Bullwhip Effect In The Supply Chain: A Danger

* Debomalya Ghose

*Assistant Professor, Department of Business Administration, Assam University, Silchar-788011, Assam.
Email: debomalyaghose@gmail.com

Abstract:

We live in the "Information age". Data Warehouses, Web services, XML, Wireless, the Internet and Portals are just a few technologies dominating the business page of the daily newspaper. Distorted information from one end of a supply chain to the other can lead to tremendous inefficiencies: excessive investment in inventory, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and missed production schedule. And thus causes the Bull Whip Effect. The bullwhip effect is the magnification of demand fluctuations, not the magnification of demand. The bullwhip effect is evident in a supply chain when demand increases and decreases. The effect is that these increases and decreases are exaggerated up the supply chain. The essence of the bullwhip effect is that orders to suppliers tend to have larger variance than sales to the buyer. The more chains in the supply chain the more complex this issue becomes. This distortion of demand is amplified the farther demand is passed up the supply chain. Here in this paper it is explained with the help of some cases and it has shown that how the information causes the variability on the order.

Key Words: Supply Chain, Demand Fluctuation, Bullwhip Effect, Production Rate Variability, Stock Level Variability

1. Introduction

Fierce competition in today's global markets, the introduction of products with shorter life cycles, and the heightened expectations of customers have forced business enterprises to invest in, and focus attention on, their supply chains. The idea is to apply a total systems approach to managing the entire flow of information, materials, and services from raw materials suppliers through factories and warehouses to the end customer (Chase & Aquilano 2009: 102-103).A supply chain, logistics network, or supply network is a coordinated system of organizations, people, activities, information and resources involved in moving a product or service in physical or virtual manner from supplier to customer. Supply chains link value chains.[1]

Today, the ever increasing technical complexity of standard consumer goods, combined with the ever increasing size and depth of the global market has meant that the link between consumer and vendor is usually only the final link in a long and complex chain or network of exchanges (Gilbert & Ballou 1999: 61-73) . Although many companies and corporations today are of importance not just on national but also on global scale, none are of a size that enables them to control the entire supply chain, since no existing company controls every link from raw material extraction to consumer (Rudberg & Olhager 2003: 29-39).

The rest of this paper is organized as follows: first it provides a description of the Bullwhip Effect, how it became aware, a brief literature review of research work, main factors contributing to the Effect and its consequences. next some selected cases of simple supply chain models and the variability of production rates and stocks are presented. Then it describes actions against the Bullwhip Effect. Finally, conclusions are given.

1, See, Nagurney, A. (2006). Supply chain network economics: dynamics of prices, flows, and profits, Edward Elgar Publishing, Cheltenham

2. Bull Whip Effect

In examining the demand for Pampers disposable diapers, executives at Procter & Gamble noticed an interesting phenomenon. As expected, retail sales of the product were fairly uniform; there is no particular day or month in which the demand is significantly higher or lower than any other. However, the executives noticed that distributors' orders placed to the factory fluctuated much more than retail sales. In addition, P&G's orders to its suppliers fluctuated even more. This increase in variability as we travel up in the supply chain is referred to as the bullwhip effect. The effect indicates a lack of synchronization among supply chain members. Even a slight change in customer sales ripples backward in the form of amplified oscillations upstream, resembling the result of a flick of a bullwhip handle. Because the supply patterns do not match the demand patterns, inventory accumulates at various stages (Fig. 1).

The concept has its roots in Forrester's Industrial Dynamics. [2] Because customer demand is rarely perfectly stable, businesses must forecast demand in order to properly position inventory and other resources (Simchi-Levi & Kaminsky 2009: 159-163). Variability coupled with time delays in the transmission of information up the supply chain and time delays in manufacturing and shipping goods down the supply chain create the Bullwhip Effect (Lee & Padmanabhan 1997: 546-558). Forecasts are based on statistics, and they are rarely perfectly accurate. Because forecast errors are a given, companies often carry an inventory buffer called "safety stock". Moving up the supply chain from end-consumer to raw materials supplier, each supply chain participant has greater observed variation in demand and thus greater need for safety stock. In periods of rising demand, down-stream participants will increase their orders. In periods of falling demand, orders will fall or stop in order to reduce inventory (Baganha & Cohen 1998: 72-83) . The effect is that variations are amplified as one moves upstream in the supply chain (further from the customer) (Metters 1997: 89-100). Bullwhip Effect is also attributed to the separate ownership of different stages of the supply chain. Each stage in such a structured supply chain tries to amplify the profit of the respective stages, thereby decreasing the overall profitability of the supply chain .

Factors contributing to the Bullwhip Effect: forecast errors, overreaction to backlogs, lead time (of information – orders and of material) variability, no communication and no coordination up and down the supply chain, delay times for information and material flow, batch ordering (larger orders result in more variance), rationing and shortage gaming, price fluctuations, product promotions, free return policies, inflated orders.

Anderson et al. present a system dynamics model to investigate upstream volatility in the machine tools industry. By a series of simulation experiments they test several hypotheses about the nature of the Bullwhip Effect, e.g. how production lead times affect the entire supply chain.

A number of researchers designed games to illustrate the Bullwhip Effect. The most famous game is the "Beer Distribution Game" (Sterman, 1989: 321-339). It was developed at MIT to simulate the Bullwhip Effect in an experiment, and has been used widely for nearly four decades.

To address the Bullwhip Effect, many techniques are employed to manage various supply chain processes, such as order information sharing, demand forecasting, inventory management, and shipment scheduling (Li & Sikora 2001: 34-37) .

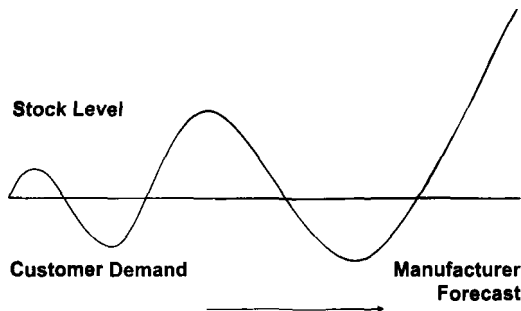2, See, Forrester, J. W. (1961). Industrial dynamics, MIT Press, Cambridge

Figure 1: Stock variability amplification in a supply chain due to Bullwhip Effect.

Lee et al. cite several factors causing the Bullwhip Effect under rational decision making on the part of channel members, and suggest methods (such as information sharing and strategic partnerships) to decrease the amount of variance amplification in the supply chain.

This phenomenon is not harmful by itself, but because of its consequences (Carlsson & Fuller 2000: 1-26):

Excessive inventory investments: Since the Bullwhip Effect makes the demand more unpredictable, all companies need to safeguard themselves against the variations to avoid stock-outs;

Poor customer service levels: Despite the excessive inventory levels mentioned in the first consequence, demand unpredictability may cause stockouts anyway;

Lost revenues: In addition to the poor customer service levels of the second consequence, stockouts may also cause lost revenues;

Reduced productivity: Since revenues are

lost, operations are less cost efficient;

More difficult decision-making: Decisions-makers react to demand fluctuations and adapt (production and inventory) capacities to meet peak demands;

Sub-optimal transportation: Transportation planning is made more difficult by demand

uncertainties induced by the Bullwhip Effect;

Sub-optimal production: As transportation, greater demand unpredictability causes missed production schedules.

3.TWO CASES WITH MODELS OF SIMPLE SUPPLY CHAINS

The objective of this paper is to illustrate and discuss the impact of inventory control policies at different demand processes (the Bullwhip Effect). The results (changes in order sizes and stocks) for all stages in supply chains are compared.

The main cause of variability is a perfectly understandable and rational desire by the different links in the supply chain to manage their production rates and stock levels sensibly (Slack & Chambers 2001: 56-58). To demonstrate this, two special cases with comments are following.

3.1 Case : Stable demand with a single 5 % change in demand

Here a four-stage supply chain is presented, where a manufacturer is served by three tiers of suppliers (see Fig. 2 and Table I). The market demand has been running at a rate of 100 items per period, but in period 2 demand reduces to 95 items per period. All stages in the chain work on the principle that they will keep in stock one period's demand (P1).

Table I: Changes of production rates and stock levels along supply chain (single 5 % change, one period's demand stock).

| Period	Demand (Market)	Manufacturer		Supplier 1		Supplier 2		Supplier 3	
		Production Rate	Stock Start/ Finish	Production Rate	Stock Start/ Finish	Production Rate	Stock Start/ Finish	Production Rate	Stock Start/ Finish
1	100	100	100/100	100	100/100	100	100/100	100	100/100
2	95	90	100/95	80	100/90	60	100/80	20	100/60
3	95	95	95/95	100	90/95	120	80/100	180	60/120
4	95	95	95/95	95	95/95	90	100/95	60	120/90
5	95	95	95/95	95	95/95	95	95/95	100	90/95
6	95	95	95/95	95	95/95	95	95/95	95	95/95
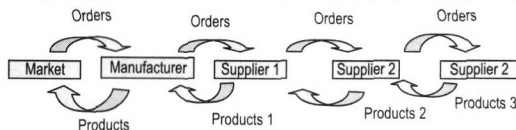
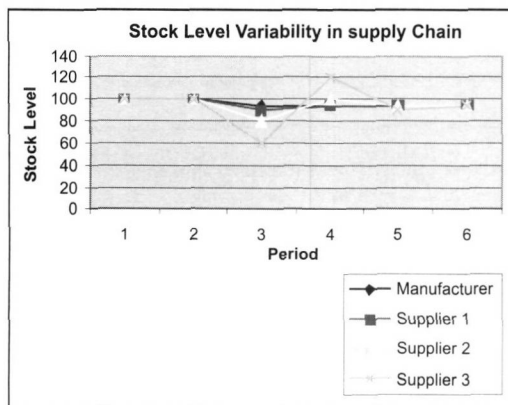*Figure 2 Presentation of a four stage supply chain.*

Figure 5: Stock level variability in a supply chain during 7 periods (P2).

The column headed 'Stock' for each level of supply shows the starting stock at the beginning of the period and the finish stock at the end of the period. At the beginning of period 2, the manufacturer (M) has 100 units in stock (that being the rate of demand up to period 2). Demand in period 2 is 95 and so the M knows that it would need to produce sufficient items to finish up at the end of the period with 95 in stock (this being the new demand rate). To do this, it need only manufacture 90 items; these, together with 5 items taken out of the starting stock, will supply demand and leave a finished stock of 95 items. The beginning of period 3 finds the M with 95 items in stock. Demand is also 95 items and therefore its production rate to maintain a stock level of 95 will be 95 items per period. The manufacturer now operates at a steady rate of producing 95 items per period. We should note that a change in demand of only 5% has produced a fluctuation of 10% in the M's production rate.

The same logic is used through to the first-tier supplier (S1). At the beginning of period 2, the S1 has 100 items in stock. The demand which it has to supply in period 2 is derived from the production rate of the M. This has dropped down to 90 in period 2. The S1 therefore has to produce sufficient to supply the demand of 90 items and leave one period's demand (now 90 items) as its finish stock. A production rate of 80 items per period will achieve this. It will therefore start period 3 with an opening stock of 90 items, but the demand from the M has now risen to 95 items. It therefore has to produce sufficient to fulfil this demand of 95 items and leave 95 items in stock. To do this, it must

produce 100 items in period 3. After period 3 the S1 then resumes a steady state, producing 95 items per period. The fluctuation has been even greater than that in the M's production rate, decreasing to 80 items a period, increasing to 100 items a period, and then achieving a steady rate of 95 items a period.

This logic can be extended right back to the third-tier supplier (S3). After period 5 the S3

resumes a steady state, producing 95 items per period. The fluctuation of production rate has been the most drastic, decreasing to 20 items a period, increasing to 180 items a period.

In this simple case, the decision of how much to produce each period was governed by the following relationship:

Production rate = 2 × demand – starting stock (>=0)   (1)
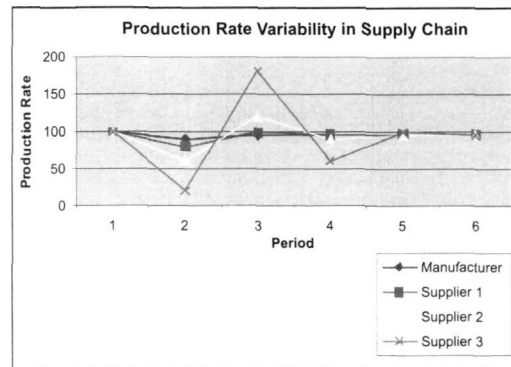

Figure 4: Production rate variability in a supply chain during 6 periods (P1).

The second stock keeping policy requires to keep in stock two periods' demand (P2). The situation at all supply stages is shown in Table II.

Table II: Changes of production rates and stock levels along supply chain (single 5 % change, two periods' demand stock).

Period	Demand (Market)	Manufacturer		Supplier 1		Supplier 2		Supplier 3	
		Production Rate	Stock Start/ Finish	Production Rate	Stock Start/ Finish	Production Rate	Stock Start/ Finish	Production Rate	Stock Start/ Finish
1	100	100	200/200	100	200/200	100	200/200	100	200/200
2	95	85	200/190	55	200/170	0	200/145	0	200/200
3	95	95	190/190	115	170/190	200	145/230	400	200/400
4	95	95	190/190	95	190/190	55	230/190	0	400/345
5	95	95	190/190	95	190/190	95	190/190	0	345/250
6	95	95	190/190	95	190/190	95	190/190	35	250/190
7	95	95	190/190	95	190/190	95	190/190	95	190/190

The fluctuation of production rate has been extreme: 5 % change in demand has produced at M (max.) 15 % change in production rate; at S1 first 45 % decrease and after that 15 % increase over the initial value; at S2 and S3 the production even stopped in the 2 period and then it is doubled at S2 and increased to 400 items (+400 %) at S3; the and 5 period. In the 7th period consequence later is that S3 was completely shut down in 4th S3 has achieved a steady rate of 95 items a period (see Fig. 5 and 6) In this case, the decision of how much to produce each period was governed by the following relationship:

Production rate = 3 × demand − starting stock (>=0)   (2)
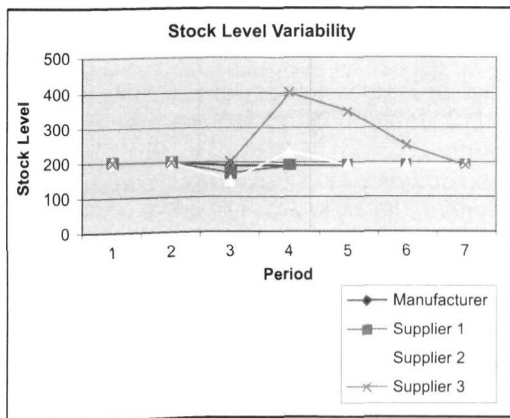

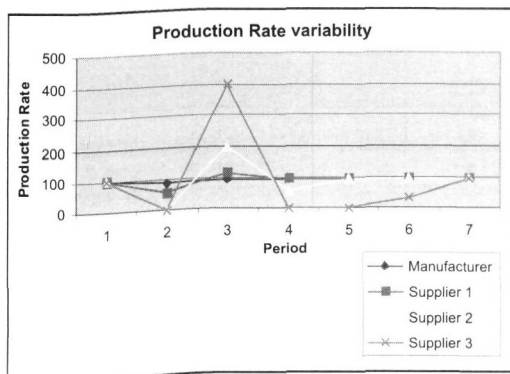Figure 5: Stock level variability in a supply chain during 7 periods (P2).

Figure 6: Production rate variability in a supply chain during 7 periods (P2).

It can be seen that the Manufacturer orders to the Supplier 1 (and farther up the supply chain) experience demand fluctuate far more drastically than the market demand. Small movements at the end of the supply chain trigger exponential movements down the chain. Suppliers ramp up in order to prevent stock-outs.

Shown case does not include any time lag between a demand occurring in one part of the supply chain and it being transmitted to its supplier. In practice there will be such a lag!

Additionally a very simplified mechanism of the Bullwhip Effect is described here. If a retail store that typically sells 100 units a week all of the sudden sells nearly 200 per week, then this is going to result in the supplier producing more than 200 in order to have a safety stock for its customer. Now the supplier is producing 200+X.

The supplier's supplier now needs to ramp up in order to have a safety stock that results in 200+X+Y. As we go down the supply chain, more variables are tagged onto the end of that equation.

The problem is, the supply chain as a whole needs to be able to satisfy the same demand. If the retail store needs 200 units, then everyone in the chain should be prepared to supply 200 units.

3.2 Case : Changing demand in periodic 10 % increases and later in 10 % decreases

Table III and Table IV present a two-stage supply chain (very simple model, but widely used in real situations) for an item with sales growing at 10 % per period for 4 periods and then shrinking by 10 % for 4 more periods.

P1: Both stages in the chain work on the principle that they will keep in stock one period's demand − Eq. (1). Orders and deliveries are made in the same period.

Table III: Changes of production rates and stock
levels (continual 10 % demand changes, P1)

Period	Demand (Market)	Manufacturer		Stock Start/ Finish	Supplier		Stock Start/ Finish
		Production Rate			Production Rate		
1	100	100		100/100	100		100/100
2	110	120		100/110	140		100/120
3	121	132		110/121	144		120/132
4	133	145		121/133	158		132/145
5	146	159		133/146	173		145/159
6	131	116		146/131	73		159/116
7	118	105		131/118	94		116/105
8	106	94		118/106	83		105/94
9	95	84		106/95	74		94/84

For example, in period 2 the sales of 110 units result in order and delivery of 120 units to bring the period 3 beginning stock to its desired level of 110. Table III clearly shows the Bullwhip Effect. The sales go up 46 % (100 to 146), and thereafter go down 35 % (146 to 95). Orders to the manufacturer go up by 59 % (100 to 159), and then down by 47 % (159 to84). Orders to the supplier go up by 73 % (100 to 173) and then down immediately by 58 % (173 to 73).

 P2: Both stages in the chain work on the principle that they will keep in stock two periods' demand – Eq. (2).

Table IV: Changes of production rates and stock levels (continual 10 % demand changes, P2).

Period	Demand (Market)	Manufacturer		Stock Start/ Finish	Supplier		Stock Start/ Finish
		Production Rate			Production Rate		
1	100	100		100/100	100		100/100
2	110	120		100/110	140		100/120
3	121	132		110/121	144		120/132
4	133	145		121/133	158		132/145
5	146	159		133/146	173		145/159
6	131	116		146/131	73		159/116
7	118	105		131/118	94		116/105
8	106	94		118/106	83		105/94
9	95	84		106/95	74		94/84

In period 2 the sales of 110 units result in ending stock of 90, which is thereafter corrected by an order and delivery of 130 units to bring the period 3 beginning stock to its desired level of 220. The sales go up 46 %, and thereafter go down 35 %. Orders to the manufacturer go up by 72 % (100 to 172), and then down by 58 % (172 to 73). Even more dramatically, orders to the supplier go up by 102 % – more than doubled (100 to 202) and then down by 100 % (202 to 0). In the 6th period the production at the supplier is completely shut down.

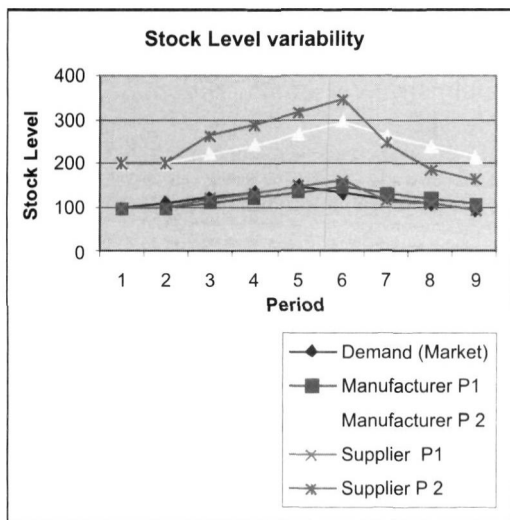Both scenarios regarding variability of stocks and production orders are shown in Fig. 7 and 8.

Figure 7: Stock variability in a two-stage supply chain (policies: P1, P2).

The second presented case is very real. Retailers often make unexpected promotions to increase the demand at some periods. As a result, although the demand fore some specific periods might increase, some customers will delay or reduce their next purchases. This will decrease the customers' demands in the subsequent periods and uncertainty in the supply chain will increase (Lin 2006: 328-336).
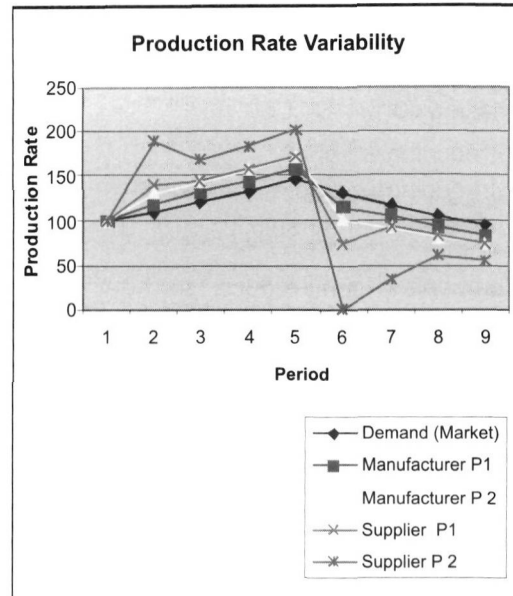

Figure 8: Production rate variability in a two-stage supply chain (policies: P1, P2).

It is important to note that besides stock effects, similar problems would be extant in

manufacturing capacity requirements, response times, and obsolescence (Vollmann & Berry 2005: 45-47).

Both cases are very real. The above examples where suppliers have been shut down completely for many weeks when the orders at the end of the supply chain are reduced only slightly!

4.COUNTER MEASURES FOR THE BULL WHIP EFFECT

Lee et al propose some actions to counteract the causes of bullwhip (access the sell-thru data or POS data in order to have "good" data for the forecast; discount on assorted truckload to reduce order batching; special purchase contract to counteract the price fluctuation; flexibility limited over time to counteract the shortage gaming).

Simchi-Levi et al. identify 4 suggestions for reducing the bullwhip effect:

1. reducing uncertainty;
2. reducing variability;
3. reducing lead-time;
4. strategic partnership.

Companies can reduce uncertainty by sharing information along the whole SC, providing each stage with complete information on actual customer demand, reducing reliance on forecasting (relying more on direct demand data). Dejonckheeere et al. examines the beneficial effect of information sharing through computer based technology (e.g. EPOS) to reduce forecast errors. They implement a dynamic control system of replenishment rules.

Variability inherent customer demand process can be reduced by drastically reducing price promotion, using a consistent price strategy, which means offering a price as low as possible everyday, without periodic price promotion.

Lead-time can be reduced by adopting lean manufacturing and reducing costs of batching orders. The variance of orders is strictly dependent by lead time. EDI (Electronic Data Interchange) can significantly reduce order lead time that is one of the components of the total lead time between two SC stages. Furthermore, companies should realize that greater savings could be realized by implementing computer order system, allowing administrative costs reduction (small orders).

A FRAMEWORK FOR SUPPLY CHAIN COORDINATION INITIATIVE

Causes of Bullwhip Demand forecast update	Information sharing	Channel Alignment	Operational Efficiency
	Understanding system dynamics Use Point of Sale (POS) Data Electronic Data Interchange (EDI) Internet Computer assisted ordering (CAO)	Vendeor managed Inventory (VMI) Discount for Information sharing Consumer Direct	Lead time reduction Echelon Based Inventory reduction
Order Batching	EDI Internet Ordering	Discount for Truck load assortment Delivery appointments Consolidation Logistics Outsourcing	Reduction in fixed cost of ordering by EDI CAO
Price Fluctuations		Continuous Replenishment Program (CRP) Everday low cost (EDLC)	Everyday Low Price (EDLP) Activity Based Costing (ABC)
Shortage Gaming	Sharing Sales capacity and inventory data	Allocation based past sales	

Finally, adopting strategic partnerships, for sharing information and effective inventory management along the whole SC can significantly reduce the bullwhip effect. One of the most important strategic partnerships is the VMI (Vendor Managed Inventory): manufacturer manages its own inventory product at the retailer outlet, deciding how much inventory to keep on hand and how much to ship to the retailer in each period (Simchi-Levi & Kaminsky 2009: 159-163).

Recently, Wang et al. affirm that the bullwhip effect caused by certain predictable factors (the ones described in (Lee & Padmanabhan 1997: 546-558)) is only one kind of information distortion. The author define an extended bullwhip effect, caused by uncertain factors that cannot be deduced and predicted. The causes of the "extended" bullwhip are various and could be contrived or physical. The extended bullwhip effect is destructive and damages the information, reducing efficiency, waste manpower and so on.

Even though Lee et al. refer to a kind of flexibility (limited over time) as an action to counteract the bullwhip effect, there are none study on the interaction between flexibility and Bullwhip effect reduction.

5.CONCLUSION

For make-to-stock production systems, which are included in different supply chains, the production plans and activities are based on demand forecasting. The orders are supplied by stock inventory, in which the policy emphasizes the immediate delivery of the order, good quality, reasonable price, and standard products. The customers expect that delays in the order are inexcusable, so the supplier must maintain sufficient stock (Fogarty & Blackstone 1991: 34-37).

It has been recognized that demand forecasting and ordering policies are two of the key causes of the Bullwhip Effect.

The Bullwhip Effect is a wasteful phenomenon that occurs due to a lack of information across the supply chain. Basically, the Bullwhip Effect is safety stock for safety stock; because suppliers hold extra stock for their customers the same way retailers hold extra stock for their customers. Suppliers need safety stock, for the safety stock.

Situations where information is not shared between the manufacturer (with chained suppliers) and the retailers may cause a heavier burden on the safety stock or a greater expenditure in shortage cost. The negative effect on business performance is often found in excess stocks, quality problems, higher raw material costs, overtime expenses and shipping costs. In the worst-case scenario, customer service goes down, lead times lengthen, sales are lost, costs go up and capacity is adjusted. An important element to operating a smooth flowing supply chain is to mitigate and preferably eliminate the Bullwhip Effect.

In the paper we experimented with two special cases of simple supply chains using two stock keeping policies, identical for all stages in the chain. Results are discussed and shown in tables and charts.

For future study, we will focus on different stock keeping policies at all stages of a supply chain. The investigation will be based on spreadsheet simulation; the Bullwhip Effect will be measured by the standard deviation of orders.

REFERENCES

Anderson, E. G.; Fine, C. H.; Parker, G. G. (2000). Upstream Volatility in the Supply Chain: The Machine Tool Industry as a Case Study, Production and Operations Management, Vol. 9, No. 3, 239-261.

Baganha, P. M.; Cohen, A. M. (1998). The stabilizing effect of inventory in supply chains, Operations Research, Vol. 46, No. 3S, 72-83.

Carlsson, C.; Fullér, R. (2000). Soft computing and the bullwhip effect, Economics and Complexity, Vol. 2, No. 3, 1-26.

Chase, R. B.; Aquilano, N. J.; Jacobs, F. R. (2009).Operations management for competitive advantage, McGraw-Hill/Irwin, Boston.

Dejonckheere J., Disney S.M., Lambrecht M.R., Towill D.R., 2004, The impact of information enrichment on the Bullwhip effect in supply chains: A control engineering perspective, European Journal of Operation research, Vol. 153, pp. 727-750.

Donovan, R. M. (2002). Supply Chain Management: Cracking the Bullwhip Effect, Available from: http://www.edm1.com/donovan.pdf, Accessed: 2007-06-10

Fogarty, D. W.; Blackstone, J. H.; Hoffmann, T. R. (1991). Production & inventory management, South-Western, Cincinnati.

Gilbert, S. M.; Ballou, R. H. (1999). Supply chain benefits from advanced customer commitments, Journal of Operations Management, Vol. 18, No. 1, 61-73

Lee, L. H.; Padmanabhan, V.; Whang, S. (1997). Information distortion in a supply chain: the Bullwhip Effect, Management Science, Vol. 43, No. 4, 546-558.

Li, J.; Shaw, M. J.; Sikora, R. T. (2001). The effects of information sharing strategies on supply chain performance, Technical Report.

Lin, C.; Lin, Y.-T. (2006). Mitigating the bullwhip effect by reducing demand variance in the supply chain, International Journal of Advanced Manufacturing Technology, Vol. 28, 328-336

Metters, R. (1997). Quantifying the Bullwhip Effect in supply chains, Journal of Operations Management, Vol. 15, No. 2, 89-100

Rudberg, M.; Olhager, J. (2003). Manufacturing networks and supply chains: An operations strategy perspective, Omega, Vol. 31, No. 1, 29-39

Simchi-Levi, D.; Kaminsky, P.; Simchi-Levi, E. (2009). Designing and managing the supply chain, McGraw-Hill, New York

Slack, N.; Chambers, S.; Johnston, R. (2001). Operations Management, Prentice Hall, Harlow

Sterman, J. (1989). Modeling managerial behaviour: misperceptions of feedback in a dynamic decision making experiment, Management Science, Vol. 35, No. 3, 321-339.

Vollmann, T. E.; Berry, W. L.; Whybark, D. C.; Jacobs, F. R. (2005). Manufacturing planning and control for supply chain management, McGraw-Hill/Irwin, Boston

Wang J., Jia J., Takahashi K., 2005, A study on the impact of uncertain factors on information distortion in supply chains, Production Planning & Control, Vol. 16, No. 1, pp 2-11.