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INVESTIGATION OF THE BULLWHIP EFFECT USING SPREADSHEET SIMULATION

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Abstract
Superior supply chains are one of the best ways to compete in today's marketplaces. In Supply Chain Management, overall supply chain evaluation needs to include an important logistical effect known as the Bullwhip Effect. It shows how small changes at the demand end of a supply chain are progressively amplified up the supply chain. Production plans are based on demand forecasting and suppliers not only react on changed demand, they adapt the level of safety stock (variation of stocks and orders increases). In this paper two special situations in a four-stage supply chain are studied: i) stable demand with a single 5 % change in demand (with application of four different stock keeping policies), and ii) changing demand with alternating 5 % changes in demand (up and down, with another three stock keeping policies). The results of spreadsheet simulations are shown in tables and charts. Increasing variability of production orders and stock levels up the supply chain is evident. The Bullwhip Effect is measured by the standard deviation of orders. The comparison of the results shows that the Bullwhip Effect can be partially reduced by appropriate stock keeping policy.
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Key Words: Supply Chain, Changing Demand, Bullwhip Effect, Ordering Policy

1. INTRODUCTION

Companies increasingly find that they must rely on effective supply chains to successfully compete in the global market and networked economy. Supply Chain Management integrates supply and demand management within and across companies. It is said that the ultimate goal of any effective Supply Chain Management System is to reduce inventory (with the assumption that products are available when needed). 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, 2].

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. Today, the ever increasing technical complexity of standard consumer goods, combined with the ever increasing size and depth of the global market means that the link between consumer and vendor is usually only the final link in a long and complex chain or network of exchanges [3, 4].

For make-to-stock production systems, which are involved 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 [5]. It has been recognized that demand forecasting and ordering policies are two of the key causes of the Bullwhip Effect which is described later. In the paper a spreadsheet simulation explores a series of stock keeping policies under different demand patterns.

The organization of the paper is as follows. In the next section some basic facts of the Bullwhip Effect and a brief literature review of research work are provided. In section 3 the details of the investigated model of a four-stage supply chain are presented. Two special cases with 7 different stock keeping policies are described. Section 4 analyses and discusses the presented cases. Concluding remarks are given in the final section.

2. LITERATURE REVIEW FOR THE BULLWHIP EFFECT

The Bullwhip Effect is named after the action of a whip where each segment further down the whip goes faster than that above it ("whiplash effect"). The same effect occurs in a supply chain, but in reverse order. The term was coined by Procter & Gamble management who noticed an amplification of information distortion as order information travelled up the supply chain. The Bullwhip Effect is an observed phenomenon in forecast-driven distribution channels. The effect indicates a lack of synchronization among supply chain members. Because the supply patterns do not match the demand patterns, inventory accumulates at various stages (Fig. 1). Ordering more than needed now and less than needed later implies the supplier's orders in the chain are more volatile than the supplier's demand, which is the Bullwhip Effect. The concept has its roots in Forrester's *Industrial Dynamics* [6]. Because customer demand is rarely perfectly stable, businesses must forecast demand in order to properly position inventory. 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). Forrester also pioneered the simulation approach for studying the effect.

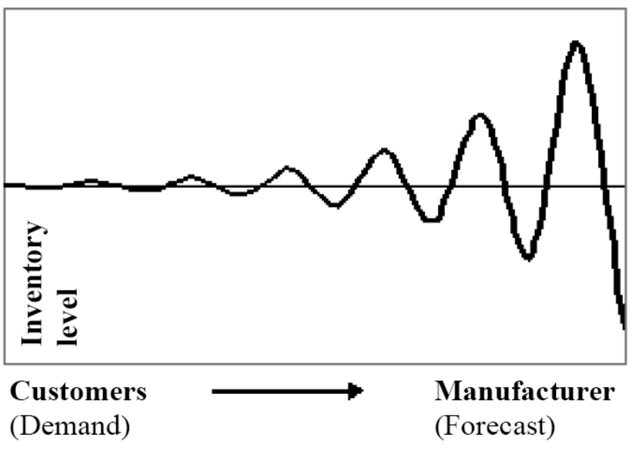


Figure 1: Amplification of inventory level in a supply chain due to Bullwhip Effect.

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, 7-9]. An important question is: Do companies in a supply chain agree to share demand information? Some solutions to both situations are presented in [10].

Factors contributing to the Bullwhip Effect:

- forecast errors,
- overreaction to backlogs,
- lead time (of information – production 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.

A number of researchers designed games to illustrate the Bullwhip Effect. The most famous game is the "Beer Distribution Game" [11, 12]. It was developed at MIT to simulate the Bullwhip Effect in an experiment, and has been used widely for nearly five decades.

Anderson *et al.* [13] 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.

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 [14, 15].

Lee *et al.* [7] cite several factors causing the Bullwhip Effect under rational decision making on the part of chain members, and suggest methods (such as information sharing and strategic partnerships) to decrease the amount of variance amplification in the supply chain.

Anderson and Morrice [16] analyzed the Bullwhip Effect in service industries, which cannot hold inventory, and in which backlogs can only be managed by adjusting capacity.

This phenomenon is not harmful by itself, but because of its consequences [17]:

- excessive inventory investments,
- poor customer service levels,
- lost revenues,
- reduced productivity,
- more difficult decision-making,
- sub-optimal transportation,
- sub-optimal production (over- and underproduction),
- higher costs.

How can the Bullwhip Effect be ameliorated? Companies must understand fully its main causes and implement some new strategies [18]. 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.

3. A FOUR-STAGE SUPPLY CHAIN MODEL

The objective of this paper is to illustrate and discuss the impact of stock keeping policies to the Bullwhip Effect. The results (changes in order sizes and stocks) for all stages in a supply chain are compared.

We consider a periodic review system in discrete time. We present a four-stage single-item supply chain where a manufacturer is served by three tiers of suppliers (see Fig. 2). There are no stock capacity limits, no production limits and one order per period is presumed for each stage in the chain. Order sizes are rounded. Orders and deliveries are made in the same period. The results were obtained by the means of spreadsheet simulation. The spreadsheets are designed in Microsoft Excel so they are user-friendly and easy to understand.

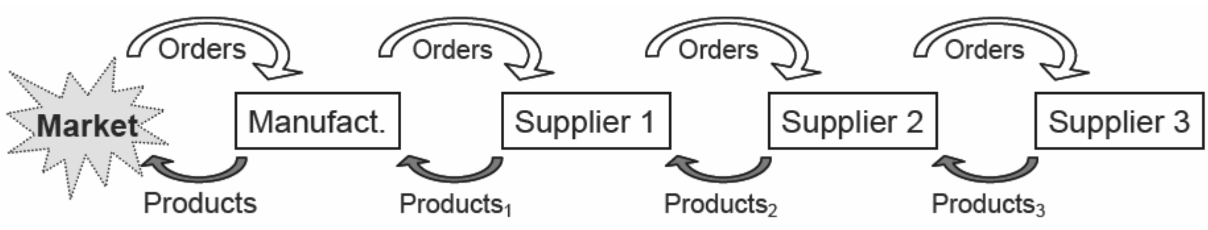


Figure 2: Presentation of a four-stage supply chain [19].

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

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 and keeps that value in other periods (this case was motivated by a case presented in [19]). Four stock keeping policies (P_1 – P_4) for the stages in the chain are studied.

a) P_1: All stages in the chain work on the principle that they will keep in stock one period's demand (1 - 1 - 1 - 1).

Table I: Changes of production orders and stock levels along supply chain – P_1

Simulation 1		Stock keeping policy:	M 1			S1 1			S2 1			S3 1	

Period	Market Demand	Manufacturer Stock-start	Order	Stock-final	Supplier 1 Stock-start	Order	Stock-final	Supplier 2 Stock-start	Order	Stock-final	Supplier 3 Stock-start	Order	Stock-final
1	100	100	100	100	100	100	100	100	100	100	100	100	100
2	95	100	90	95	100	80	90	100	60	80	100	20	60
3	95	95	95	95	90	100	95	80	120	100	60	180	120
4	95	95	95	95	95	95	95	100	90	95	120	60	90
5	95	95	95	95	95	95	95	95	95	95	90	100	95
6	95	95	95	95	95	95	95	95	95	95	95	95	95
7	95	95	95	95	95	95	95	95	95	95	95	95	95
		Stand.dev.:	3		Stand.dev.:	7		Stand.dev.:	18		Stand.dev.:	48	
		Max./Min.:		1,05	Max./Min.:		1,11	Max./Min.:		1,25	Max./Min.:		2

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 needs 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 needs to manufacture only 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 (order size) 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. Therefore, it 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 in each period was governed by the following relationship:

$$\text{Order size} = 2 \times \text{demand} - \text{starting stock} \quad (\geq 0) \tag{1}$$

The changing situation in stock levels and order sizes during 7 periods is presented in Fig. 3.

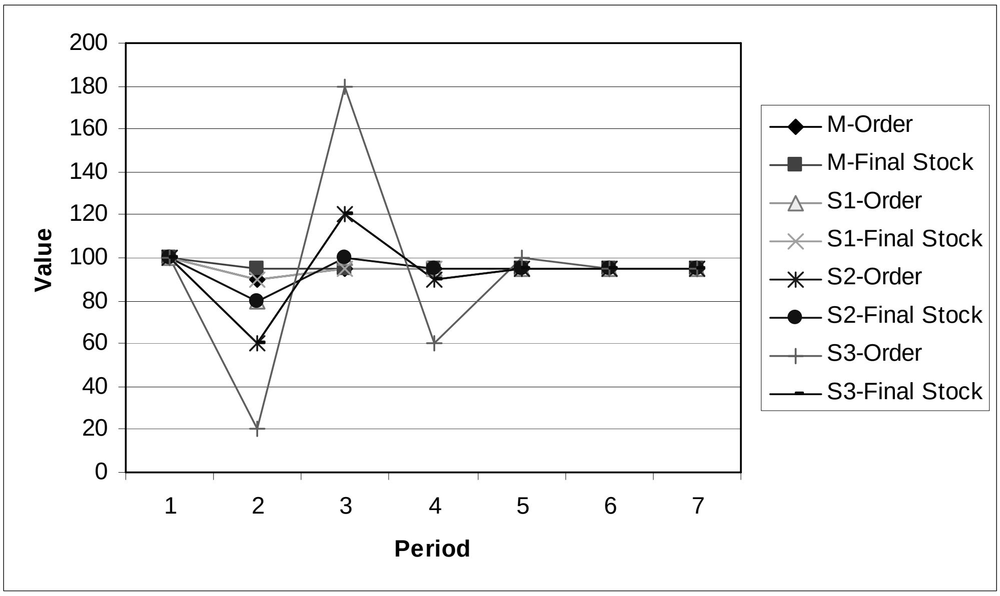


Figure 3: Order size and stock level variability in a supply chain during 7 periods (P_1).

b) P_2: All stages in the chain work on the principle that they will keep in stock different (increasing) period's demand (1 - 1,33 - 1,67 - 2). The second stock keeping policy requires for *S3* to keep in stock two periods' demand. The situation at all supply stages is shown in Table II.

Table II: Changes of production orders and stock levels along supply chain – P_2

Simulation 2	Stock keeping policy:	M	S1	S2	S3
		1	1,33	1,67	2

	Market	Manufacturer			Supplier 1			Supplier 2			Supplier 3		
Period	Demand	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final
1	100	100	100	100	133	100	133	167	100	167	200	100	200
2	95	100	90	95	133	77	120	167	39	129	200	0	161
3	95	95	95	95	120	101	126	129	141	169	161	262	282
4	95	95	95	95	126	95	126	169	85	159	282	0	197
5	95	95	95	95	126	95	126	159	95	159	197	88	190
6	95	95	95	95	126	95	126	159	95	159	190	95	190
7	95	95	95	95	126	95	126	159	95	159	190	95	190
		Stand.dev.:	3		Stand.dev.:	8		Stand.dev.:	30		Stand.dev.:	87	
		Max./Min.:		1,05	Max./Min.:		1,11	Max./Min.:		1,31	Max./Min.:		1,75

The fluctuation of production rate has been on a large scale: 5 % change in demand has produced at *M* (max.) 10 % change in production rate; at *S1* first 23 % decrease and after that 1 % increase over the initial value; at *S2* first 61 % decrease and after that 41 % increase over the initial value; at *S3* the production stopped in the 2nd (and 4th) period and then it is increased to 262 items. In the 6th period *S3* has achieved a steady rate of 95 items a period (see Fig. 4).

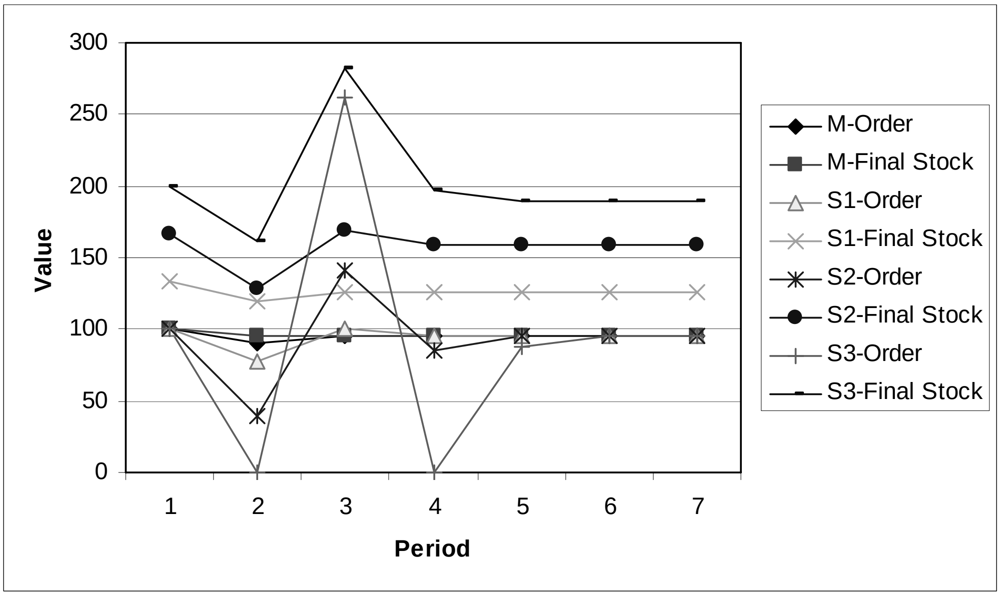


Figure 4: Order size and stock level variability in a supply chain during 7 periods (P_2).

c) P_3: All stages in the chain work on the principle that they will keep in stock different (decreasing) period's demand (2 - 1,67 - 1,33 - 1). The situation at supply stages is shown in Table III.

5 % change in demand has produced at *M* 15 % change in production rate; at *S2* and *S3* the situation is just like at P_2 regardless of lower safety stock (Fig. 6).

Table III: Changes of production orders and stock levels along supply chain – P_3

Simulation 3		Stock keeping policy:	M 2			S1 1,67			S2 1,33			S3 1		

		Manufacturer			Supplier 1			Supplier 2			Supplier 3		
Period	Demand	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final
1	100	200	100	200	167	100	167	133	100	133	100	100	100
2	95	200	85	190	167	60	142	133	7	80	100	0	93
3	95	190	95	190	142	112	159	80	181	149	93	269	181
4	95	190	95	190	159	95	159	149	72	126	181	0	109
5	95	190	95	190	159	95	159	126	95	126	109	81	95
6	95	190	95	190	159	95	159	126	95	126	95	95	95
7	95	190	95	190	159	95	159	126	95	126	95	95	95
		Stand.dev.:	4		Stand.dev.:	16		Stand.dev.:	51		Stand.dev.:	90	
		Max./Min.:		1,05	Max./Min.:		1,18	Max./Min.:		1,86	Max./Min.:		1,95

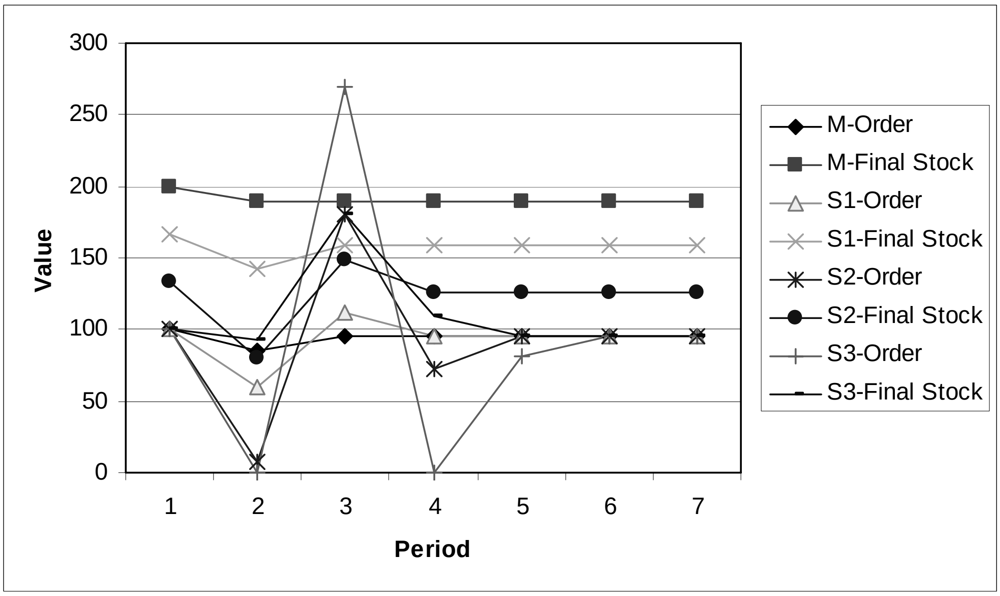


Figure 5: Order size and stock level variability in a supply chain during 7 periods (P_3).

d) P_4: All stages in the chain work on the principle that they will keep in stock two period's demand (2 - 2 - 2 - 2). The situation is shown in Table IV.

Table IV: Changes of production orders and stock levels along supply chain – P_4

Simulation 4		Stock keeping policy:	M 2			S1 2			S2 2			S3 2		

	Market	Manufacturer			Supplier 1			Supplier 2			Supplier 3		
Period	Demand	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final
1	100	200	100	200	200	100	200	200	100	200	200	100	200
2	95	200	85	190	200	55	170	200	0	145	200	0	200
3	95	190	95	190	170	115	190	145	200	230	200	400	400
4	95	190	95	190	190	95	190	230	55	190	400	0	345
5	95	190	95	190	190	95	190	190	95	190	345	0	250
6	95	190	95	190	190	95	190	190	95	190	250	35	190
7	95	190	95	190	190	95	190	190	95	190	190	95	190
		Stand.dev.:	4		Stand.dev.:	18		Stand.dev.:	60		Stand.dev.:	143	
		Max./Min.:		1,05	Max./Min.:		1,18	Max./Min.:		1,59	Max./Min.:		2,11

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^{nd} period and then it was doubled at *S2* and increased to 400 items 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. 6).

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

$$\text{Order size} = 3 \times \text{demand} - \text{starting stock} \quad (\geq 0) \tag{2}$$

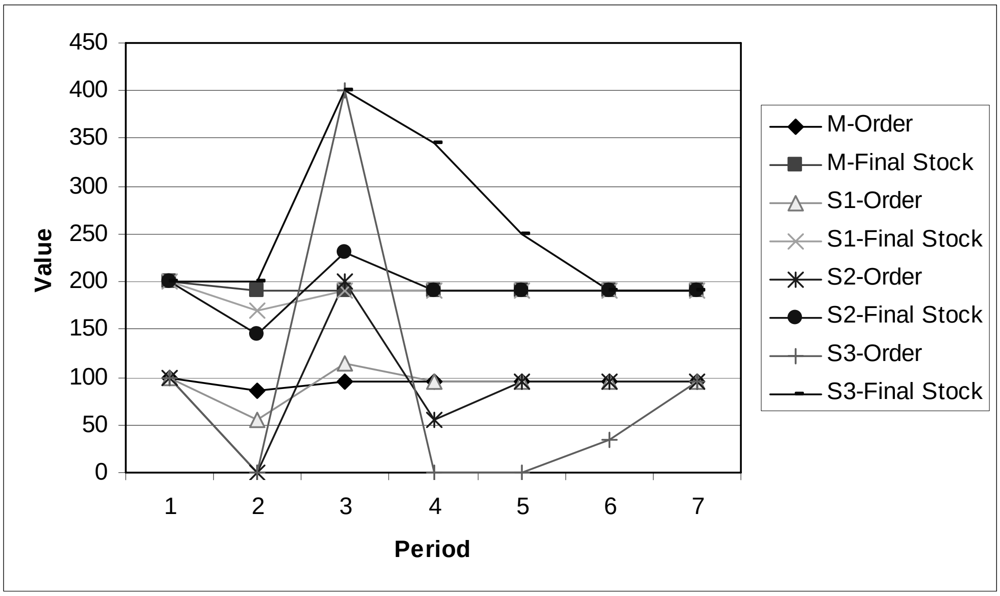


Figure 6: Order size and stock level variability in a supply chain during 7 periods (P_4).

It can be seen that the Manufacturer orders to the Supplier 1 (and further up the supply chain) experience demand fluctuation 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.

3.2 Case 2: Changing demand with 5 % up and down changes

The market demand has been running at a rate of 100 items per period, but after period 2 it is alternating between 95 and 100. The next period orders are predicted by a moving average of past *n* orders (*n* = 1, 2, 3). Three stock keeping policies (P_5 – P_7) for the stages in the chain are compared.

a) P_5: *n* = 1, see Table V and Fig. 7.

Table V: Changes of production orders and stock levels along supply chain – P_5

Simulation 5		Stock keeping policy:		M 1			S1 1			S2 1			S3 1
	Market	Manufacturer			Supplier 1			Supplier 2			Supplier 3		
Period	Demand	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final
1	100	100	100	100	100	100	100	100	100	100	100	100	100
2	95	100	90	95	100	80	90	100	60	80	100	20	60
3	100	95	105	100	90	120	105	80	160	120	60	260	160
4	95	100	90	95	105	75	90	120	30	75	160	0	130
5	100	95	105	100	90	120	105	75	165	120	130	200	165
6	95	100	90	95	105	75	90	120	30	75	165	0	135
7	100	95	105	100	90	120	105	75	165	120	135	195	165
		Stand.dev.:	8		Stand.dev.:	22		Stand.dev.:	62		Stand.dev.:	108	
		Max./Min.:		1,05	Max./Min.:		1,17	Max./Min.:		1,6	Max./Min.:		2,75

Alternating demand between 95 and 100 items per period has produced at *M* variation of order size from 90 to 105, at *S3* between 0 (production shut down in 4th and 6th period) and 260 (max. value in 3rd period). The ending supplier *S3* sees (in cycles) huge jumps in demand and then tremendous drops.

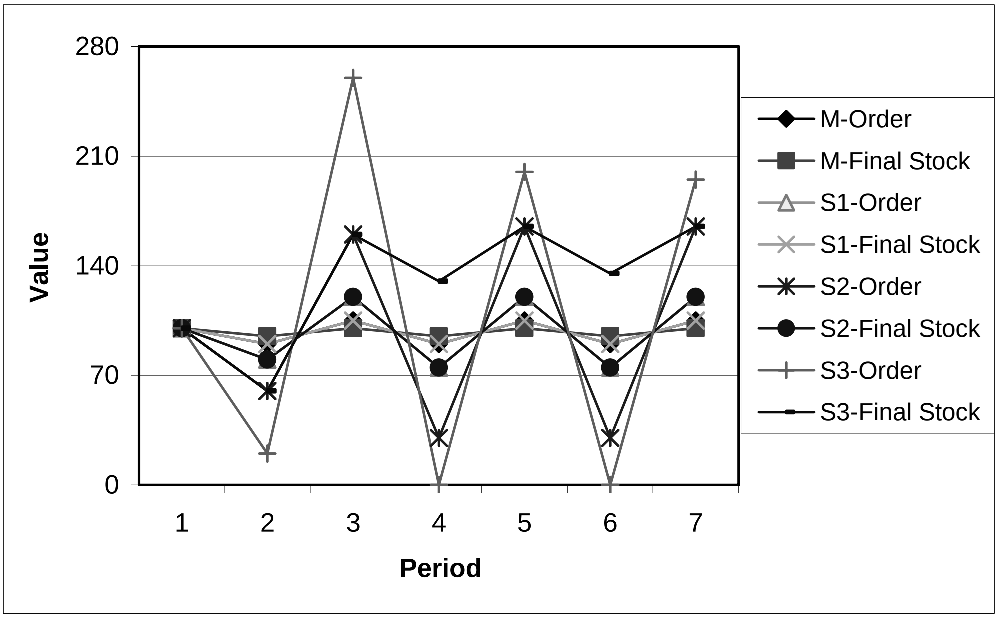


Figure 7: Order size and stock level variability in a supply chain during 7 periods (P_5).

b) P_6: $n = 2$, orders are predicted by a moving average of past 2 orders, see Table VI and Fig. 8.

Average of past 2 orders (alternating between 95 and 100) practically annuls the Bullwhip Effect, but at *S3* production rates still vary between 78 (in 2nd period) and 106 (in 4th period) items per period.

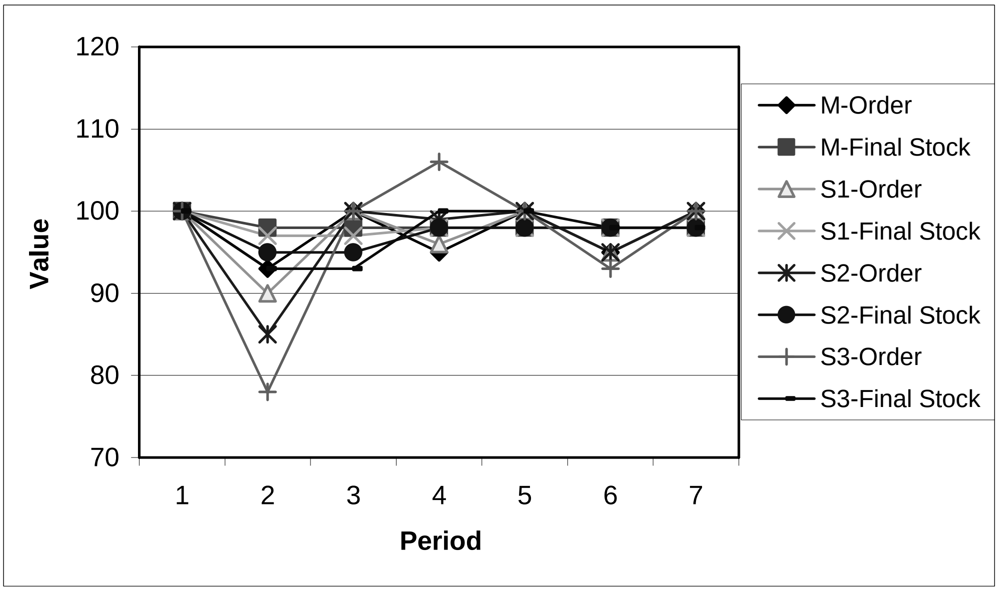


Figure 8: Order size and stock level variability in a supply chain during 7 periods (P_6).

Table VI: Changes of production orders and stock levels along supply chain – P_6

Simulation 6		Stock keeping policy:	M 1			S1 1			S2 1			S3 1	
	Market	Manufacturer			Supplier 1			Supplier 2			Supplier 3		
Period	Demand	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final
1	100	100	100	100	100	100	100	100	100	100	100	100	100
2	95	100	93	98	100	90	97	100	85	95	100	78	93
3	100	98	100	98	97	100	97	95	100	95	93	100	93
4	95	98	95	98	97	96	98	95	99	98	93	106	100
5	100	98	100	98	98	100	98	98	100	98	100	100	100
6	95	98	95	98	98	95	98	98	95	98	100	93	98
7	100	98	100	98	98	100	98	98	100	98	98	100	98
		Stand.dev.:	3		Stand.dev.:	4		Stand.dev.:	6		Stand.dev.:	9	
		Max./Min.:		1,02	Max./Min.:		1,03	Max./Min.:		1,05	Max./Min.:		1,08

c) P_7: n = 3, see Table VII and Fig. 9.

Table VII: Changes of production orders and stock levels along supply chain – P_7

Simulation 7		Stock keeping policy:	M 1			S1 1			S2 1			S3 1	
	Market	Manufacturer			Supplier 1			Supplier 2			Supplier 3		
Period	Demand	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final	Stock-start	Order	Stock-final
1	100	100	100	100	100	100	100	100	100	100	100	100	100
2	95	100	93	98	100	91	98	100	88	97	100	84	96
3	100	98	100	98	98	100	98	97	100	97	96	100	96
4	95	98	94	97	98	92	96	97	89	94	96	85	92
5	100	97	101	98	96	103	98	94	107	98	92	114	99
6	95	98	94	97	98	92	96	98	90	96	99	86	95
7	100	97	101	98	96	104	99	96	108	100	95	115	102
		Stand.dev.:	4		Stand.dev.:	6		Stand.dev.:	8		Stand.dev.:	13	
		Max./Min.:		1,03	Max./Min.:		1,04	Max./Min.:		1,06	Max./Min.:		1,11

The situation is in this case not critical, but it is becoming worse through the supply chain. The fluctuation of production rate has been the most drastic at *S3*, decreasing to 84 items a period, increasing to 115 items a period. The results with the policy P_6 are better.

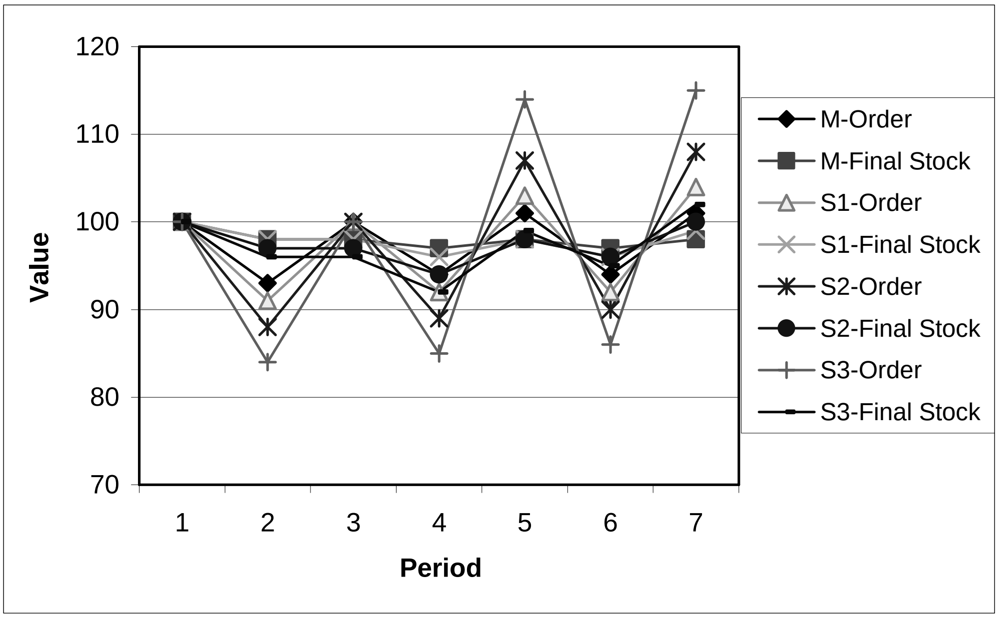


Figure 9: Order size and stock level variability in a supply chain during 7 periods (P_7).

4. ANALYSIS AND DISCUSSION

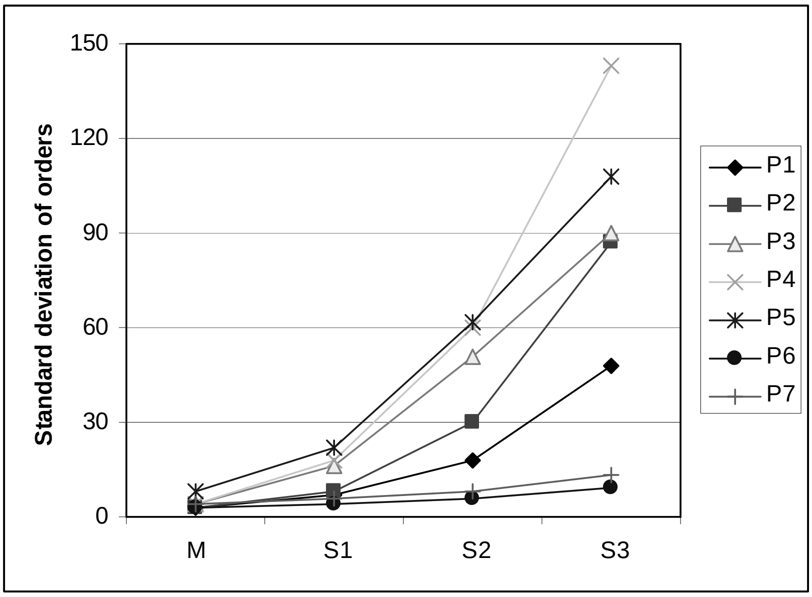
Relations between variable stocks for all applied policies are summarized in Table VIII. Max/Min ratios of stocks are calculated. Using P_6 policy causes even lower stocks ratio than the market's demand ratio (with the exception of *S3*).

Table VIII: Max/Min ratios of stocks for applied policies P_1 – P_7.

Stock keeping policy	Max/Min ratio (Stocks)			
	Manufacturer	**Supplier 1**	**Supplier 2**	**Supplier 3**
P_1	1,05	1,11	1,25	2,00
P_2	1,05	1,11	1,31	1,75
P_3	1,05	1,18	1,86	1,95
P_4	1,05	1,18	1,59	2,11
P_5	1,05	1,17	1,60	2,75
P_6	1,02	1,03	1,05	1,08
P_7	1,03	1,04	1,06	1,11

Remark: Market's Max/Min demand ratio: 1,05

The Bullwhip Effect is measured by the standard deviation of orders. For all examples the results are shown in Fig. 10. Policies P6 and P7 perform the best. But the orders' standard deviation (σ_o) larger than the demand standard deviation indicates that the Bullwhip Effect is present (amplification). Higher σ_o implies a wildly fluctuating order pattern, resulting in rapid changes of the production rates in each period (and higher production costs).



Remark:
Market's demand σ:
- for P_1 – P_4: $\sigma = 1,9$
- for P_5 – P_7: $\sigma = 2,7$

Figure 10: Standard deviation of orders for all chain stages in relation to stock keeping policy.

Additionally for the end supplier *S3* the ratio between standard deviation of orders (σ_o) and standard deviation of stocks (σ_s) is calculated for all policies (see Table IX). Lower ratio means that even smaller changes of production orders present quite big changes in necessary stock level. When the ratio is low the dependence between standard deviation of orders and standard deviation of stocks is more sensitive regardless of the (safety) stock level (some more in-depth analyses are needed).

Table IX: Ratios between standard deviations of orders and stocks for *S3*.

Policy	P_1	P_2	P_3	P_4	P_5	P_6	P_7
σ_o / σ_s	2,7	2,3	2,8	1,7	2,8	2,8	3,9

To reduce the Bullwhip Effect relating to our investigation we can make some statements:

- decreasing stock keeping policy through the chain is more appropriate – upstream suppliers should reduce the safety stock level (see P_2),
- in case of alternating demand changes the demand pattern should be studied (determination of the cycle length *n*) and then the forecast of next period's demand could be determined by moving average of past *n* demands (see P_6),
- reasonable limits of maximal stocks, which should never be exceeded, must be defined.

The presented cases are very real. We have seen examples where suppliers have been shut down completely for many periods when the orders at the end of the supply chain are reduced only slightly! Retailers often make unexpected promotions to increase the demand at some periods. As a result, although the demand for 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 [20].
It is important to note that besides stock effects, similar problems would be extant in manufacturing capacity requirements, response times, and obsolescence.

5. CONCLUSION

The Bullwhip Effect is one of the main reasons for inefficiencies in supply chains. 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 [19]. The main cause of variability through the chain is a perfectly understandable and rational desire by the different links in the supply chain to manage their production rates and stock levels sensibly. The Bullwhip Effect can occur if changes in demand requirements are moving slowly through the chain or large lot sizes and infrequent orders cause lags in information, or insufficient sharing of accurate information is typical. 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.

In this paper we have experimented with two special cases of a simple four-stage single-item supply chain using 7 inventory control policies. In the first case with the initial stable demand and later a single 5 % reduction in demand the orders were calculated to assure stocks proportional to the last demand. In the second case with alternating demand (± 5 %) we used the moving average forecasting technique. Results are discussed and shown in tables and charts. They illustrate how the parameters of the inventory control policy induce or reduce the Bullwhip Effect. It is generally accepted that the more data we use from the past, the closer our forecast will approach the average demand. In our future work we will define some new criteria for numerical evaluation of the Bullwhip Effect based on the supply chain simulation parameters and results.

We conclude that improper demand forecasting may have a devastating impact on the Bullwhip Effect, resulting in significant inventory and production costs increase. Inflexible production with frequently switching production rates up and down is almost impossible.

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