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BULLWHIP EFFECT ANALYSIS BY SIMULATION EXPERIMENTS IN ECHELON UNDER (R, s, S) INVENTORY POLICY

Samir Žic [a], Tonči Mikac [a], Irena Kos [b], Jasmina Žic [b]

[a] University of Rijeka, Faculty of Engineering, Croatia
[b] Vorax d.o.o., Rijeka, Croatia

Abstract: *In order to improve their performance on market, modern companies and supply chains are focused to reduce all excess costs, especially those related to inventories and logistics. However, reducing such costs must be taken into consideration seriously, since there are many difficult-to - predict interdependencies between variables of periodic (R, s, S) review inventory systems. In order to set up the inventory system in most optimal manner or predict its behavior, simulation experiments should be executed.*

Keywords*: Bullwhip effect, Supply chain, Simulation experiment, Inventory management*

1. INTRODUCTION AND PREVIOUS RESEARCHES

Modern companies and supply chains compete globally in a large number of independent variables with non-trivial dependencies. Together with constant fluctuations in inventory levels, structural and logistical characteristics of a supply chain also change. Therefore, influential variables of supply chain inventory management systems need to be monitored continuously; forecasted and optimal business scenarios in response to future events should be calculated. In order to optimize the properties of the supply chain inventory systems it is necessary to thoroughly investigate the interdependence of variables in inventory management system.

Researches from Houlihan [1987], Taylor [1999], and Fransoo and Wouters [2000] describe the bullwhip effect in Make-to-stock supply chains. Works from Baganha and Cohen [1998], Graves [1996], and Cachon [1999] are dealing with the increased deviation of demand information when transferred away from the market, and Chen et al. [2000] and Metters [1997] were trying to analytically quantify the consequences of the bullwhip effect. Forrester in his work [1958] describes tendencies of business systems to amplify, cause delay and distort information about actual market demand as this information moves further away from it. This phenomenon was first recognized by the manufacturers with own inventories of raw materials, semi-finished and finished products intended for sale. Lee et al. [1997a], [1997b] call this phenomenon the Bullwhip effect since small changes or variances in customer's demand often cause a large increase in orders received in companies within the supply chain towards the direction of the manufacturer.

A small variance in actual consumer demand can result in the various companies operating at different stages of a supply chain being subject to the bullwhip effect (Fig. 1). Forrester's work concluded that the bullwhip effect occurs due to unstable business conditions and proposes a methodology of simulation of dynamic models of business systems. The study by Lee et al.

showed that the bullwhip effect is caused by the following effects: (1) Forrester effect, or lead-times and demand signal processing, (2) Burbidge effect, or order batching, (3) Houlihan effect, or rationing and gaming, and (4) promotion effect, or price fluctuations.

Sterman's work [1989a] determined an additional cause of the bullwhip effect which occurs due to the limited human possibilities of perception and management of complex dynamic systems. The above, as well as numerous other studies have shown the negative impact of behavioral causes on the supply chain.

Increase of customer demand gives rise to a number of problems: the accumulation of excess inventories at certain times followed by serious inventory shortages and low customer fill rate, excess or insufficient capacity, unstable and inefficient production leading to higher costs resulting from the corrective actions that have to be taken.

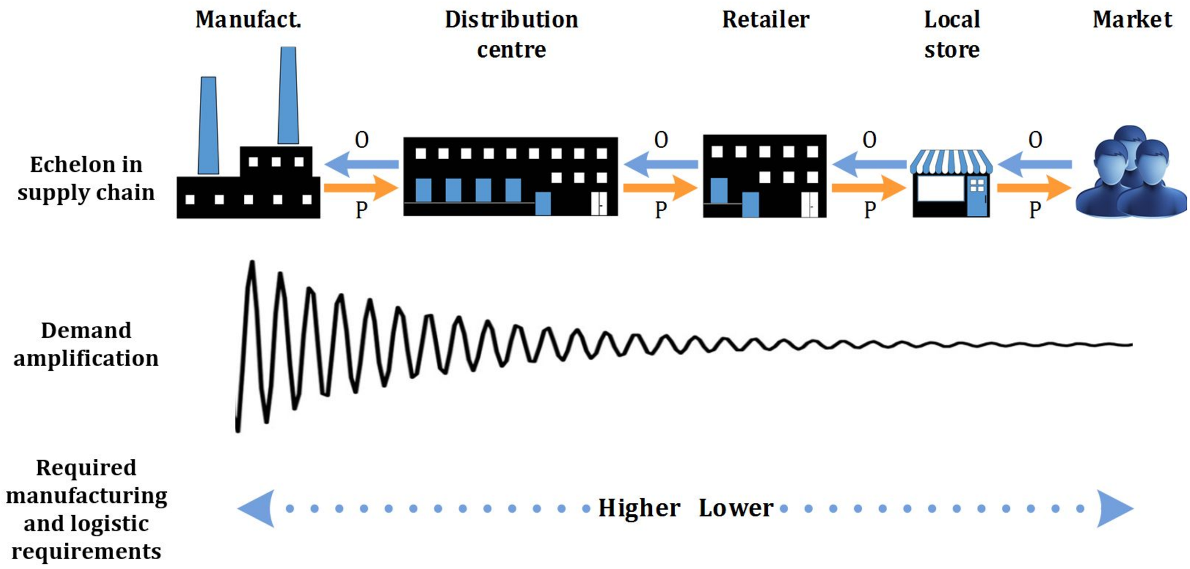

Figure 1. Oscillation demand in the supply chains in the direction of the manufacturer

This type of deviation from the actual market demand causes significant costs and ultimately calls into question the existence of the supply chain for continuously increased costs, overload production, increased logistics requirements, insufficient or excessive inventories and thus insufficient storage and logistics capacities, resulting with a low percentage of meeting market demands. Due to the significant and negative impact of the bullwhip effect in supply, and thus in many other business indicators, the bullwhip effect becomes the research subject of numerous scientists and business experts.

This paper is organized as follows. Section 2 presents the setup of simulation experiments and experimental work with a 300 simulation experiments of periodic (R, s, S) review inventory system. In section 3, the conclusions are provided.

2. EXPERIMENTAL WORK

Demand within the supply chain is often random and unpredictable. Where it is not possible to accurately predict market demand, simulation experiments are used to examine the occurrence and size of the bullwhip effect. The positive results of the application of simulation experiments were confirmed by works of Ouyang and Daganzo [2008] and Baccadoro et al. [2008].

Chen et al. [2000] suggested that the bullwhip effect could be measured by the ratio of σ^2/μ between the input and output flows in each echelon in a supply chain; or between the final demand and the manufacturer when the whole supply chain is to be evaluated as can be seen in equation (1).

$$Bullwhip = \frac{\sigma_O^2 / \mu_O}{\sigma_D^2 / \mu_D} \quad (1)$$

where:

- O represents orders; D represents demand
- σ^2 - variance of demand observed in echelon
- μ – mean demand observed in echelon

2.1. Setup of simulation experiments

Experiments will simulate performance of periodic (R, s, S) review inventory system of one echelon in traditional supply chain. Monitoring period is 5000 days (several times longer than similar researches have worked with), mean demand μ = 99,998, variance of demand observed in echelon σ^2 = 1857,532 and distribution of demand is generated as normal, independent and identically distributed. Simulation experiments were created and analyzed by OptimInventory software in cases where fill rate of 99,9%±0,01% is achieved. This tight tolerances are needed in order to reduce the number of results and to get better understanding of (R, s, S) inventory policy. Echelon does not backlog unfulfilled demand.

Variables on the supplier side of echelon are as follows: lead time is 3 days, observed echelon and its supplier work every day in week and minimal order quantity is 100 products.

OptimInventory is a computer application that simulates real world inventory conditions in either individual echelons or whole supply chain. It offers in depth and intelligent analysis of multiple types of inventory systems allowing significant reductions in costs and simultaneously increasing customer satisfaction and fill rate on the market.

2.2. Experimental work

Best simulation experiment (SE) is considered to be the one that has lowest level of inventory but manages to satisfy desired fill rate of 99,9%±0,01%. This simulation experiment will be assigned with ID value 1, after which the software will increase level of inventories and recalculate fill rate.

It is important to know that with inventory level increase (especially order up to level – S); many different factors affect the inventory system. Only those experiments that satisfy fill rate will be analyzed and the software will calculate following variables in each of them: lower inventory level (s), upper inventory level (S), exact fill rate, minimal and maximal stock level, average inventory level, number of shipments, total number of products shipped, bullwhip factor etc.

For this paper, 300 simulation experiments were examined and results are shown on figures 2 to 6.

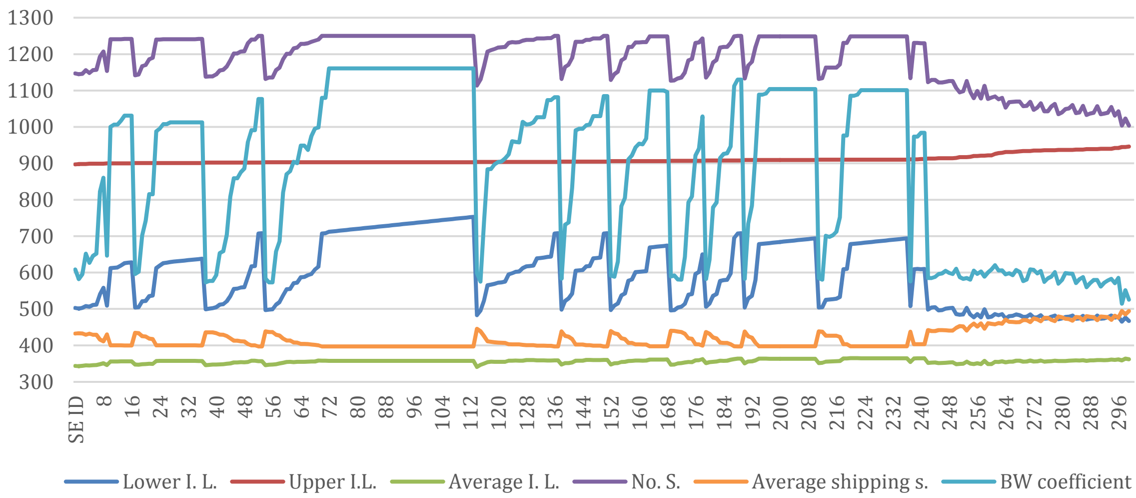

Figure 2. Results of SEs sorted by ascending simulation experiment's ID

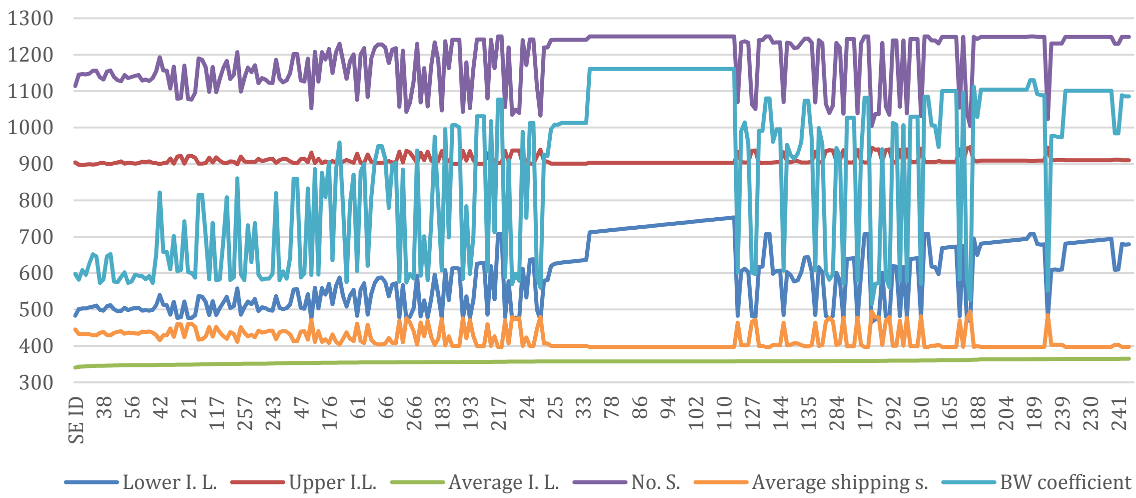

Figure 3. Results of SEs sorted by ascending values of average daily inventory level (average I. L.)

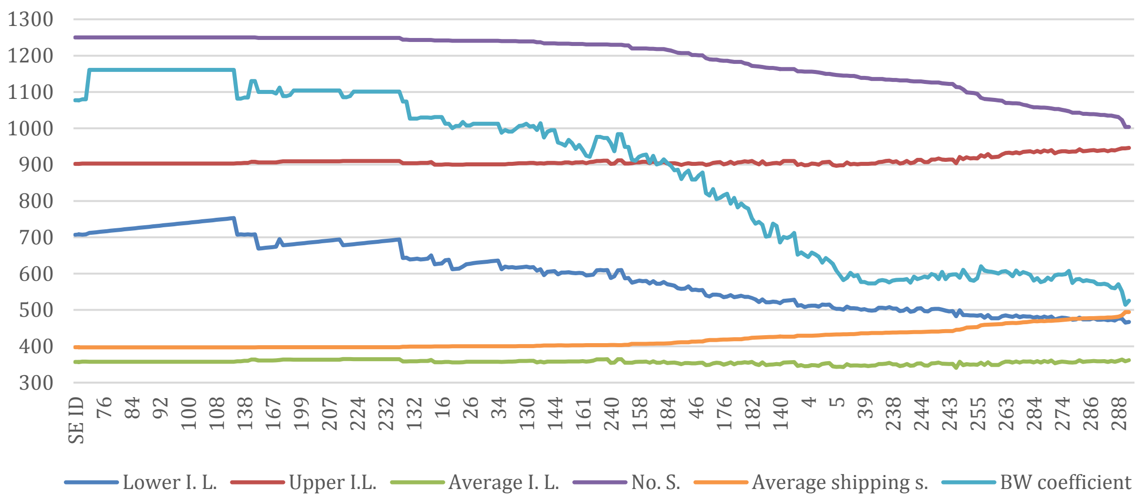

Figure 4. Results of SEs sorted by descending value of required number of shipments (No. S.)

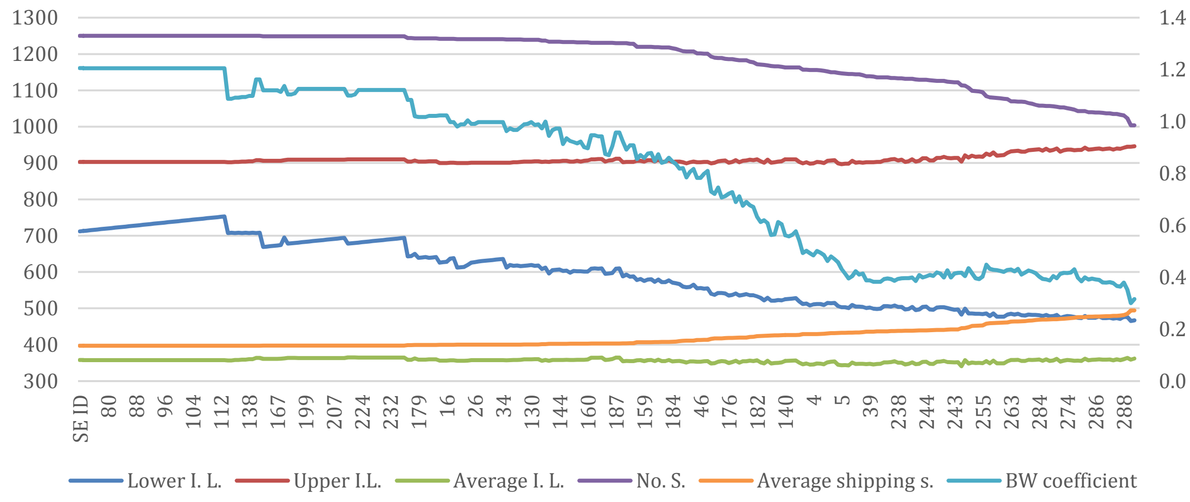

Figure 5. Results of SEs sorted by ascending values of minimal required average shipping size

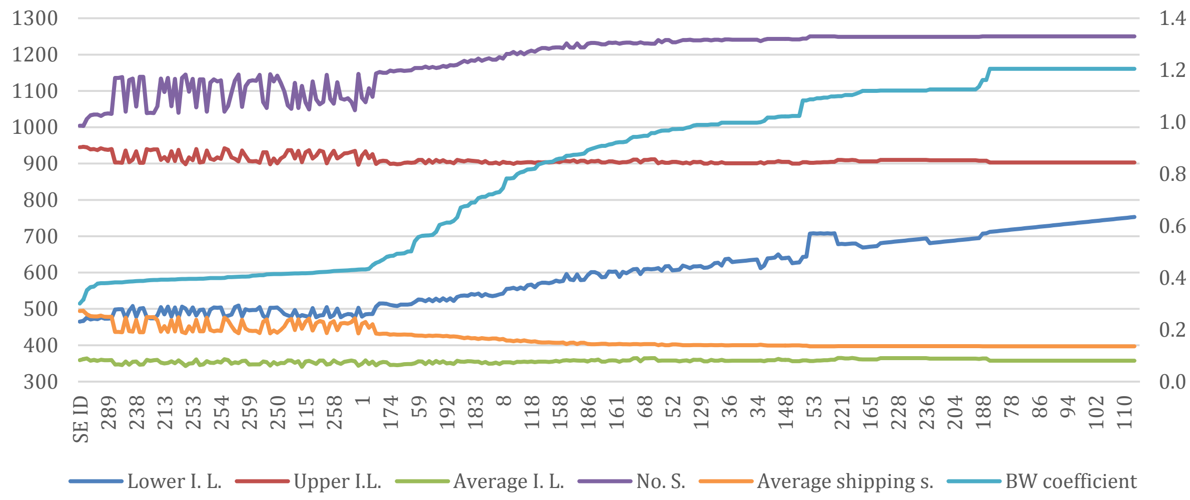

Figure 6. Results of SEs sorted by ascending value of Bullwhip coefficient (secondary Y axis)

3. CONCLUSION

From these 300 simulation experiments it is noticeable that important variables of inventory management system show significant oscillations resulting in more or less negative effects on echelon. This concludes with previous work on SEs used in (R, s, S) inventory systems. It is also important to notice that these simulations analyzed only one product in echelon and if we assume that bigger retailer stores can hold up to 80.000 products it is clear that fine tuning of inventory system is impossible without advanced simulation software such as the one used in this paper.

Another important thing noticeable from figures 2-6 is the fact that with reducing number of required shipments, bullwhip effect significantly reduces in an absolute value and its variance is significantly lowered too. Therefore this research shows that by setting characteristic inventory levels higher than needed and respectively reducing number of deliveries to specific echelon, one can actually reduce the bullwhip effect. If this setup is monitored regularly, negative effects such as increase in average inventory level can be avoided.

This level of analysis is computationally very intensive but offers benefits that, in the long run, offer significant savings and make echelons and supply chains more effective and competitive on global market. In the future we plan to explore the behavior of periodic (R, s, S) review inventory system with different delivery terms, batching size and backlog performance.

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