assisted ordering for order transmission also minimizes the possibility of such a practice. Interestingly, the progress in the use of activity-based-costing systems has enabled companies to recognize the excessive costs of forward buys. The spread of activity-based-costing therefore helps the strategies like every day low price and continuous replenishment.

Eliminate Gaming in Shortage Situations

When a supplier faces a shortage situation, instead of allocating products based on the orders placed, an alternative rule is to allocate in proportion to the past sales records. This removes the incentives for the customers to exaggerate their orders to game the situation. General Motors has long used this method of allocation in case of short supply. Other companies, such as Texas Instruments and HP are also switching to this method when allocation of short supply products is warranted. Gaming in shortage situations is especially high when the customers have little visibility of the supply situation and the allocation method the supplier uses. Sharing of capacity information, inventory positions, and allocation processes helps to alleviate the anxiety of the customers and lessens the need for the customers to engage in the gaming behavior.

Summary

The Bullwhip effect—delays, amplification, and distortion of demand signals—can be traced to rational decision-making within the supply chain. Lee et al. identify four causes: repeated forecast updating, order
batching, price fluctuation, and shortage gaming. These causes can be countered through three different strategies focusing on information sharing, coordination, and improving operational efficiency.

Further Reading


Distorted information from one end of a supply chain to the other can lead to tremendous inefficiencies: excessive inventory investment, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and missed production schedules. How do exaggerated order swings occur? What can companies do to mitigate them? This article describes the amplification, distortion, and delay in supply chains as a result of repeated, independent decision-making and its drivers. The root causes of this Bullwhip Effect are demand forecast updating, order batching, price fluctuation, shortage gaming. These causes are described in detail with matching counter-strategies that have proven effective from across various industries.


Do you consider distribution and inventory costs when you design products? Can you keep your customers informed of when their orders will arrive? Do you know what kind of inventory control systems your dealers use? If not, you've succumbed to the pitfalls of inventory management. You're not alone. Manufacturers have been concentrating on quality of incoming materials and outgoing products, but they haven't been paying as much attention to the costs associated with transporting and storing them. Lee and Billington describe fourteen pitfalls of supply chain management and some corresponding opportunities. The pitfalls address problems associated with information definition and supply chain management, operational problems, strategic and design issues. The more complex your network of suppliers, manufacturers, and distributors, the more likely you can gain operational efficiencies by attending to inventory.


This article describes the use of "accurate response" measures to help companies deal with uncertainty, and uses examples from the apparel industry, specifically Sport Obermeyer’s use of accurate response. Accurate response is a strategy to counter the Bullwhip effect in the apparel industry.


Advances in telecommunications and information systems have sparked a revolution in the way the retail industry competes. This chapter looks at the impact of the availability and use of these technologies on the structure of the retail industry and the role played by "quick response."