The Bullwhip Effect in Different Manufacturing Paradigm: An Analysis

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ABSTRACT
Slight fluctuation in the customer demand produces huge fluctuations in the inventory and production levels of the upstream member of the supply chain. This is known as demand amplification or the bullwhip effect. The bullwhip effect produces huge inefficiencies along the supply chain, captures much-needed working capital by high inventory levels and results in dissatisfied customers. Analyzing a set of nine case studies, results show that agile manufacturing is best suited to deal with a turbulent market with unpredictable demand.

KEYWORDS: *Bullwhip, Agile, Lean, Agility, Traditional, Manufacuring paradigm*.

JEL CLASSIFICATION *M11*

INTRODUCTION

Competitive advantage can be gained through an effective supply chain management resulting in efficiency (Chase et al, 2001). The coordination in the supply chain comprising of manufacturers, distributors, wholesalers and retailers depends on the flow of information (Lee et al., 1997a; Rudberg, 2003) However, distortion in the information flow leads to supply-demand imbalance leading to a phenomenon called the "bullwhip effect" (Lee et al, 1997a).

Companies rely on the customer demand to make production forecasts. In the demand-ridden supply chain, variation in the supply-demand is often a cause of concern for the managers. These fluctuations in the demand vary significantly between industries. In a relatively consistent demand product it might be expected that the supply chain is more accurate and efficient compared to products with seasonal demand and various business cycles. However, as one moves up the supply chain from retailers to distributors the perceived demand is amplified, which thus produces the bullwhip effect. This effect is more present in products with stationary demand as found by the logistics executive at Proctor & Gamble (Forrester, 1961). The same phenomenon is also found in various products and in different industries.

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Various researches suggest the presence of the bullwhip effect in the supply chain of the automobile industry. Blanchard (1983) concluded that the variance of demand was higher that the variance of sales. Cachon (2007) also shows the presence of bullwhip effect in the U.S automobile industry.

The objectives of this project were to build a deeper understanding of the bullwhip effect through analyzing different case studies that have already taken place. The project sets out to differentiate qualitatively between the demand amplification effects in various manufacturing systems.

This paper contributes heavily in accessing the bullwhip effect in different paradigms. There is lack of literature on bullwhip effect due to which this qualitative analysis uses cases from different industries and different manufacturing paradigms such as traditional, lean and agile in assessing the research question. Studies conducted on the bullwhip effect are superficial at best. Bullwhip effect in leagile strategy is hardly documented. The paper connected the three paradigms and assesses the bullwhip effect in leagile strategies. The aim of this paper, thus, is to show the difference of intensity of the bullwhip effect within mass, lean and agile manufacturing approaches. This study analyzes, through secondary research, the existence of bullwhip effect in different manufacturing systems. First, the three manufacturing paradigms prevalent today were categorized as: Traditional manufacturing, lean manufacturing and agile manufacturing.

This categorization was made after looking at the way production and supply chain was managed at these companies. The companies (or supply chains) belonged to different industries from automotive components to food retail. Some supply chains were international, however, most were local. All of the supply chains were a basic three-tier network as shown in figure 1.

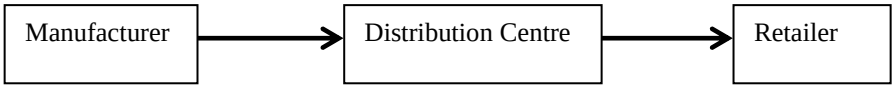

Figure 1. A simple three tier supply chain
Source: author

Section 2 analyzes the literature behind the ideas employed. It also emphasizes how different approaches have been developed, to reduce the demand amplification problem and how these approaches have evolved over time in a high competitive market economy. Section 3 gives an explanation about the methodology used to gather data for a deeper understanding of the phenomena. Case studies were gathered from different journals. Section 4 critically analyzes the case studies. The nine case studies are discussed and their results analyzed in order to gain a deeper understanding of the bullwhip phenomenon. Section 5 concludes the report with recommendations for managing the bullwhip.

1. LITERATURE REVIEW

Lee et al. (1997a), describes his idea of the *bullwhip effect* as the 'the phenomenon where orders to the supplier tend to have larger variance than sales to the buyer (i.e., demand distortion), and the distortion propagates upstream in an amplified form (i.e., variance amplification).' The name bullwhip is suggestive of the movement of the bullwhip. Small movement at the handle of a bullwhip can create bigger or larger swing at the other end

which describes how information on demand-side becomes increasingly exaggerated and distorted as it moves up the supply chain from customer, manufacturer towards supplier, driving costs up and creating inefficiency. The Beer game created by the Sloan School of Management demonstrates important principles in the supply chain. Sterman (1989) states candidates in the game are appointed to act like the members of the supply chain; the customer, retailer, manufacturer and the supplier. Each makes decision on their demand order from the orders they receive unaware of the actual customer order. As expected the inventory increases; the customer order are far lower then the aggregate inventory of the members.

The presence of the bullwhip was of systemic nature. The parts that made up the system did not know of its existence. It was actually an evidence of chaos in social systems.

As the demand orders move up the supply chain, the information is amplified. At the sales end, customers order more in order to eliminate uncertainty. Hence, the retailer observes lesser fluctuations in orders then compared to the manufacturer's order. The wholesalers to manufacturer orders are exaggerated creating higher variability, which amplifies even more when factory orders are placed to the suppliers (Lee et. al, 1997b). Figure 2 below shows a graphical representation of Lee et. al (1997b) findings. The whole process creates an upward trend. This surplus of production is balanced later when demand orders fall but this swing dampens the firm, which is left with high costs and an inefficient supply chain, and this in turn affects the industry as a whole (figure 2).

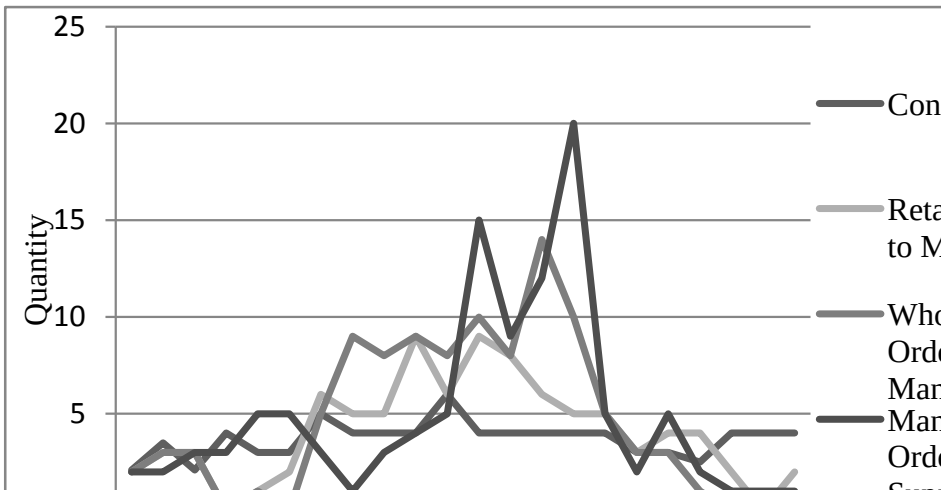

Figure 2. Demand fluctuation along the chain
Source: Lee et al. (1997)

Mitchell (1923) gives a good explanation of why the demand amplifies. He states the retailer places an order but because of the shortage of supplies the manufacturers are only able to fulfill 80% of the order. The firm could not produce to full capacity because there was an unaccountable shortage of raw materials. The retailers become disappointed because of the loss of profit associated with selling that 20%. In the next order they will increase their ordering units to make up for the loss and to make sure they get what they ordered. The retailers also order from other sources to make sure they have enough. However, when

the manufacturers sees an increase in the demand in the next order they increase the demand order further to make sure they manufacture enough to cover the increasing demand. The factory order to the supplier is even more to keep 'safety stock' at hand due to the unexpected demand increase. This whole process results in a huge surplus in the demand orders that are not really required (Fisher, 1997).

Jay Forrester (1961), at Procter and Gamble, first observed demand amplifying as the orders moved up the supply chain. He observed that consistent demand products like Pamper (disposable diapers) with little customer demand variation produces high fluctuation in the supply chain. With predicted birth rate, steady consumption rate and stable sales, the higher variance in retailer order was reported. This information flow (demand orders) was less variable with retailer's orders then compared to the distributors at the factory. The orders to the 3M (suppliers) fluctuated ever more. At Hewlett-Packard's printer supply chain the executive found the same distortion of orders from the resellers to the company's circuit division as reported by Lee et. al (1997b).

Mitchell (1923) and Stalk and Hout (1990) reported the similar behavior of the supply chain. In Barilla's pasta supply chain, Hammond's (1994) research shows higher fluctuation in their weekly orders. Philips Electronics (De Kok et al. 2005) also reported the presence of bullwhip.

Lee et al. (1997b) studied many supply chains and explains that the high degree of uncertainty and variability causes the distortion in information of the demand orders that lead every entity in the supply chain to stockpile. This results in operational inefficiency and uses valuable working capital. The grocery industry as outlined by Efficient Customer Response (ECR) estimated a $30 billion opportunity from their supply chain inefficiencies (Kurt Salmon Associate, 1993). Manufacturers like Bristol-Myers Squibb, distributors such as McKesson and retailers namely Longs Drug store in the pharmaceutical industry were found to duplicate inventories. The same was found in the computer industry at Dell and HP. The total chain contained more than one year's supply as reported by Lee et al. (1997). This, then, is not the problem relating to firm alone but rather it is industry specific.

1.1 Bullwhip Across Different Industries

The affect of bullwhip in the industry thus affects the economy as a whole (Holmstrom, 1997). For this reason, the presence of bullwhip in the industry has been an interest for many economists. Holt et al. (1968) found bullwhip in the TV industry, the jeans clothing supply chain studied by Stalk and Hout (1990), automotive and camera (Blackburn 1993), automotive (Avery et al. 1993; Taylor, 1999a), grocery (Holmsrom, 1997; Hammond, 1994; and Salmon, 1993), food by Lee et al (1995) and Fransoo & Woulters (2000), cement industry (Ghali, 1987), retail industry (Blinder 1981; Gill & Abend, 1996; Mitchell, 1923), pharmaceutical industry (Lee et a. 1997), cotton industry (Zymelman, 1965), home and personal care (Lee et al. 1997a), toys (El-Beheiry et al. 2004), tobacco and tire (Fair, 1989), electronic and furniture (Hejazi & Hilmola, 2004), machine-tool industry (Anderson et al., 2000; McCullen and Towill, 2001), automobile industry (Blanchard, 1983; Allen, 1997) and Cachon (2007) studied all industries and found the bullwhip effect.

1.2 Bullwhip In The Economy

Kondratieff (1984) studied the economy, discovering a phenomenon known as "long wave" or Kondratieff cycle. Towill et al. (2006) relates the long wave to the bullwhip; the overexpansion (demand amplification) is not profitable. Sterman (1986) explains how 'over-expansion' in the economy leads to lower employment, production and cutting back to eliminate what the industry had produced in the time of over-expansion and the overall cost associated with it. This is similar to the bullwhip effect. In the time because of increasing orders the firms sets up more equipment, raw material, employment but when the surplus of production exists they need to cut back in order to sell the produced goods in the inventory. Hence the disruptions and swings caused by bullwhip affects the economy as it affects the industry and the firm itself. Metters (1997) pointed out that bullwhip results in high costs due to the capacity on-cost and stock-out costs. The costs also increase because of the demand stock-holdings has negative consequences. Below is a graphical representation of the Kondratieff Wave (figure 3).

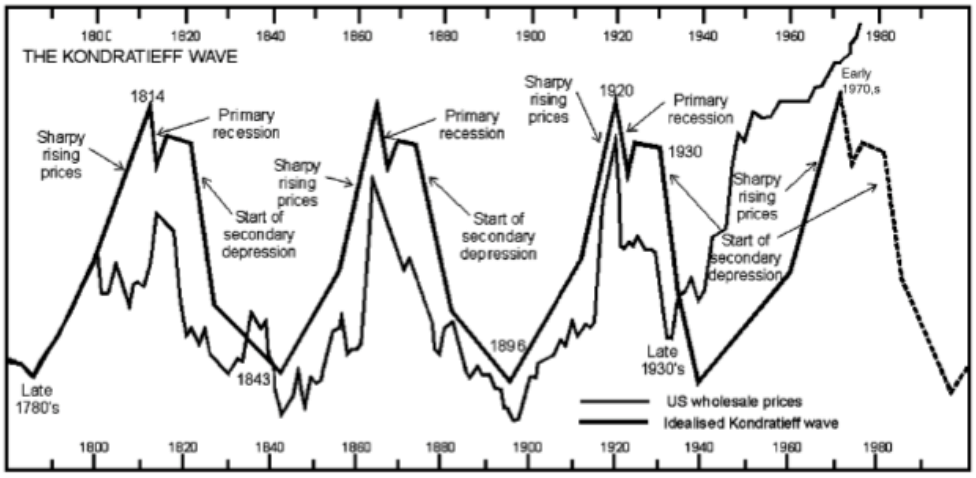

Figure 3. Periodicity in the economy
Source: Kondratieff (1984)

1.3 Causes and Remedy

Andraski (1994) suggests that the bullwhip problem in the supply chain is 80% people centered and 20% technology centered. Forrester (1980b) proposed that the problem lay in the dynamically complex and non-linear nature of supply networks. Mason-Jones et. al (2000) suggest the cause of bullwhip effect is 'system induced and directly affected by information and material flows and feedback loops'. Senge & Sterman (1992) and Towill (1982) related the bullwhip effect to the lack of managers' ability to think systemically. Nienhaus et al. (2006) also believes that the causes of the bullwhip lie in human decision-making.

1.3.1 Information Delay

Lee et al. (1997b) suggest that the demand distortion exists in the form of flow of information. The driver here is the information and the decision is based on units ordered.

Lee et al. (1997b) also explain the distortion in information arising from demand forecast updating, order batching, price fluctuation and rationing and shortage gaming.

1.3.2 Demand Forecast Updating

This occurs when the retailers base their order on the demand forecast rather than the true market demand. As this information travels up the demand gets further amplified. *Remedy:* Forrester suggested that eliminating intermediary like in the case of Apple and "Dell Direct" Lee et al. (1997b) explains how manufacturers such as IBM, HP and Apple request sell-through data from their resellers so as to eliminate demand amplification.

1.3.3 Order batching

According to Lee et al. (1997a) is an end result of two factors, the periodic review process and the processing cost. The manufacturers can reduce the information distortion by asking for sell-through data so that they can manufacturers units based on sales than on the data. Reducing transaction cost can help remedy the batch size and ordering cost. Nabisco, for example, uses computer assisted ordering that is paperless reducing the ordering cost. This system orders less and smaller batches which removes demand distortion and makes the system more efficient.

1.3.4 Price fluctuations

These arise when the wholesale gives price discounts while the retailers do Every Day Low Price (EDLP). These strategic buying causes buyers to capitalize on the discount offered on the short period leaving the manufactures production schedule uneven along with the inventory cost. Fisher (1997) demonstrated how ordering more to take advantage of pricing strategy could be damaging. Manufacturers like Pillsbury, P&G and Kraft regularly carry out trade promotions. *Remedy* suggested is for the manufacturer and buyer to sign a contract under lower price or discount but the goods will be delivered over some period of time. This way the inventory cost of the buyers and manufactures is reduced and also enjoy strategic pricing policy.

1.3.5 Rationing and shortage gaming

This is when the manufacturers make decisions based on the order data. They need to carefully understand when interpreting the orders. Gaming can take place when the retailers order more to 'self-protect' themselves when there is no shortage in reality but only imagined as explained by Mitchell (1923). In a shortage situation manufacturers can allocate supplies using a different rule Companies like HP, Texas Instruments, GM allocate supplies proportionate to the market share of the retailer in the previous period. Cancellation, and free returns also contribute to gaming. One *remedy* is to restrict buyer's flexibility. Sharing forecast information is another way carried out by HP, Lands' End and SUN.

1.4 Problems of Bullwhip

The problem of bullwhip effect is mainly two-folds: higher cost and lower efficiency. Blinder (1986) suggests that there are 'cost shocks' associated with the bullwhip as well. Measurement also is a problem as there are many measure. The most popular measure has also been criticized upon.

1.5 Measurement

Lee et al (1997a) used a model-based analysis to show the amplified data causes bullwhip in three settings: correlated and seasonal demand, batch ordering and finite capacity. In a study Cachon et al. (2007) the formula was used for the calculation of the bullwhip. A ratio greater than one suggests the presence of demand amplification, while less than one means that amplification does not exist in the supply chain.

When the seasonality is considered, Cachon et al. (2007) found variability dampening manufacturing and retail industry then when seasonality was not considered. It was also observed that seasonality did not play any part in the wholesale industry. The wholesalers usually order large batch sizes because they are not restricted by space as the retailers. Cachon et al. (2007) observed that bullwhip results are higher without seasonality compared to seasonality. Variance ratio is most widely used measure and to detect bullwhip effect. It is the ratio of the upstream and downstream demand variation. However, many experts have stressed on the weakness of this measure.

1.6 Proposed Solutions

Many solutions have been proposed to eliminate bullwhip. Initially, Forrester (1958) and Burbidge (1991) outline six supply chain solutions: control system, time compression, information transparency, echelon elimination, synchronization principle and the multiplier principle which was demonstrated by Wikner et al. (1992) and Anderson et al. (2000). Wikner et al. (1991) of the operations manager school proposes remedies: "improvement in each echelons decision values, better timing of rules among different echelons, reduction of time delays, removal of some distribution of echelons, better information flow along the chain."

Lee et al. (1997a) also proposed some remedies: Information Sharing (IS) actions that speed up information flow from downstream to upstream, Channel Alignment (CA) groups aiming to increase co-ordination of process, Operational Efficiency (OE) increasing and improving efficiency and reducing time. Miragliotta (2006) has provided a conclusive table outlining all the remedies suggested by researchers around the IS-CA-OE paradigm and also providing a new approach to eliminate bullwhip effect. Three modeling layers: physical layer, reconstruction layer and control layer have been pointed out. The causes of bullwhip fall in these layers. The determinants are the redesign action while the triggers are the filtering actions. Each company faces different problems that cause the bullwhip hence the delay in the physical layer is a trigger to analyze the firm's machines and process capability etc (table 1).

Table 1. New taxonomy of the bullwhip

	Determinants (redesign actions)	**Trigger (filtering actions)**	
		Internal	**External**
Physical layer	Linear gain Delays & feedbacks Batching (quantity)	Machine reliability Process capability	Supply reliability
Reconstructor layer	Delays + modeling errors: In accounting In forecasting	Machine Errors: In accounting In forecasting In measuring	

	Determinants (redesign actions)	**Trigger (filtering actions)** **Internal**	**External**
	In measuring performances	performances In accounting	
Control layer	Batching (quantity, frequency) Delays (in the control model) Irrational decision making		Price promotions/advertising Campaigns Shortage gaming Financial deadlines

Source: Miragliotta, 2006

Geary et al. (2006) has summarizes approaches presented by different authors in the figure below. The solutions are grouped as OR theory, filter theory, control theory, what-if simulation, and ad-hocracy (figure 4).

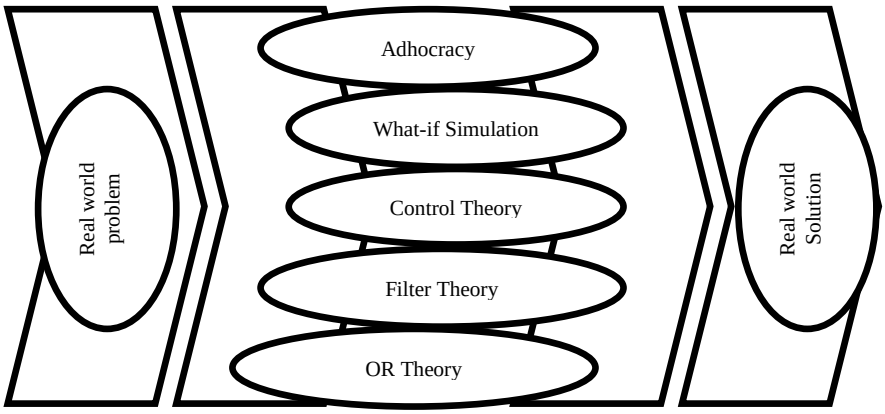

Figure 4. Categorization of solutions of bullwhip
Source: Geary et al. (2006)

1.7 Introduction to the various manufacturing systems

The demand amplification effect varies in different manufacturing paradigms. The *degree* of amplification of fluctuation varies according to the manufacturing and supply chain management policies implemented. Below the three policies are looked in greater detail.

1.7.1 Traditional

Mass production system is as old as industrialization itself. Henry Ford, founder of the Ford Motor Company in 1913 manufactured cars that were simple, small and most importantly cheap (Hounshell, 1984). The mass production system based its strength on economies of scale. Producing Model T on a large bases with cheaper price lead him to capture the market and sell the products at large. Lacey (1986) defines mass production as 'single purpose manufacturing combined with the smooth flow of materials in the assembly line; large volume production, high wages and low prices.' Thus, economies of scale were captured but it also created small delays very costly. The company moved towards improving the assembly line to specialization and decentralization (Ford, 1923). When the company decided to produce a new model, it required a change in the whole system from

the suppliers, to the assembly. Pietrykowski (1995) explains how Ford and mass production became popular but also lead to cul-de-sac situation (Raff & Trajtenberg, 1996). This was because mass-manufacturing system had many weaknesses; most importantly, it was unable to deal with rapid market changes. According to Duguay et. al (1997) mass production has the following features: Reducing costs through economies of scale, production divided into small, repetitive tasks, innovation as a means to improvement and existence of 'adversarial' relationship with suppliers.

Duguay et al (1997) also explains how agile production is better as compared to mass production. Although the era of technical changes had been well documented, little or no quantitative analysis of mass manufacturing is available.

1.7.2 Lean

After the 1973 oil shock the focus of Japanese companies shifted to reducing or eliminating wastes thereby cutting costs (Monden, 1983). The lean strategy came from the realization of the scarcity of resources and a fiercely competitive industry. Lean methodology implemented the strategic leveraging of resources.

Taichi Ohno, an engineer at Toyota Motors, claims that the lean revolution did not happen overnight, however, it was a process of small step-by-step improvements that took thirty years (Ohno, 1988). Lean processes started primarily at Toyota under two engineers, Taichi Ohno and Shigeo Shingo. Later, the two authors published books on production processes and so the *lean* revolution first began in Japan and spread to the rest of the world.

There were huge gaps of efficiency between Toyota and other car manufacturers; this solidified the superiority of lean philosophy. Based on Dyer's (1994) research the following table shows the efficiency at Toyota in comparison to other car manufacturers. Toyota implemented a lean framework while the rest were grounded in the traditional supply chain management and production methods (table 2).

Table 2. Car manufacturers and efficiency compared

Variable	Chrysler	Ford	General Motors	Nissan	Toyota
Quality	148.4	120.9	131.7	110.6	78.6
Cycle Time	80.7	77.7	86.5	51.4	50.0
Auto Inventory/Sales	9.8%	8.4%	8.1%	5.1%	2.3%
Suppl. Inventory/Sales	10.7%	10.1%	11.2%	8.8%	7.3%
Auto Maker ROA	4.1%	4.2%	2.8%	5.5%	13.0%
Suppliers ROA	5.4%	5.5%	4.8%	5.6%	7.1%

Source: Dyer, 1994

Lean manufacturing was 'an enhancement of mass production' (Motwani, 2003). After mass manufacturing and the assembly line continuous improvements were being sought after in production and the supply chain. Toyota sought improvement in every process; the system that emerged was called the 'lean' system. This lean methodology focused on cutting costs and reducing/eliminating the seven lean wastes. The lean approach divided activities into three types; value-adding activities, non-value adding activities and necessary non-value adding activities. The seven lean wastes were identified: Transport, inventory, motion, waiting, over processing, overproduction and defects.

Basically, the lean approach stressed on continuous improvement, minimum defects, and efficiency by producing in small batches. The major shift among mass production system and lean is that lean system emphasizes the importance of constant innovation within and without the company. On the other side, mass production just stresses producing large quantities to benefit from economies of scale. Lean emphasized strategy; doing more with less; and adapting to the continuously changing environment whilst reducing costs as much as possible.

The improvement in efficiency of manufacturing from mass to lean production was evident; companies outside the car industry also started applying lean principles. Also, in the beginning lean was an organization-wide philosophy, however, it soon incorporated networks of suppliers becoming an inter-organizational approach.
Lean system proposed *Shojinka*, meeting variability in demand through flexibility. This reflects the fact that demand variations were accepted as a fact and production was changed to meet the demand and avoid excess inventories (Monden, 1983: 99).
According to Knill (1999) successful implementation of lean requires focus on five parts: Supplier programs, continuous improvements, flexibility, eliminate waste and zero waste.

As the figure 4 shows lean's strength lay in connecting the strategic to the operational level, thus, having an excellent strategic implementation.

1.7.3 Agile

The concept of agility owes its birth to the field of social systems. Emery and Trist (1965) proposed the notion that organizations were open systems that existed in environments. They divided uncertainties within environments in four types, the most intense which was termed *turbulent field*; where uncertainty arose from the environment itself. Figure 5 shows the changing variables that an organization has to deal with constantly.

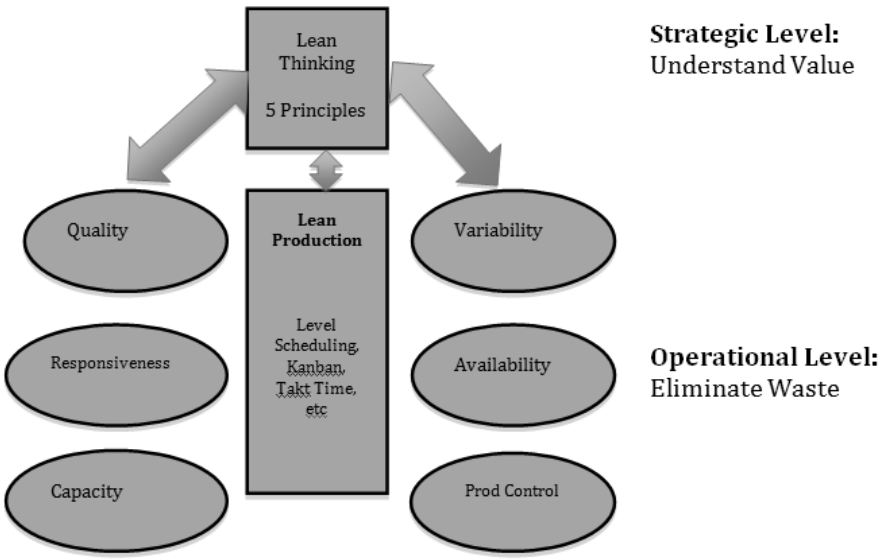

Figure 5. Strategic and operational levels
Source: Hines et al. (2004)

In business, the concept of agility first came forward from the Iacocca Institute in 1991 (Nagel & Dove, 1992). Agility was defined as the 'ability to respond with ease to unexpected but anticipated events' (Oleson, 1998).

Another definition of agility in manufacturing was by Sarkis (2001):

Agile manufacturing = flexible manufacturing + lean manufacturing

Narasimhan et al. (2006) wrote that agile processes were focused on superior flexibility and speed of delivery and that they were 'built upon' lean methodology. Now agile is being termed as an alternative to or improvement of" lean manufacturing (Mason-Jones et al., 2000). Lean manufacturing is adopted where there is a stable demand while agile is suitable to markets with volatile demand. Mason-Jones et al. (2000) also introduced the leagile paradigm where both lean and agile processes can be used by the utilization of a 'decoupling point'.

Parkinson (1999) claims that the agility revolution in the manufacturing came about largely due to the increasing intensity of competition. Gunasekaran (1998) claims that focus towards customer satisfaction, business system integration, shortening product life cycles, customized services, and flexibility in meeting volatile demand gave rise to what is known as agile manufacturing. This variety-variability matrix gives Christopher's (2000) perspective on agile and lean systems. This differentiation between agile and lean is essential in how both the systems cope with demand fluctuations (figure 6).

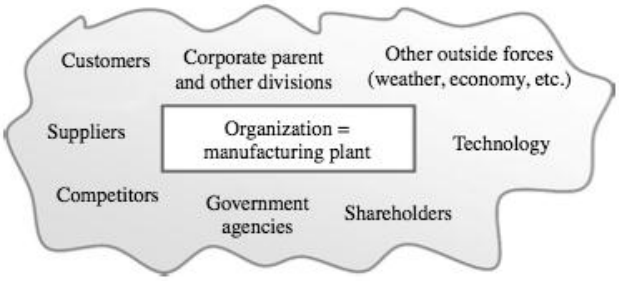

Figure 6. Organization and its environment
Source: Yauch (2011)

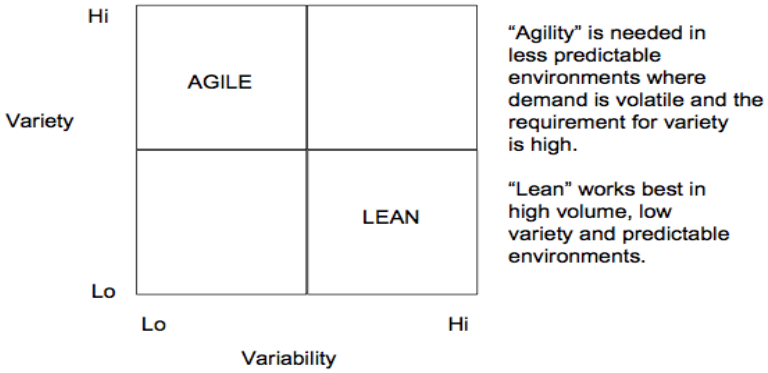

Figure 7. Variety-variability matrix
Source: Christopher (2000)

Many definition of agility proposed however all are synonymous to responsiveness to changing market requirements (Ramesh & Devadasan, 2007). Thus, there is a focus on speed in the agile paradigm.

2. Methodology

Data was collected using case studies. All data is based on research already conducted by academic professionals. As the study is qualitative, the causes of the demand amplification effect and the measures implemented to counteract the effect were analyzed and there effectiveness assessed.

Initially, it was planned to include consistent cases for the ease of comparability. However, the cases on bullwhip are still limited, especially, in terms of manufacturing paradigms and there was also a lack of consistency. Due to this, eight cases were included that had significant information for them to be analyzed in detail. For example, Forrester (1958) and Zymelman's (1965) studies were synthetic – a simulation ran on industry data. However, most of the cases are reflections of actual companies and the results of implementation of new policies. Where it was not explicitly mentioned if the company was lean, agile or traditional Narasimhan et al.'s (2006) variables were used to differentiate between manufacturing paradigms. Here, low performers were equated to Mass manufacturers. The cases were divided on the bases of purchasing and inventory policy, production methods, priorities (whether minimizing cost or customer service) into three categories: Traditional, lean and agile.

A significant weakness of this case analysis was the difference of external variables such as industry type, firm type, geographic location, demand patterns and size. In retrospect, these differences might give a deeper look into the demand amplification effect.

Primarily, the goal of the research is to conclude the effect of different manufacturing paradigms on the bullwhip effect. Going deeper, it aims to throw light on the causes of those differences. Unfortunately, only one case was discovered that covered agile manufacturing in detail. Below is a list of the cases included in the study (table 3).

Table 3. Case studies in analysis

Author	Industry	Number of Echelons	Manufacturing paradigm	Details
Forrester, 1958	Hard goods (simulation)	3	Traditional	Simulated
Zymelman, 1965	Cotton Textile	3	Traditional	Simulated
Hejazi & Hilmola, 2006.	Electronic supply chain	3	Traditional	Make-to-stock
Hammond, 1995	Barilla SpA, Pasta Supply Chain	3	Traditional	Inefficient Supply Chain
Taylor, 2000	Automotive Components	3	Lean	JIT and pricing policies, minimum stock.

Author	Industry	Number of Echelons	Manufacturing paradigm	Details
Kok et. al, 2005	Philips Electronics	3	Lean	-
Hejazi & Hilmola, 2006	Furniture Supply Chain	3	Lean	Assemble-to-order
Fransoo & Woulters, 2000	Food	3	Lean	Highly seasonal demand
McCullen & Towill, 2001	Mechanical Engineering Products	3	Agile	JIT, SMED, delivery time given most importance

2.1 CASE 1: Automotive Components (Taylor, 2000)

2.1.1 Discussion

The supply chain analyzed here was a 3-echelon chain. The automotive steel supply chain included a steel producer, two steel service centers, six component producers and many automobiles OEM (original equipment manufacturers). The figure below shows the supply chain with the companies involved (figure 7).

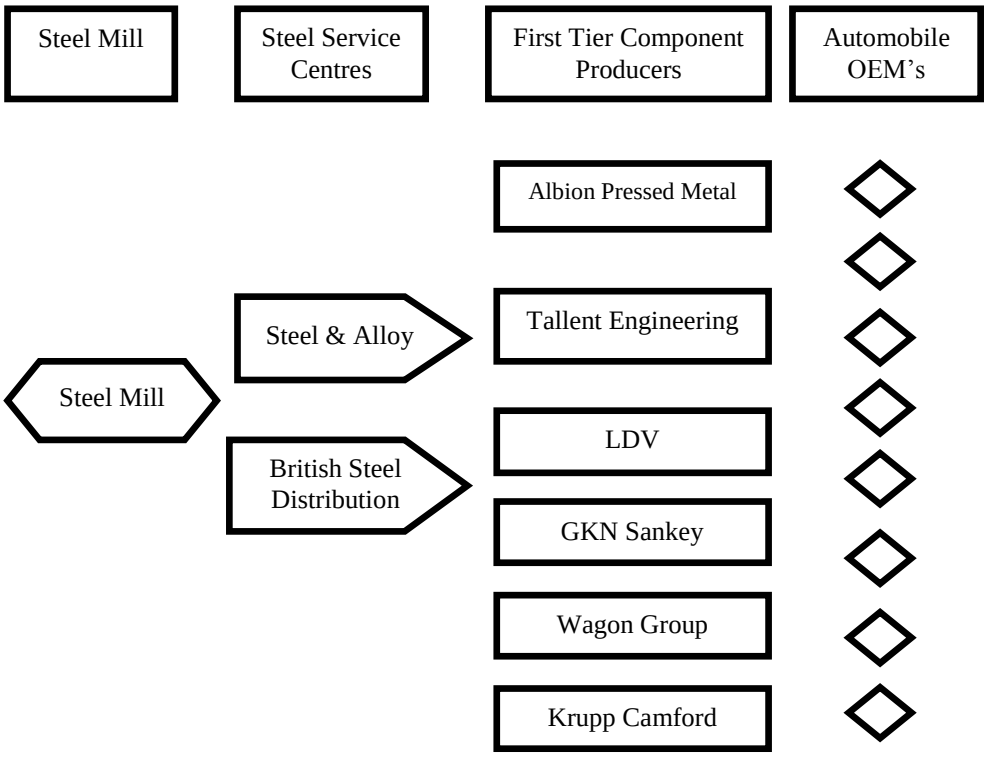

Figure 7. The Steel Automotive Supply Chain
Source: Taylor (2000)

A disaggregated approach to the measurement of demand amplification was used where individual products through the value stream were analyzed. This approach is more specific than mapping demand amplification across many product lines. The project was based on the demand of two high volume parts demanded by car manufacturers. To quantify demand amplification, demand and activity data were needed. Demand data was based on actual demand and forecasts, while activity data included production and dispatch activity gathered from various points in the value chain.

Figure 8 shows that the OEM demand is stable, however, as the bullwhip is transferred across the chain Service Centre Advanced Orders to Mill are greatly amplified. Some causes were identified for the bullwhip effect were demand variability, supply variability, functional silos and decision-making, stock minimization and J.I.T and pricing policy.

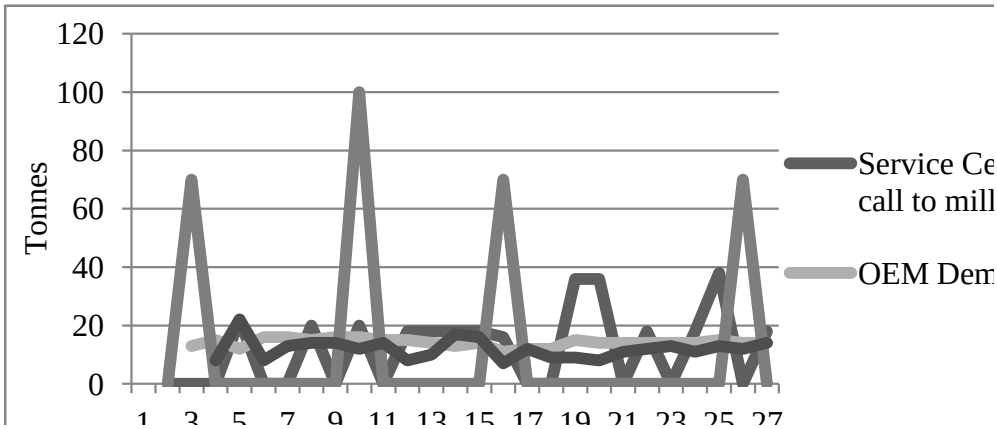

Figure 8. Variability along the whole chain
Source: Taylor (2000)

The paper then sought to educate personnel about the adverse effects of demand amplification. Then, a demand management team was formed. This team comprised of one person from each company. This was an effort to centralize decision making of demand across the supply chain so as to reduce the amplification of the bullwhip as stressed in the literature.

The demand management team after understanding the bullwhip made some decisions:

1. Weekly demand between the component manufacturer and the service center were set at the average demand from the OEM – 14 tonnes/week.
2. Weekly demand between the service center and steel mill was set at one coil/week for weeks.
3. Demand information from the OEM was shared directly with the component manufacturer, service center and steel mill through the demand management team.
4. Significant changes in the demand on OEM would be directly communicated through the demand management team.
5. Safety stocks were determined at different point along the chain
6. Bulk order prices were made available for smaller but regular batches.

2.1.2 Results

After implementation of, primarily, a central demand management team the fluctuations of mill dispatches have been significantly reduced, even when the OEM demand fluctuation is greater than in the last observation.

The OEM demand during the first ten weeks of the project remained at 13.5 tonnes/week as anticipated (figure 9). Demand regularization reduced any amplification that might have travelled along the chain. There was some unexpected variation in demand, which was coped by the system, because of the centralized decision making of demand. The figure above also shows the steady reduction in inventory after implementing the aforementioned. These findings encouraged the senior management to carry on with the study. The delivery from service center to component manufacturer improved to 100% on time delivery – an increase from 95%.

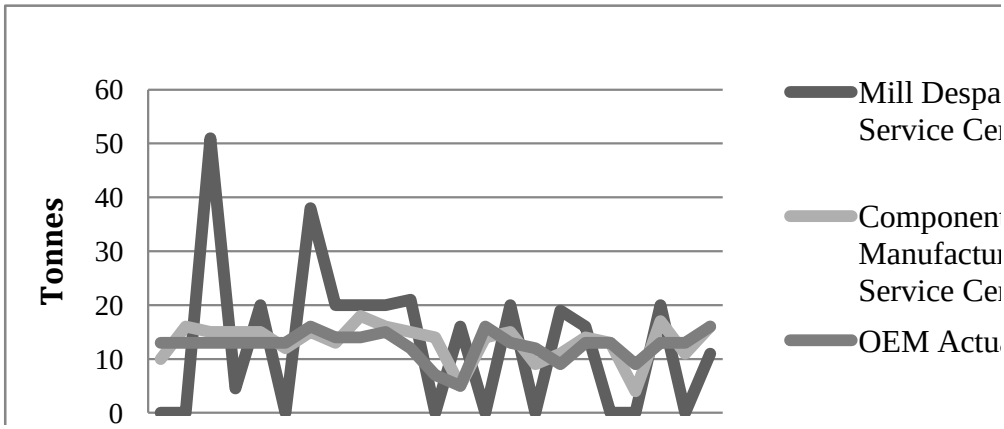

Figure 9. Actual demand and supply during the trial
Source: Taylor (2000)

Taylor noted that the demand fluctuation was dependent on decision of the amount to order from upstream suppliers and the previous order in queue. If less stock were ordered previously the decision to order extra inventory for the next period would be the initial trigger of amplification.

Managerial decision-making was on a functional basis whereby managers made logical decisions according to the best of their knowledge, however, these decision were beneficial for the company in question and not the whole supply chain. It was seen that these managers who decided inventory and production levels thought only about their own responsibilities and not the wider system. Thus, *unintended consequences* were realized elsewhere in the supply chain eventually resulting in the further amplification.

The implementation of a lean strategy throughout the supply chain reduced many small fluctuations. These fluctuations were damped primarily because of demand smoothing and a level scheduling policy.

Also, inventory levels were kept to a minimum as a lean policy stresses on minimum inventory and Just-in-time. It was seen that companies expected their suppliers to meet the variations in demand through JIT 'no matter how variable demand was'. In the steel supply chain, buffer stock was not kept in consideration of demand variability, these factors further amplified the demand. Furthermore, demand was also amplified as steel mills delivered a minimum order of up to 70 tonnes batches; however, the OEM demand was constant at 13.5 tonnes per week. Minimum inventory policy of the steel mill created unpredictable and haphazard demand.

The demand management team reduced Forrester's (1958) *information distortion* through the chain. The three steps that were implemented proved reduction in the demand amplification in 13 weeks. An increase in delivery reliability was also noted which was attributed to the decrease in demand variability. The project stated that even in a JIT system, safety or buffer stock acted to reduce the amplification.

2.2 CASE 2: Cotton Textile (Zymelman, 1965)

In this case study, Zymelman (1965) incorporated research from the cotton textile gray goods industry through actual prices, production, mill inventories, unfilled orders and personal interviews. Then, a stabilization policy was simulated and its effects documented.

The U.S. cotton gray goods industry at that time was in a market structure known as perfect competition, where there were many competitors involved in the market. The market was subject to periodic fluctuations. However, the negative effects of fluctuations were realized, such as, swing in workforce demand, prices and subsequently profits were noted. Zymelman (1965) proposed that collaboration between the industry actors would help stabilize these inconsistencies. The following diagram shows the supply chain layout and the number of firms involved.

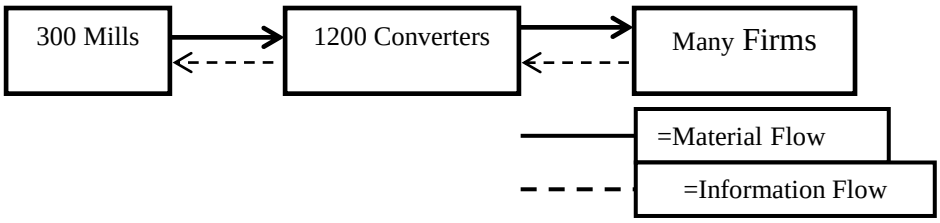

Figure 10. The cotton supply chain
Source: Zymelman (1965)

Mills produced cotton while converters process that into cut cotton cloth for the firms, which sew them into garments. It was noted that an accumulation of inventories at the mill significantly reduced the bargaining power of the mills, thus, converter companies were essentially price-takers. Converters companies based their buying decision on the demand for cotton cloth; the price expectations from the mills and the converter's inventory needs. It took three months for a producer to deliver an order to the converter and the producers delivered from a buffer stock as it took six month for a producer to process an order.

The simulation was run on an analog computer as flexibility and its timesaving properties were given an emphasis over accuracy and processing capacity of a digital computer. This research was based on analyzing a small variation in demand that resulted in fluctuations of inventory levels, production levels and prices. The trigger of amplification was an external variable i.e. the demand from cutter companies.

2.2.1Results

The simulation showed that the demand from cutters was not the only trigger of the fluctuations. Changes in unfilled orders and inventories were directly related to the level of fluctuations. Zymelman's (1965) study proposed that the decision of production at the mills should also be based on the ratio of unfilled orders to inventories. It was also discovered that inventories and unfilled orders were to be given more importance in order to reduce the fluctuations in inventories. Secondly, it was concluded that the companies should base decision-making on the ratio of unfilled orders to inventories.

In the LEAP program (automotive components) endogenous variables were also found to impact amplification. According to Zymelman, only variables that arose from outside the system (such as demand) caused fluctuations in inventory, production and prices.

2.3 CASE 3: Household Appliances (Forrester, 1958)

Jay Forrester ran a simulation on the household appliances industry. It was a mass manufacturing system with three tiers in the supply chain. This study was the first of its kind, giving breakthrough insights into the bullwhip effect in 1958.

Forrester identifies flows of information, materials, money, manpower, and capital equipment as amplifiers of fluctuations. In a mass production network, the demand amplification is greater than among lean network. The action suggested by Forrester were faster order handling, better forecasting of demand, and better sales data.

Figure 11 shows the effect of a sudden 10% increase in orders. Whereas the rise in order is 10% the subsequent rise in factory output is by 40%. Moreover, there is also a lag of several weeks. Figure 12 shows the effect of 10% increase in sales but with 'reasonably reliable sales data'. Here, the rise in orders only affects a rise of 16% in the factory output. This study stresses how better sales data could reduce the bullwhip effect.

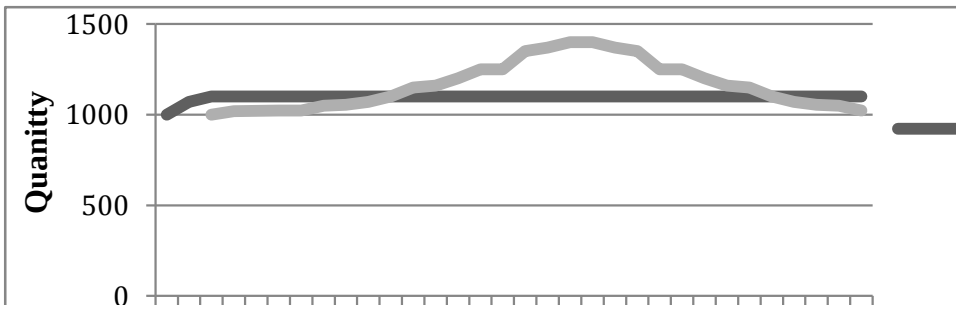

Figure 11. Response of production-distribution system to a sudden 10% increase in retail sales

Source: Forrester (1958)

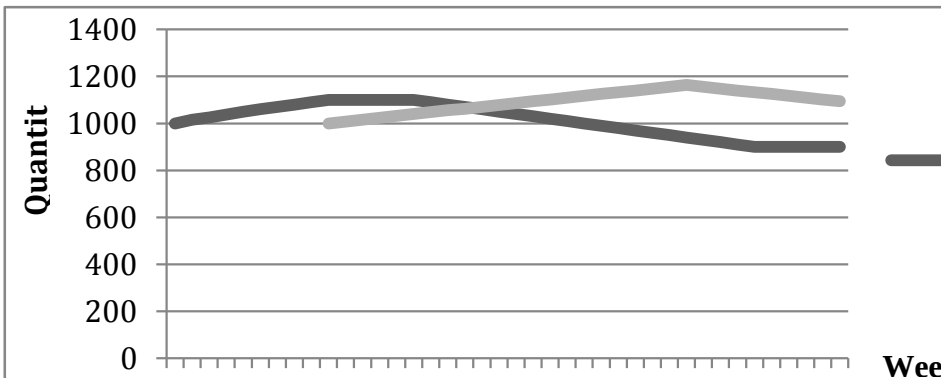

Figure 12. Orders and production output comparison
Source: Forrester (1958)

2.4 CASE 4: Electronics And Furniture (Hejazi & Hilmola, 2006)

The authors take into account two cases. The first is the analysis of the furniture supply chain in Finland. The furniture company utilizes a make-to-stock strategy. The second case is of an electronic manufacturer. However, this electronic manufacturer utilized an assemble-to-order type of policy. They followed a 'pull' demand management system, which can be categorized as lean. This difference among strategies also gives some variation of results and deeper insights into using a different manufacturing strategy.

These differences were because of the nature of the companies or supply chain. The electronic manufacturer had a high product variety while a lower volume, and the opposite was true for the furniture company, as shown in the diagram.

2.4.1 Furniture Supply Chain

The furniture company implemented a make-to-stock supply chain strategy in the local finish furniture industry. The have expanded aggressively in the past through Greenfield investments. In the year 2002, they had annual revenue of 43 million euros. The supply chain observed consisted one product family that included dressers, commodes and chests. This was a three tier supply chain comprising of manufacturer, distribution center and retailers (figure 13). Figure 14 displays existence of a seasonal pattern in demand. Figure 15 show a comparison of sales of retailers, purchase orders from distributor and deliveries from the manufacturer.

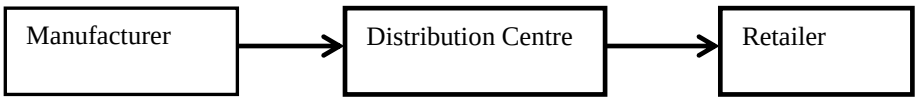

Figure 13. The furniture supply chain
Source: authors

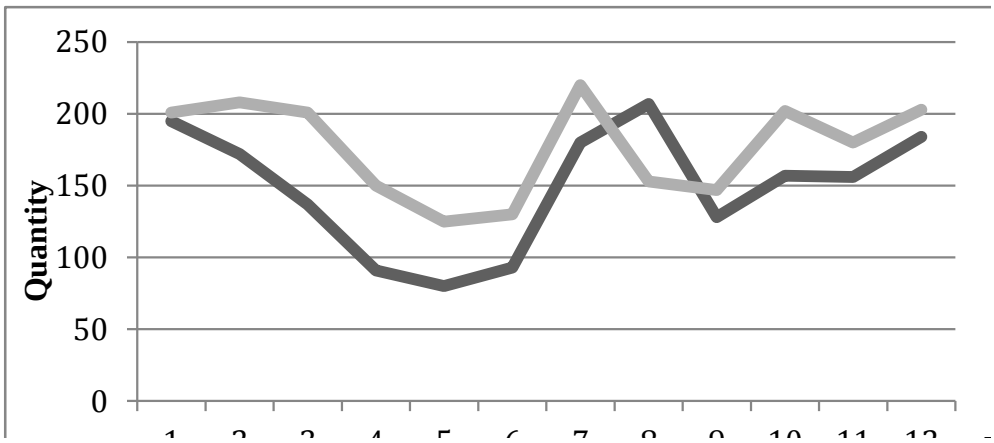

Figure 14. Seasonal demand pattern
Source: Hejazi & Hilmola (2006)

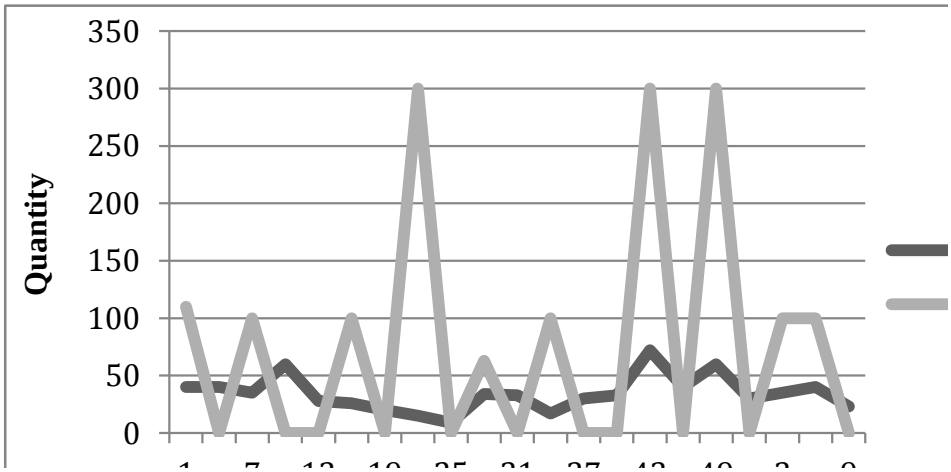

Figure 15. Sales and deliveries comparison
Source: Hejazi & Hilmola (2006)

Order batching was identified as the major cause of bullwhip effect in this company. The cause of order batching was the production lot sizes of the manufacturer; a minimum quantity of order was needed to produce. Another reason was long set-up times (of 15-45 minutes) when producing a different order. Manufacturing was also constrained by a bottleneck; the painting, varnishing and staining of products. Thus, manufacturing lot sizes were directly connected to the amplification of demand.

An implementation of a leaner policy would reduce set up times, which would mean smaller batches of production. Together, these two would increase the efficiency of production and decrease lead times.

2.4.2 Electronics Supply Chain

The electronics company is involved in assemble-to-order and is a part of a large international supply chain. Over the past, they have grown organically and in 2002 there annual revenue was at 54 million euros. It was a three-tier supply chain consisting of distributor, manufacturer and system integrator. The product chosen for the study was a platform used for transmitting cable signal. The demand mostly was regular but there were times of erratic demand (figure 16). Figure 17 shows the demand versus time. Again, there is a seasonal fluctuation in demand. Figure 18 shows the existence of demand amplification across the chain.

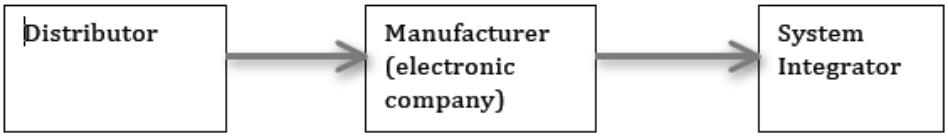

Figure 16. Electronics supply chain
Source: Hejazi & Hilmola (2006)

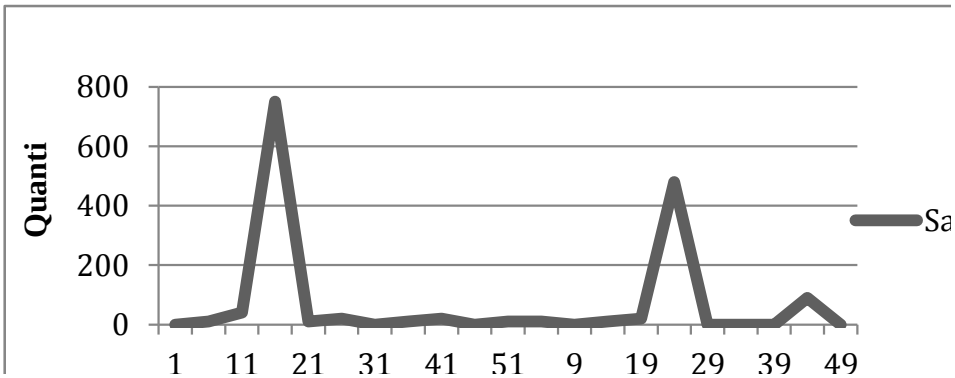

Figure 17. Sales orders for optical node
Source: Hejazi & Hilmola (2006)

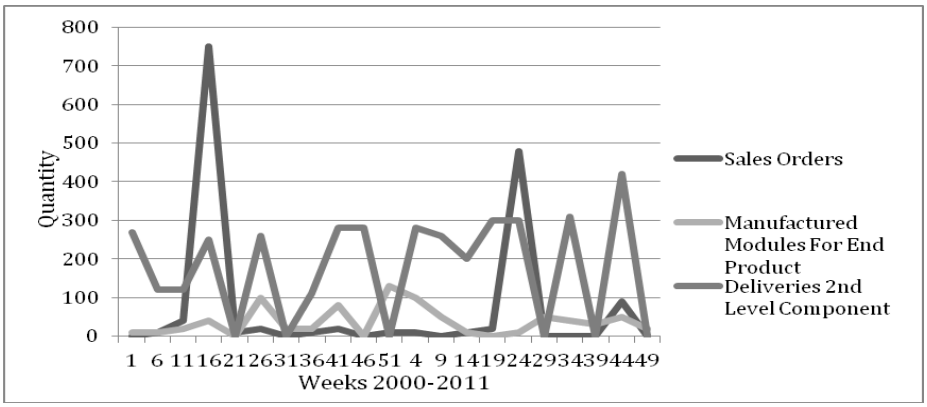

Figure 18. Three tier demand comparison
Source: Hejazi & Hilmola (2006)

Two facts can be concluded from the above graph; first, the difference order quantity and production quantity, and second, the difference between order and supply quantity. Note the difference of intensity and time lag between demand and manufacturing.

2.4.3 Discussion

Both of these companies were evolving towards becoming a fully lean approach based firms. However, as the electronics company follows an assemble-to-order production it has evolved more towards becoming lean comparatively, as assemble-to-order policy reflects a pull system.

The furniture company is relatively less lean as it follows a make-to-stock. Also constraints and bottlenecks also limited the productive capacity of furniture business. There is a clear difference among bullwhip of the two companies, which is attributable to the degree they have evolved at being lean.

The authors claim that production lot sizes and transfer batches were *partly* able to reduce the bullwhip. They identify order batching (size of manufacturing batches) as the main cause of amplification. They also discovered that there was a difference between production quantity, order quantity and supply quantity. These variables combined to contribute to the bullwhip. Orders were received in large quantities while deliveries were made in smaller batches. In both cases, thus, order batching, was the major cause of amplification for the upstream of the supply chain. VMI (vendor managed inventory) was proposed as the solution for the furniture company. It was also suggested reducing set up times and delivering products in more frequent and smaller batches would reduce the effect for the electronics chain.

2.5 CASE 5: Glosuch Supply Chain (McCullen & Towill, 2001)

McCullen and Towill (2001) incorporate both experiential and simulation techniques to study the bullwhip effect in the precision mechanical engineering industry. They analyze Glosuch supply chain's six years time-series data to evaluate pattern in demand and supply through the chain.
This supply chain consists of three echelons comprising of a U.K. factory, a U.K. finished goods warehouse and a number of overseas warehouses (figure 19).

Figure 19. The glosuch supply chain
Source: McCullen & Towill (2001)

Firms in the study implemented Total Quality Management (TQM), partnering across the supply chain, Single Minute Exchange of Dies (SMED), small and more frequent delivery batches, and JIT production. Trucks picked supplies from docks every hour and delivered to customer's plants. However, even in such a time-sensitive supply chain manufacturer's excess capacity was to blame subsequent amplifications. The entire chain is forecast driven and all echelons have there own decision-making.

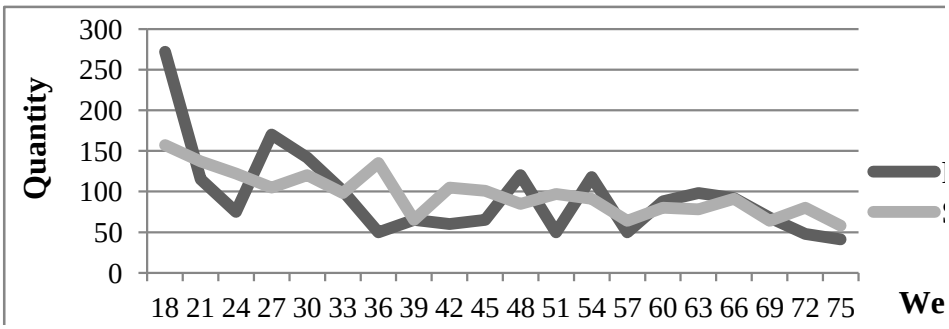

Figure 20. Production and sales comparison
Source: McCullen & Towill (2001)

An analysis of the original Glosuch supply chain revealed that overseas subsidiaries greatly exaggerated demand and safety stock were depleted because of such demand. After experiencing amplification because of greatly magnified sudden demand by foreign subsidiaries it was decided to implement an agile strategy. The company implemented a rapid response manufacturing program and information system integration through the supply chain.

The effect of implementing this agile strategy was reflected in the reduction of information and material processing lead-time from 23 weeks to 2 weeks. Evidently, a migration from lean to agile policy reduced lead times by 91%. As part of the study, three inquiries were made: Was there a bullwhip effect in the Glosuch original supply, was it reduced by implementing an agile strategy and does agility reduce variability?

Figure 20 shows how bullwhip was reduced in the original supply chain and reduced to a greater degree after implementing an agile strategy. The graph also shows steady reduction in variability as Glosuch climbs the learning curve. An average bullwhip reduction of 36% was realized in two echelons and in a period of four years global inventory was reduced by 45%. Thus, rapid response manufacturing and information system integration had achieved the results that were predicted in literature.The figure shows the graph of both production and sales. It is clearly evident how amplification is slowly reducing with time as the system learns. Table 4 shows the eventual reduction in Glosuch's global inventory. In year 4, there is a total reduction of 45% which is almost half.

The authors attempt to implement an approach that eliminates the initial trigger of amplification at the source. Their solutions were highly effective. It also shows that the greatest improvement in terms of bullwhip reduction is when a company evolves from lean to agile.

Table 4. Reduction in global inventory

	Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Weeks	31	26	22	20	17
Difference of Stock	-	-5	-4	-2	-3
Total % change	-	-17%	-29%	-35%	-45%

Source: McCullen & Towill (2001)

2.6 CASE 6: Food (Fransoo & Wouters, 2000)

Two three-tier supply chains were analyzed in a lean environment; one was meals product and the other salads. In this study, the author tested whether the use of real time EPOS data by the manufacturer would make an impact on the bullwhip effect. Daily demand for both of the supply chain was analyzed for 72 days. The main factors of demand variability were promotional activities, price fluctuations and weather patterns. The weather factor was especially evident in salads. Figure 21 shows the supply chain. Table 5 shows the amplification ratios of both the supply chains. The results show that there is greater amplification in supply chain of greater fluctuating demand

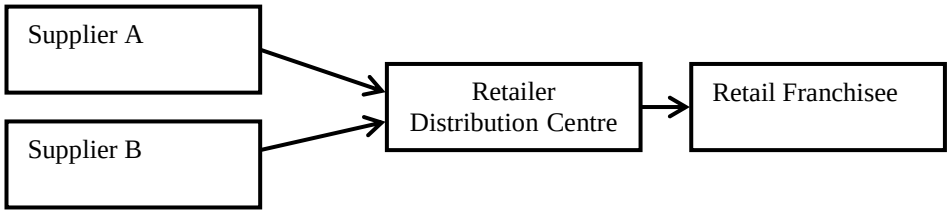

Figure 21. The food supply chain
Source: Fransoo & Wouters (2000)

2.6.1 Results

According to Table 5, the bullwhip effect in salads is far more than in meals this is due to sudden increases in temperature, which affected the demand for salads. Authors claimed EPOS (electronic point-of-sale) information to the supply would reduce the bullwhip. Another variable that could stabilize demand was a more stable production. The sharing of EPOS data signifies to an extent the sharing of real-time demand information, which, in effect reduces the information distortion

Table 5. Amplification ratios in salad and meals supply chain

Echelons	Bullwhip Effect meals	Bullwhip Effect Salads
Production	1.75	1.23
Distribution Center	1.26	2.73
Retail Franchisee	1.67	2.09

Source: Fransoo & Wouters (2000)

2.7 CASE 7: Philips Electronics (Kok et al, 2005)

In 1999, Philips Semiconductor and Philips Optical Storage formally studied the bullwhip effect in their supply chain. These companies operate under Philips Electronics, a global consumer electronics manufacturer. This study highlights the actions and results of the attempt made by Philips to reduce demand amplification. Increased fluctuations were observed in Philips Semiconductor, which was a supplier of Philips Optical Storage. Collaborative Planning Project was undertaken with the objective of reducing fluctuations. The process of wafer-fabrication was identified as a bottleneck.

The Collaborative-Planning (CP) Project was implemented with the ultimate aim of reducing the bullwhip. It centralized decision-making of production and deliveries to the CP staff. The figure 22 shows the reduction of the ratio between on-hand stock and work-in-process from 70% to 30%. The results of centralizing decision-making were overall stock reduction, reduction of obsolescence and increased agility in the chain. Financially, these reflected as a 1.5% increment of profit. Furthermore, they freed a capital of $5 million that could be used to fulfill working capital requirements. These results support the fact that central demand management greatly diminishes the bullwhip.

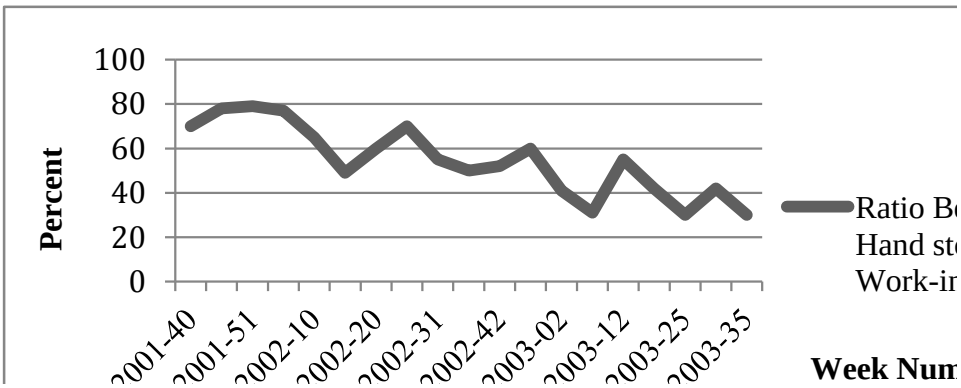

Figure 22. Ratio between on-hand stock and work-in-process
Source: Kok et al. (2005)

2.8 CASE 8: Barilla Spa (Hammond, 1994)

Barilla Spa is a pasta company in Italy. After inefficacies in the supply chain a JIT program was applied to its supply chain in collaboration with the company's distributor, Cortese. A pilot implementation of JITD (Just-In-Time Distribution), between Barilla and its distributors reduced the stock-out rate from 5% to less than 1%. This was achieved through daily demand information sharing through fax or the Internet. After this success, a full JITD program was implemented. Below is a graph of the reduction in stock after implementation of the JITD. The co-ordinates for the following two graphs were not available. Therefore, it was taken as it is from the case (figure 23). There was also an obvious reduction in percentage stock outs from 7% to virtually none. This improvement is a direct effect of JIT distribution, which makes stock management more efficient. Figure 24 shows the bullwhip reduction before and after the implementation of the new policy.

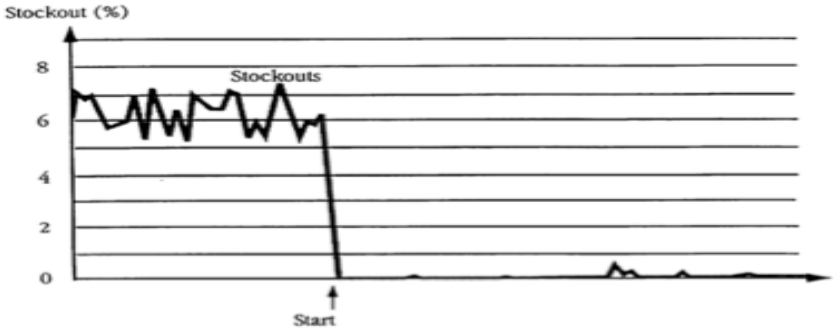

Figure 23. Stock out rate from marchese DC to retailers, before and after the start of JIT
Source: Hammond (1994)

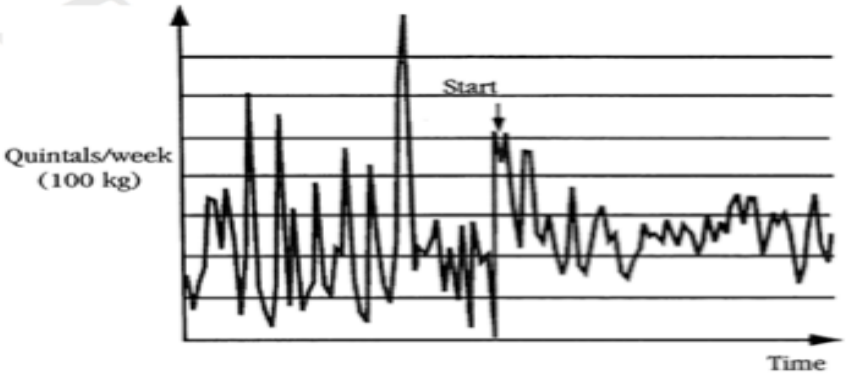

Figure 24. Bullwhip reduction in barilla supply chain
Source: Hammond (1994)

Not only did these improvements effected efficiency but there was also a rise in customer service noticed, as orders were delivered on schedule. Small and more frequent deliveries also influenced the reduction of amplification. As the paper showed promising results, Barilla plans to incorporate the JIT distribution in their manufacturing processes.

3. RECOMMENDATIONS

In pursuing the reduction of demand amplification, the companies in the supply chain should be thoroughly analyzed. This is because demand amplification can result from a multitude of factors. Then, all that information should be synthesized by the use of techniques such as rich-picture mapping, cause-and-effect diagrams, input-output diagrams and value chain analysis among others. This step is necessary to view the supply chain as a system. This is because bullwhip is fundamentally a systemic phenomenon and it can only be realized if the whole system is scrutinized. Subsequently, the supply chain members need to collaborate to counter this phenomenon by relevant measures along the chain. The study has expressed that a reduction and near elimination is possible. It, however, also depends on the strategic priorities of all companies in the supply chain. Every firm is in a stage where it has to start by treating one of the causes of bullwhip. That option is the major amplifier of demand. The company should then implement policies step by step to diminish the bullwhip altogether.

McCullen and Towill (2001) recommend firms to implement their four principles in order to systemically address all the root causes of the bullwhip effect. These principles were so effective that Geary et al.'s (2006) solution were a derivative of these.

CONCLUSION

After a brief look at table 6, the effectiveness of central demand management is evident. This is because centrally managing demand targets three root causes of amplification – namely, information delay, demand forecast updating and, rationing and shortage gaming. Fluctuations amplify, as the upstream member of the supply chain is not aware of the actual end-consumer demand, however, sharing demand data diminishes such possibility. Thus, central demand management has been identified as the major solution to the bullwhip effect with a high certainty of dampening the effect.

Table 6. Analysis of the cases

Author	Industry	Manufac-turing Paradigm	Cause	Solution	Improvement/ Results
Zymelman, 1965	Cotton Textile (simulation)	Traditional	Volatile demand, inefficient inventory policy, speculation of demand	Production schedule should be based on the ratio of unfilled orders over inventory	Reduction in fluctuation after applying solution to the model
Forrester, 1958	Hard goods (simulation)	Traditional	Simulation with changes in variables such as reliability of sales data	More reliable sales data, better order handling,	Decrease of factory production variation from 40% to 16%, thus amplification reduced
Hejazi & Hilmola, 2006.	Electronic supply chain	Traditional	Large single purchase quantities set by the distributor	Combined purchases, Sales order not equal to manufacturing lot size	Prevented amplification' and 'Partly avoided the bullwhip' (Hejazi & Hilmola, 2006)
Hammond, 1994	Pasta Supply Chain	Traditional	General inefficiencies in the supply chain	JIT Distribution, flexible delivery load, advanced demand management and marketing integration,	Reduction in stock outs from 6% to near 0%. 46.7% decrease in inventory at Marchese DC. Significant reduction in bullwhip.
Fransoo & Woulters, 2000	Food	Lean	Rationing and shortage gaming.	Shared EPOS (electronic point-of-sale) information	Results not published
Hejazi & Hilmola, 2006	Furniture Supply Chain	Lean	Order Batching: Large manufacturing lot sizes of the upstream member	Shorter set-up times, Vendor Managed Inventory	'Prevented amplification' and 'Partly avoided the bullwhip' (Hejazi & Hilmola, 2006)
Kok et al, 2005	Electronics (Philips)	Lean	Long lead times, wafer-fabrication as a bottleneck, shortening product life cycles and volatile demand,	Inter-organizational collaboration in demand management	Overall stock reduction, reduction of obsolescence and increased agility. 1.5% increases in profit. 40% decrease in ratio between on-hand stock and work-in-process.

Author	Industry	Manufac-turing Paradigm	Cause	Solution	Improvement/ Results
Taylor, 2000	Automotive Components	Lean	Functional silo decision-making, JIT expectations from the next upstream partner, pricing policy, minimum order size.	Central demand management team, removal of price policy on small but regular orders, regular schedules	Obvious reduction in amplification, better customer service, decrease in inventory levels
McCullen & Towill, 2001	Mechanical Engineering Products	Agile	Safe stock depletion, order exaggerations, unresponsive supply chain (lead time=23 weeks)	Pull system introduced, partnership arrangements, planning cycle changed from monthly to daily	Reduction of lead-time by 91%. Average bullwhip reduction of 36%. 45% reduction in global inventory in 4 years.

In conclusion, this report proposes that collaboration between supply chain members as a necessary ingredient in the fight against demand amplification. Collaboration among members of the supply chain also reduces the effect as more steps are taken in order to think about the whole system rather than one company. Collaboration has been identified as a major counter-measure for it treats most of the problems simultaneously by facilitating information exchange. The functional silo decision-making concept is thus becoming extinct as companies realize the potential of holistic thinking.

Also, bullwhips that are caused by order batching can only be *partly reduced* by measures such as small but regularized deliveries and vendor-managed inventory.

The delivery policies were also a major cause for inducing bullwhip. For example, in the automotive supply chain (Taylor, 2000) minimum batches sizes for order were identified as main cause. This was countered by an agreement where 'smaller but more regularized' order would be delivered at the same cost (Taylor, 2000).

In terms of the bullwhip, there is a continuum upon which manufacturing paradigms have evolved. This has largely been a result of the change in the macro-environment. Table 6 shows the how *natural selection* has made traditional manufacturing rare because of a general focus towards efficiency and market responsiveness.

As agile and lean developed after the identification of the demand amplification, they are better equipped to deal with demand amplification. Lean philosophy stresses efficiency and cost effectiveness; JIT distribution and SMED methods enable companies to respond to fluctuations in demand much better as compared to traditional production (table 7).

Table 7. Evolution of bullwhip

Environmental Factors	Industrialization and Post-War Reconstruction	Free Market Economy And Cut Throat Competition	Faster Economic Cycles and Shorter New Product Development/ Product life cycles
Manufacturing Paradigm Continuum	Traditional	Lean	Agile
Primary Focus	▪ Make product available to wider public ▪ Price reduction based on economies of scale	▪ Cost Efficiency ▪ Reliability	▪ Market Responsiveness ▪ Customer Satisfaction
Affect on Bullwhip	Demand amplification identified	▪ Reduction in the bullwhip effect	Near total reduction.

Agile goes a step further; the main focus of agility is market responsiveness. This means that agile supply chain is quickly able to respond to changes in the marketplace. For instance, fashion clothing industry is uncertain demand with new fashions coming every few months. For such companies the primary aim is to the get product to the customer as soon as possible. In such a case, agile manufacturing is the best possible solution. However, there is a trade-off of going from lean to agile – higher costs.

It is stressed that there is a need for further research on fast and agile supply chains in order to understand, in greater depth, how agility counters the bullwhip, and to codify the methods that are more effective in dealing with the bullwhip across supply chain.

References

Allen, D.S. (1997). Do inventories moderate fluctuations in output? *Federal Reserve Bank of St. Louis Rev. 79* (4), 39–50.

Anderson, E., Fine, C., & Parker. G. (2000). Upstream volatility in the supply chain: The machine tool industry as a case study. *Journal of Production and Operations Management*, *9*(3) 239-261.

Andraski, J.C. (1994). Foundations for a successful continuous replenishment programme. *International Journal of Logistics Management, 5* (1), 1–8.

Avery, C.N., Lariviere, M.A., & Harrison, J.M. (1993). *Case S-OIT-IC at the Raychem Corporatio*n, Graduate School of Business, Stanford University, CA.

Batchelor, R. (1994). *Henry Ford, mass production, modernism and design*. Manchester: Manchester University Press.

Blackburn, J.D. (1991). *Time-Based Competition: How time based competition is reshaping global markets.* BusinessOne Irwin, Homewood

Blanchard, O.J. (1983). The production and inventory behavior of the American automobile industry. *Journal of Political Economy*, *91*(3) 365–400.

Blinder, A. (1981). Retail inventory investment and business fluctuation. *Brookings Papers on Economic Activity*, *2*, 443-505.

Blinder, A. (1986). Can the production smoothing model of inventory behavior be saved? *Quarterly Journal of Economics*, 101(3), 431-53.

Burbidge, J.L. (1991). Period batch control (PBC) with GT – the way forward from MRP, *Paper presented at the BPCIS Annual Conference*, Birmingham.

Cachon, T., Randall, G., & Schmidt, G.M. 2007. In search of the bullwhip effect. *Journal of Manufacturing & Service Operations Management*, *9*(4) 457–479.

Chase, R.B., Aquilano, N.J., & Jacobs, F.R. (2001). *Operations Management for Competitive Advantage*. McGraw Hill/Irwin: Boston

Chen, F., Drezner, Z., Ryan, J.K., & Simchi-Levi, D. (2000). Quantifying the Bullwhip Effect in a simple suly chain: The impact of forecasting, lead times and information. *Journal of Management Science*, *46*(3), 436–443.

Christopher, M., (2000). The Agile Suly Chain: Competing in Volatile Markets. *Journal of Industrial Marketing Management*, *29*(1), 37-44.

De Kok, T., Janssen, F., van Doremalen, J., van Wachem, E., Clerkx, M., & Peeters, W. (2005). Philips Electronics synchronizes its suly chain to end the bullwhip effect. *Interfaces*, *35*(1), 37–48.

Duguay, C. R., Landry, S., & Pasin, F. (1997). From mass production to flexible/agile production. *International Journal of Operations and Production Management*, *17*(12), 1183-1195.

Duguay, C., Landry, S., & Pasin, F. (1997). From mass production to flexible/agile production, *International Journal of Operations and Production Management*, *17*(12), 1183-1195.

Dyer, J. (1994). Dedicated Assets: Japan's Manufacturing Edge, *Harvard Business Review*, *72* November/December

El-Beheiry, M., Wong, C.Y. and El-Kharbotly, A., (2004). Empirical quantification of bullwhip effect (with application to a supply chain). *Proceedings 13th Working Seminar on Production Economics*, IGLS, vol. 3, 83–95.

Emery, F., & Trist, E. (1965). The causal texture of organizational environments. *Journal of Human Relations*, *18*, 21- 32.

Fair, R.C. (1989). The production-smoothing model is alive and well. *Journal of Monetary Economics*. *24*, 353–370.

Fisher, M. (1994). *National Bicycle*. The Wharton School Case, Philadelphia, PA.

Fisher, M. (1997). What is the right supply chain for your product? *Harvard Business Review*, March/April, 105–116.

Ford, H. (1923). *My Life and Work*. Garden City, NY: Garden City Publishing Company.

Forrester, J. (1961). *Industrial Dynamics*. MIT Press and John Wiley & Sons: New York.

Forrester, J. W. (1980). System Dynamics -- Future Opportunities. 7-21. In: Augusto A. Legasto, Jay W. Forrester, and James M. Lyneis, eds. System Dynamics. TIMS Series in the Management Sciences, *14*. Amsterdam: North Holland.

Fransoo, J.C., & Wouters, M.J.F. (2000). Measuring the Bullwhip Effect in the supply chain. *Supply Chain Management: An International Journal*, *5*(2), 78–89.

Geary, S., Disney, S.M., & Towill, D.R. (2006). On Bullwhip in Supply Chains historical review, present practice and expected future impact. *International Journal of Production Economics. 101*(1), 2-18.

Ghali, M., (1987). Seasonality, aggregation and the testing of the production-smoothing hypothesis. *American Economic Review*. 77(3). . 464-469

Gill, P. & Abend, J. (1996). Wal-Mart: the supply chain heavyweight champ, *Supply Chain Management Review*, *1*, 8-16.

Gunasekaran, A. (1998). Agile Manufacturing: enablers and an implementation framework. *International Journal Of Production Research*, *36*(5), 1223-1247.

Hammond, J. (1990). *Quick Response in the Apparel Industry*. Harvard Business School Case: Cambridge, MA.

Hammond, J. (1994). Barilla SpA (a). Harvard Business School case #9-694-046.

Hejazi, A., & Hilmola, O. (2004). Manufacturing lot sizing as a source of Bullwhip Effect—case study of electronics and furniture supply chains, *Proceedings of the Thirteenth Working Seminar on Production Economics*, *4*, 125-140.

Hines, P., Holweg, M., & Rich, N. (2004). Learning to evolve: A review of contemporary lean thinking, *International Journal of Operations & Production Management*, *24*(10), 994 – 1011.

Holmstrom, J. (1997). Product range management: A case study of supply chain operations in the European grocery industry. *International Journal of Supply Chain Management*, *2*(8), 107–115.

Hounshell, D. A. (1984). *From the American system to mass production*. Baltimore: The John Hopkins University Press.

Hout, T., & Stalk, G. (1990). How time-based management measures performance, *Strategy & Leadership*, *18*(6), 26-29.

Knill, B. (1999). How lean manufacturing matchs todays business. *Material Handling Engineering.* October, 87-91.

Kondratieff, N.D. (1984). *The Long Wave Cycle*. Richardson and Snyder: New York.

Kurt Salmon Associates. (1993). ECR: Enhancing the Consumer Value in the Grocery Industry. Food Marketing Institute: Washington.

Lacey, R. (1986). Ford: The men and the machine. Little Brown & Co.: n/a

Lee, H.L., Padmanabhan, V., & Whang, S. (1997a). Information distortion in a supply chain: the bullwhip effect. *Journal of Management Science*. 43(4), 546–558.

Lee, H.L., Padmanabhan, V., & Whang, S. (1997b). The bullwhip effect in supply chains. *Sloan Management Review*, *38*(4), 93–102.

Lee, H.L., Padmanabhan, V., & Whang, S. (1995). The Paralyzing curse of Bullwhip Effect in a Supply Chain. *Stanford University*, March 17th

Lee, H.L., So, K.C., & Tang, C.S. (2000). The value of information sharing in a two-level supply chain. *Journal Of Management Science*, *46*(5), 626–643.

Mason-Jones, R., Naylor, B., & Towill, D. (2000). Lean, agile or leagile? Matching your supply chain to the marketplace. *International Journal of Production Research*, *38*(17), 4061-4070.

McCullen, P., & Towill, D. (2001). Practical ways of reducing bullwhip: the case of the Glosuch global supply chain. *Control*, December/January, 24–30.

Metters, R. (1997). Quantifying the bullwhip effect in supply chains. *Journal of Operations Management*, *15*(2), 89–100.

Miragliotta, G. (2006). Layers and mechanisms: A new taxonomy for the Bullwhip Effect. *International Journal Production Economics*, *104* (2), 365–381.

Mitchell, T. (1923). Competitive illusion as a cause of business cycles. Quarterly Journal of Economics, *38*(4), 631–652.

Monden, Y. (1983). *Toyota Production System.* Atlanta, Ga: Institute of Industrial Engineers.

Motwani, J. (2003). A business process change framework for examining lean manufacturing: A case. *Industrial Management and Data Systems*, *103* (5/6), 339.

Nagel, R.N., & Dove, R. (1992). *21st Century Manufacturing Enterprise Strategy*, Iacocca Institute, Lehigh University, Bethlehem, PA.

Narasimhan, R., Swink, M., & Kim, S.W. (2006). Disentangling leanness and agility: An empirical investigation. *Journal of Operations Management*, *24*(5), 440-445

Nienhaus, J., Ziegenbein, A., & Schönsleben, P. (2006). How human behaviour amplifies the bullwhip effect—A study based on the beer distribution game online, *Journal of Production, Planning & Control*, *17*(6), 547–557.

Ohno, T. (1988). *Toyota Production System – Beyond Large-scale Production*. Productivity Press: New York.

Oleson, J. (1998). *Pathways to agility: Mass customization in action*. John Wiley & Sons: New York.

Parkinson, S. (1999). Agile manufacturing, *Work Study*, *48*(4), 134-137.

Pietrykowski, B. (1995). Fordism at Ford: Spatial Decentralization and Labor Segmentation at the Ford Motor Company. *Journal of Economic Geography*, *71*(4), 383-401.

Raff, D., & Tajtenberg, M. (1996). Quality-adjusted prices for the American automobile industry: (1906-1940). In: Bresnahan, T., & Gordon, R. (1996). *The Economics of New Goods*. University of Chicago Press: Chicago, Ch: 2.

Ramesh, G., & Devadasan, S.R. (2007). Literature review on the agile manufacturing criteria. *Journal of Manufacturing Technology Management*, *18*(2), 182-201.

Rudberg, M., & Olhager, J. (2003). Manufacturing Networks and Supply Chains: An Operations Strategy Perspective. *Omega: The International Journal of Management Science*, *31*(1), 29-39.

Sarkis, J. (2001). Benchmarking for agility, *Benchmarking. An International Journal*, *8*(2), 88-107.

Senge, P.M., & Sterman, J.D. (1992). System thinking and organisational learning: Acting locally and thinking globally in the organisation of the future. *European Journal of Operational Research*, *59*(1), 137–145.

Stalk, G.H., & Hout, T.M. (1990). *Competing Against Time, How Time Based Competition is Reshaping Global Markets*. Free Press: New York.

Sterman, J.D. (1986). The Economic Long Wave, Theory and Evidence. *Systems Dynamics Review*, *2* (Summer), 87–125.

Sterman, J.D. (1989). Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. *Journal of Management Science*, 35(3), 321–339.

Taylor, D.H. (1999). Measurement and analysis of demand amplification across the suly chain. *International Journal of Logistics Management*, *10*(2), 55–70.

Tayler, D.H. (2000). Demand Amplification: has it got us beat? *International Journal of Physical Distribution and Logistics Management*, *30*(6), 515-533.

Towill, D.R. (1982). Dynamic analysis of an inventory and order based production control system. *International Journal of Production Research*, *20*(6), 671–687.

Wikner, J., Naim, M.M., & Towill, D.R. (1992). The system simplification approach in understanding the dynamic behaviour of a manufacturing supply chain. *Journal of Systems Engineering*, *2*(2), 164–178.

Wikner, J., Towill, D.R. & Naim, M. (1991). Smoothing supply chain dynamics. *International Journal of Production Economics*, *22*(3), 231–248.

Yauch, C. (2011). Measuring Agility as a Performance Outcome. *Journal of Manufacturing Technology Management*, *22*(3), 384-404.

Zymelman, M. (1965). A Stabilization Policy For Cotton Textile Cycle, *Journal of Management Science*, *11*(5), 572-580.