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STUDY OF INVENTORIES IN SUPPLY CHAINS USING SPREADSHEET SIMULATION

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ABSTRACT
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 all realistic conditions and effects. An important logistical effect is known as the Bullwhip Effect. It represents the amplification of the order variability in a supply chain. It is understood that demand forecast variance contributes to that effect in the chain. Increasing variability of orders and inventory levels 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. In the paper we investigated a special case of a four-stage supply chain using different inventory control policies. We used spreadsheet simulation in MS Excel. Results are discussed and shown in tables and charts. The Bullwhip Effect is measured by the standard deviation of orders. Some possible improvements are discussed in the last part of the paper.
Keywords: supply chain, bullwhip effect, inventory control policy, order variability

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) [1,2].
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 [3]. 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.
A number of researchers designed games to illustrate the Bullwhip Effect. The most famous game is the "Beer Distribution Game" [4,5]. It was developed at MIT to simulate the Bullwhip Effect in an experiment, and has been used widely for nearly five decades.
Bullwhip Effect is also attributed to the separate ownership of different stages of the supply chain. Each stage tries to amplify the profit. 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 [6,7].

2. 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. 1). 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.

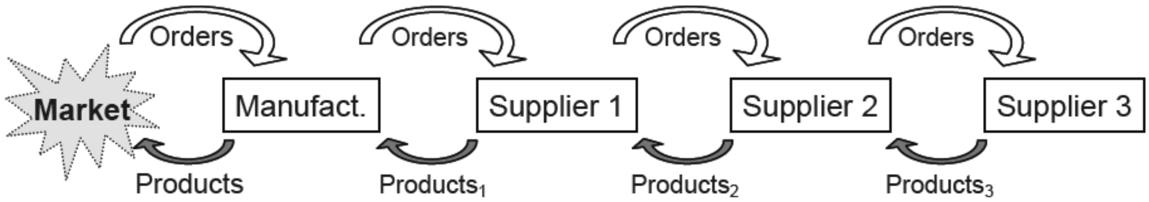

Figure 1. Presentation of a four-stage supply chain.

3. CASE: 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 ($P_1 - P_3$) for the stages in the chain are compared.

a) P_1: *n* = 1, see Table 1 and Fig. 2.

Table 1. Changes of production orders and stock levels along supply chain – P_1.

Period	Market Demand	Manufacturer Stock-start	Manufacturer Order	Manufacturer Stock-final	Supplier 1 Stock-start	Supplier 1 Order	Supplier 1 Stock-final	Supplier 2 Stock-start	Supplier 2 Order	Supplier 2 Stock-final	Supplier 3 Stock-start	Supplier 3 Order	Supplier 3 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.

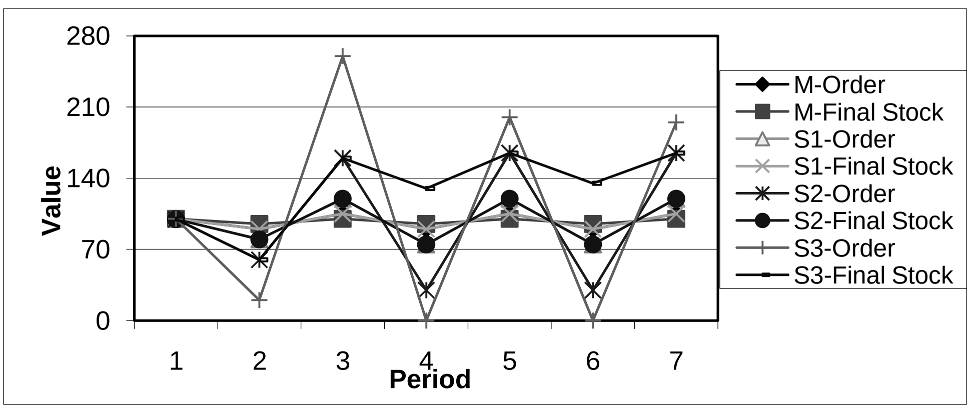

Figure 2. Order size and stock level variability in a supply chain during 7 periods (P_1).

b) P_2: n = 2, orders are predicted by a moving average of past 2 orders, see Table 2 and Fig. 3.

Table 2. Changes of production orders and stock levels along supply chain – P_2.

Period	Market Demand	Manufacturer			Supplier 1			Supplier 2			Supplier 3		
		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

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.

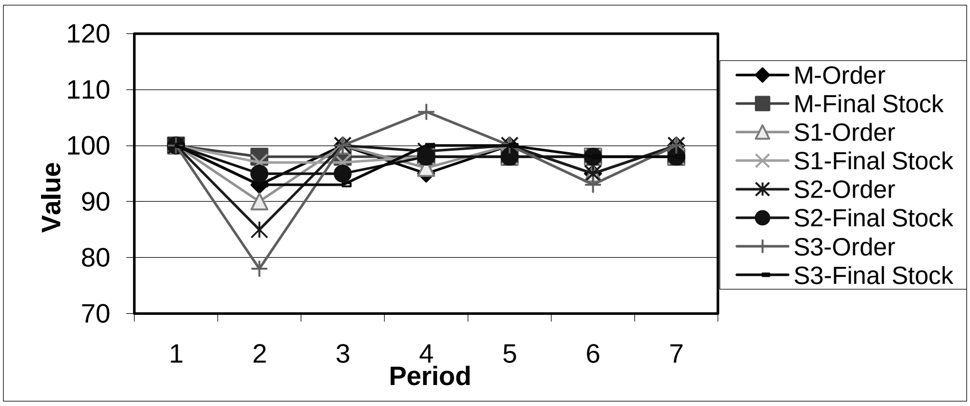

Figure 3. Order size and stock level variability in a supply chain during 7 periods (P_2).

c) P_3: n = 3, see Table 3 and Fig. 4.

Table 3. Changes of production orders and stock levels along supply chain – P_3.

Period	Market Demand	Manufacturer			Supplier 1			Supplier 2			Supplier 3		
		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_2 are better.

4. DISCUSSION

Max/Min ratios of stocks were compared. Using P_2 policy causes even lower stock's ratio than the market's demand ratio (1,05), with the exception of *S3*. The situation is more critical at P1 policy.
The Bullwhip Effect is measured by the standard deviation of orders. Policies P2 and P3 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).

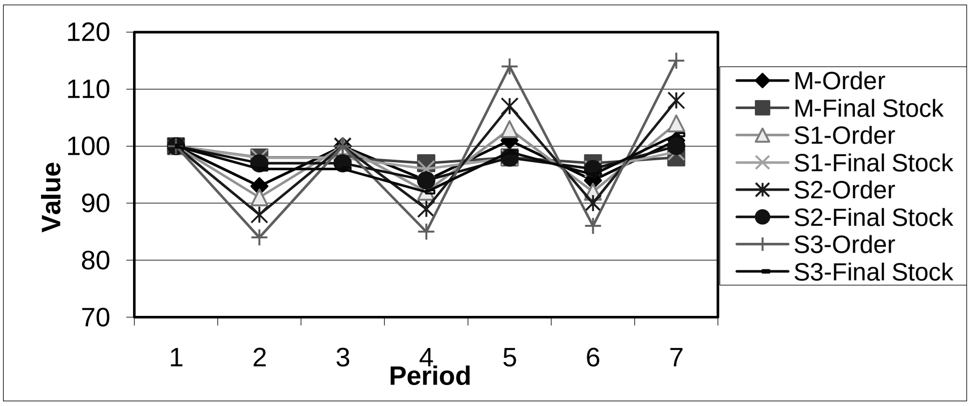

Figure 4. Order size and stock level variability in a supply chain during 7 periods (P_3).

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 4). 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 4. Ratios between standard deviations of orders and stocks for S3.

Policy	P_1	P_2	P_3
σ_o / σ_s	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,
- 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_2),
- reasonable limits of maximal stocks, which should never be exceeded, must be defined.

5. CONCLUSION

In this paper we have experimented with a special case of a simple four-stage single-item supply chain using 3 inventory control policies. In the 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.

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