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BULLWHIP EFFECT PROBLEM IN SUPPLY CHAINS

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Abstract:
In Supply Chain Management, a phenomenon called the "Bullwhip Effect" has attracted considerable attention. Overall supply chain evaluation needs to include the Bullwhip Effect. The Bullwhip Effect shows how small changes at the demand end of a supply chain are progressively amplified for operations further back in the chain. It is understood that demand forecast variance contributes to that effect in the chain. With this understanding, the authors experimented with two cases: stable demand with a single 5 % change in demand, and changing demand in periodic 10 % increases and later in the same decreases. Two stock keeping policies for all stages in the chain have been studied: to keep in stock i) one, and ii) two periods' demand. Results are shown in tables and charts. Increasing variability of production orders and stocks up the supply chain is evident. The effect indicates a lack of synchronization among supply chain members because of corrupt key information about actual demand. When we understand the nature of supply chain dynamics, there are several actions concerned with coordinating the activities of the operations in the chain, which is discussed in the last part of the paper.

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

1. INTRODUCTION

The objective of supply chain management is to provide a high velocity flow of high quality, relevant information that will enable suppliers to provide an uninterrupted and precisely timed flow of materials to customers. Many companies are achieving significant competitive advantage by the way they configure and manage their supply chain operations. 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 [1]. 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 [2].

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 [3].

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 [4].

The rest of this paper is organized as follows: Section 2 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. In Section 3 some selected cases of simple supply chain models and the variability of production rates and stocks are presented. Section 4 describes actions against the Bullwhip Effect. Finally, conclusions are given in Section 5.

2. BULLWHIP EFFECT

The term *Bullwhip Effect* was coined by Procter & Gamble management who noticed an amplification of information distortion as order information travelled up the supply chain. The Bullwhip Effect (or *Whiplash Effect*) is an observed phenomenon in forecast-driven distribution channels. 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* [5]. Because customer demand is rarely perfectly stable, businesses must forecast demand in order to properly position inventory and other resources. 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. 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. The effect is that variations are amplified as one moves upstream in the supply chain (further from the customer). 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 [1, 6–9].

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.

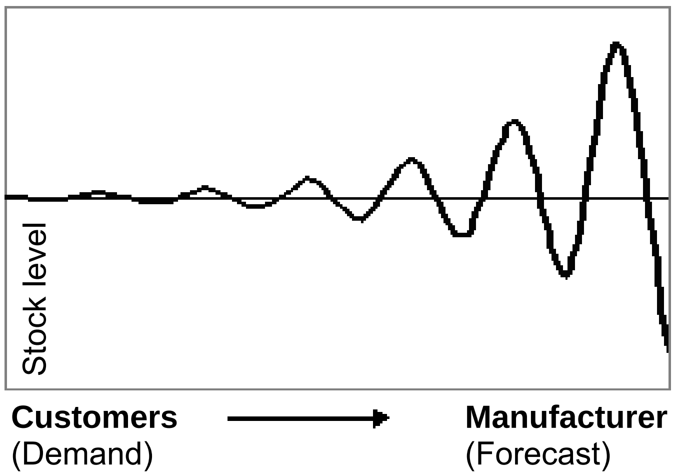

Figure 1: Stock variability amplification in a supply chain due to Bullwhip Effect.

Anderson et al. [10] 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” [11]. 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 [12].

Lee et al. [7] 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 [13]:

- Excessive inventory investments: Since the Bullwhip Effect makes the demand more unpredictable, all companies need to safeguard themselves against the variations to avoid stockouts;
- 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 [14]. To demonstrate this, two special cases with comments are following.

3.1 Case 1: Stable demand with a single 5 % change in demand

We present a four-stage supply chain 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 (P_1).

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	
		Prod. rate	Stock start / finish	Prod. rate	Stock start / finish	Prod. rate	Stock start / finish	Prod. 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

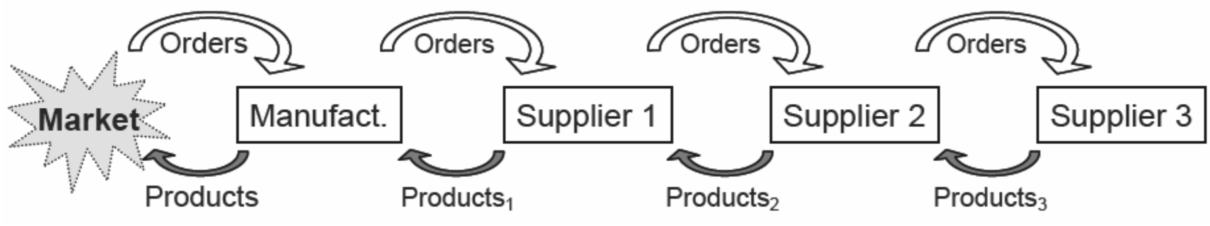

Figure 2: Presentation of a four-stage supply chain.

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.

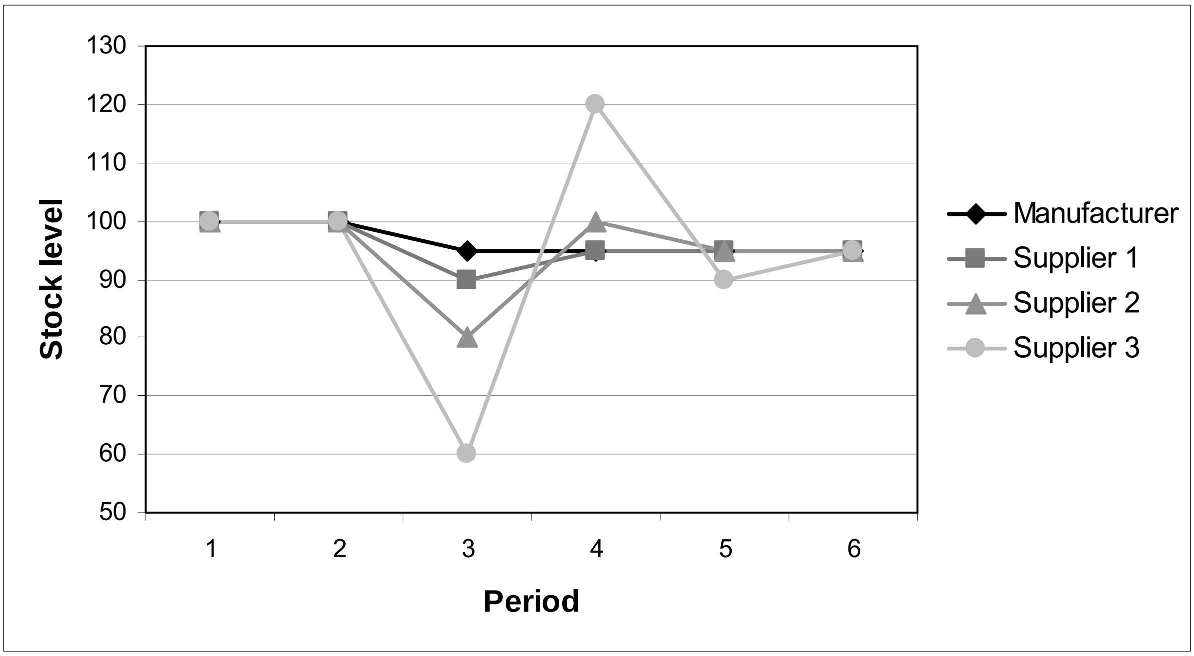

Figure 3: Stock level variability in a supply chain during 6 periods (P_1).

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:

$$\text{Production rate} = 2 \times \text{demand} - \text{starting stock} \quad (\geq 0) \qquad (1)$$

The changing situation in stock levels and production rates during 6 periods is presented in Fig. 3 and 4.

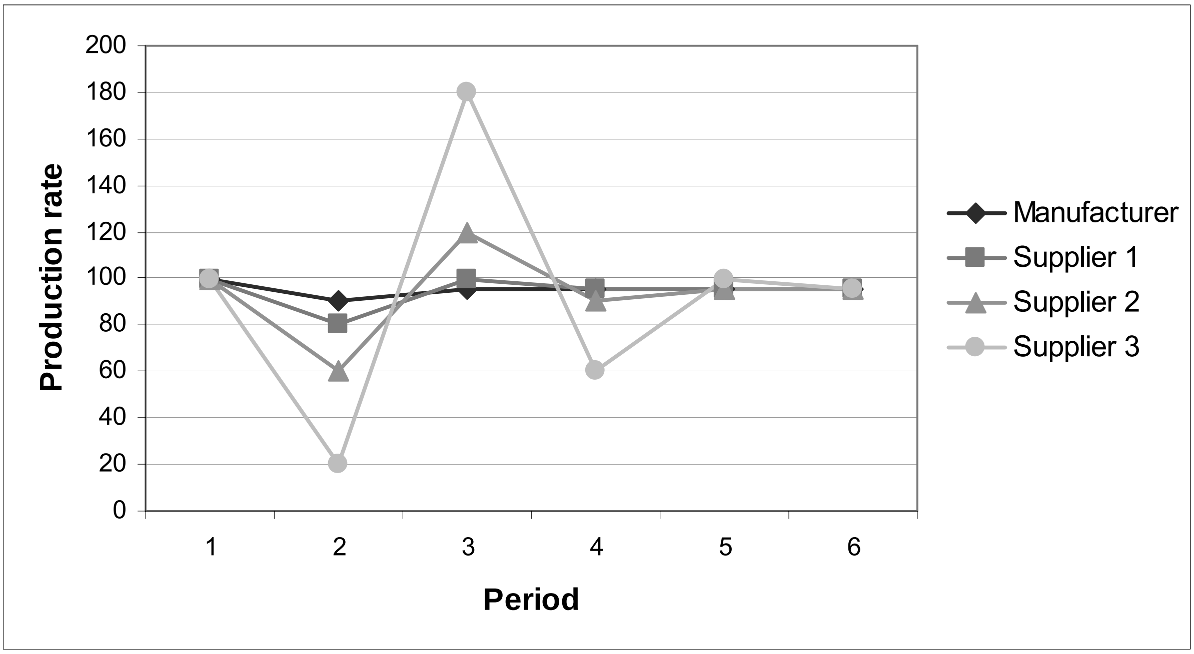

Figure 4: Production rate variability in a supply chain during 6 periods (P_1).

The second stock keeping policy requires to keep in stock two periods' demand (P_2). 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	
		Prod. rate	**Stock start / finish**	**Prod. rate**	**Stock start / finish**	**Prod. rate**	**Stock start / finish**	**Prod. 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 2nd period and then it is doubled at *S2* and increased to 400 items (+400 %) at *S3*; the consequence later is that *S3* was completely shut down in 4th and 5th period. In the 7th period *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:

$$\text{Production rate} = 3 \times \text{demand} - \text{starting stock} \quad (\geq 0) \qquad (2)$$

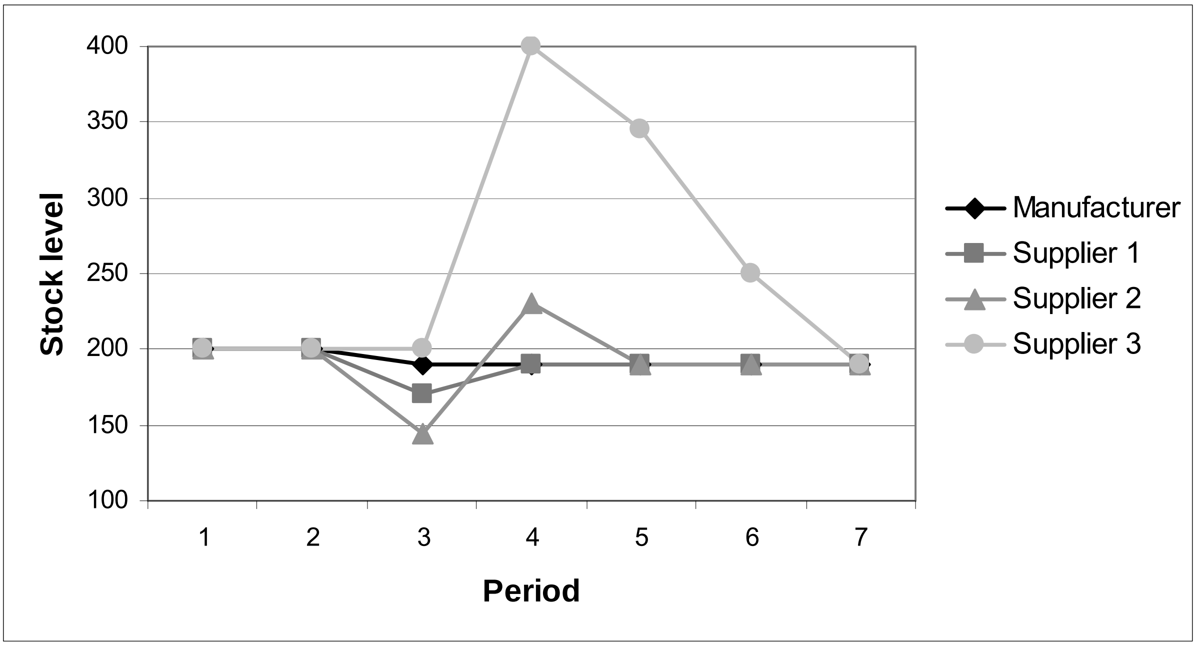

Figure 5: Stock level variability in a supply chain during 7 periods (P_2).

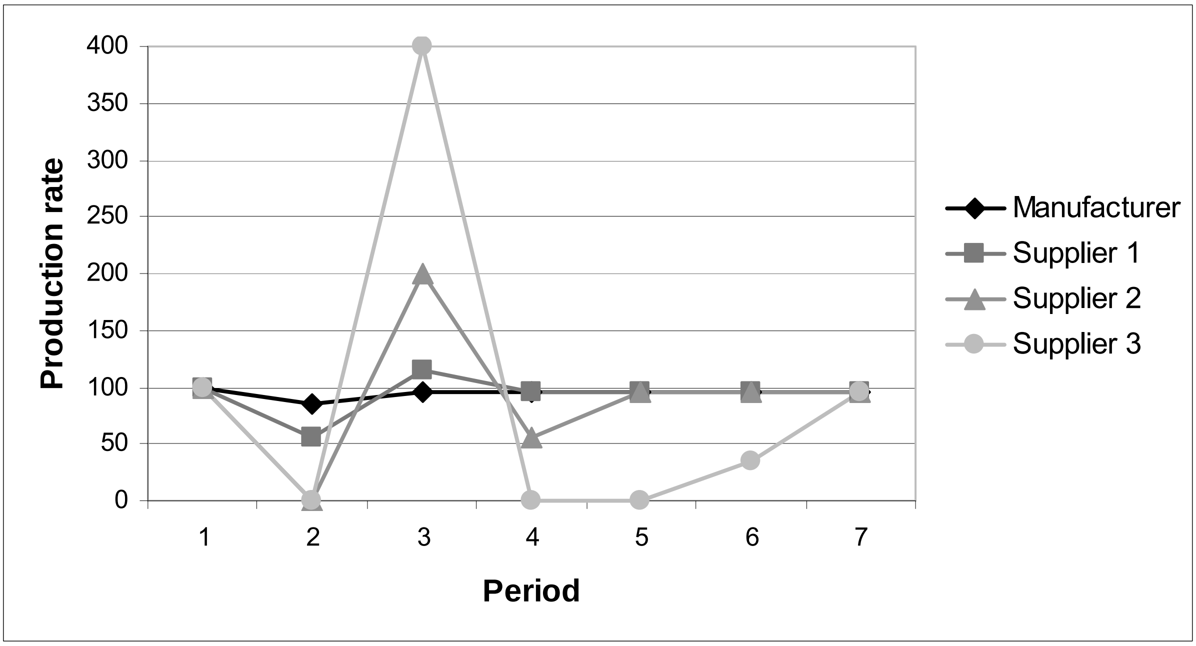

Figure 6: Production rate variability in a supply chain during 7 periods (P_2).

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 2: 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.

P_1: 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, P_1).

Period	Demand (market)	Manufacturer		Supplier	
		Production rate	Stock start / finish	Production rate	Stock start / finish
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 to 84). Orders to the supplier go up by 73 % (100 to 173) and then down immediately by 58 % (173 to 73).

P_2: 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, P_2).

Period	Demand (market)	Manufacturer		Supplier	
		Production rate	Stock start / finish	Production rate	Stock start / finish
1	100	100	200 / 200	100	200 / 200
2	110	130	200 / 220	190	200 / 260
3	121	143	220 / 242	169	260 / 286
4	133	157	242 / 266	185	286 / 314
5	146	172	266 / 292	202	314 / 344
6	131	101	292 / 262	0	344 / 243
7	118	92	262 / 236	33	243 / 184
8	106	82	236 / 212	62	184 / 164
9	95	73	212 / 190	55	164 / 146

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.

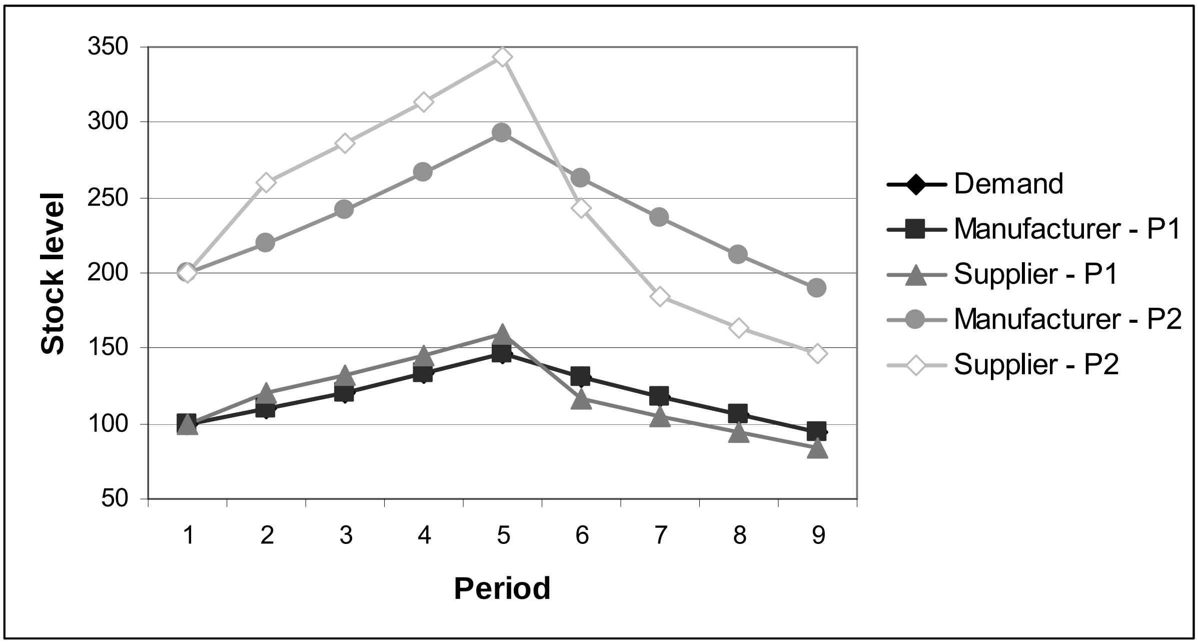

Figure 7: Stock variability in a two-stage supply chain (policies: P_1, P_2).

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 [15].

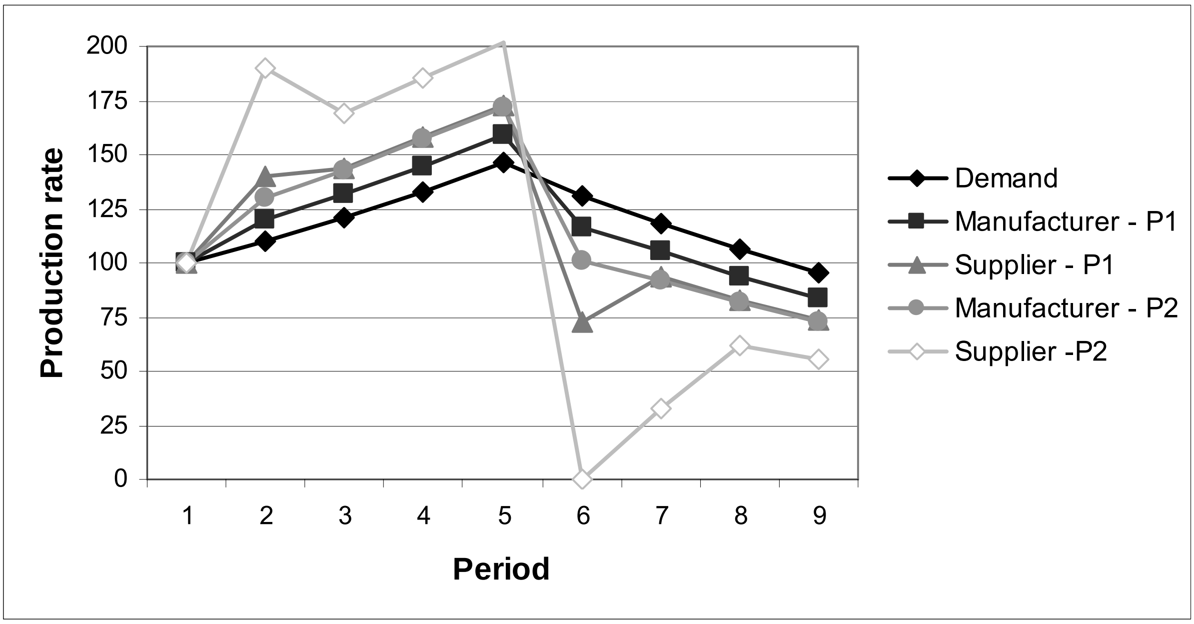

Figure 8: Production rate variability in a two-stage supply chain (policies: P_1, P_2).

It is important to note that besides stock effects, similar problems would be extant in manufacturing capacity requirements, response times, and obsolescence [16].

Both cases are very real. We have seen 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. COUNTERMEASURES TO THE BULLWHIP EFFECT

The key question becomes: How can the Bullwhip Effect be ameliorated? Companies must understand fully its main causes and implement some new strategies [17]. Different actions are possible:

- Minimize the cycle time in receiving projected and actual demand information.
- Establish the monitoring of actual demand for product to as near a real time basis as possible.
- Understand product demand patterns at each stage of the supply chain.
- Increase the frequency and quality of collaboration through shared demand information.
- Minimize or eliminate information queues that create information flow delays, centralize demand information.
- Eliminate inventory replenishment methods that launch demand lumps into the supply chain.
- Reduce the order sizes and implement capacity reservations.
- Eliminate incentives for customers that directly cause demand accumulation and order staging prior to a replenishment request, such as volume transportation discounts.
- Offer your products at consistently good prices to minimize buying surges brought on by temporary promotional discounts.
- Minimize incentive promotions that will cause customers to delay orders and thereby interrupt smoother ordering patterns; identify, and preferably, eliminate the cause of customer order reductions or cancellations.

- Decision-makers should react to demand fluctuations and adapt capacities to meet peak demands.
- Implement special purchase contracts in order to specify ordering at regular intervals, limit free return policies.

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 [18].

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.

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