

Approximation of Bullwhip Effect Function in A Three - Echelon Supply Chain

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Abstract. Supply chain includes all members who directly or indirectly involved in fulfilling a customer need. Successful lead of each supply chain requires extensive efforts and various policies that facilitate management of the main issues of supply chain, including materials, capital and information. One of the important and broad management issues in supply chain management is the bullwhip effect problem. This effect causes improper planning, increased inventory levels, reduced profits, and reduced service levels and other harmful effects on the organization. The aim of this paper is focused on studying the impact of some factors and estimating regression function, on bullwhip effect in a three-echelon supply chain including Manufacturer, Wholesaler and Retailer by considering customer demand on a Poisson process. In each echelon of supply chain six different scenarios by combining Moving Average, Exponential Smoothing and Regression methods have been used for forecasting demand. At the next step, the impact of the scenarios on Bullwhip, was evaluated by factor design and simulation methods. Finally A 2^6 experimental design is used to identify critical factors and estimate regression of Bullwhip Effect Function in a Three-Echelon Supply Chain. We have concluded that by approximating this function, if the values of different function's variables be given, the expected bullwhip effect can be estimated.

Keywords: supply chain, bullwhip effect, forecasting method, simulation, ANOVA.

1. Introduction

Supply chains are gradually became the dominant paradigm in trade and business world. Forrester, which many consider him as the founder of supply chains topics, stating that management is subject to a change that puts the success of organizations dependant on effective interaction between flow of information, materials, capital, manpower and equipment, established an idea that is today an irrefutable theory in various businesses areas [16]. It might be impossible to imagine an organization regardless of its position in a supply chain. Developing concept of the supply chain is in a way which some experts believe that competition from companies already having been transferred to the chains. In fact, major expansion of supply chains issues has been in the last two decades and many large international organizations such as Cisco, Dell, Nike, Procter & Gamble and Zara have benefited from [12]. Chopra (2006) defines supply chain as all members who directly or indirectly involved in fulfilling a customer need. Usually a supply chain has been established from five-stage of customers, retailers, wholesalers/ distributors, producers and suppliers of parts / raw materials[8]. Successful lead of each supply chain requires extensive efforts and various policies that facilitate management of the main issues of supply chain, including materials, capital and information. One of the important and broad management issues in supply chain management is the bullwhip effect problem. In short the bullwhip effect refers to the law that fluctuations in demand of the last level customer of the supply chain increases by moving along the supply chain echelons [18]. This effect was first discussed by Forrester in his book "Industrial dynamics". He considered this effect as a change in organizational behavior [10]. This effect

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causes improper planning, increased inventory levels, reduced profits, and reduced service levels and other harmful effects on the organization and on this basis many research have been done on it. Researchers have mentioned different reasons for this effect, such as demand forecasting, batch ordering, price fluctuations, rationing decisions, delays and inconsistency in the chain structure [18]. Lee and Padmanabhan (1997) have introduced four essential factors in creating the bullwhip effect: Demand forecasting, batch ordering, price fluctuations, rationing and shortages[14]. Paik and Baghchi (2005) have also considered updating forecasted demand, batch ordering, material delays, information delay, purchasing delays and number of the chain levels, as the factors influencing bullwhip effect. Extensive research has been done in the field of effects of various factors on the bullwhip effect in supply chains, so far. A group of researchers have been investigated the effects of different methods of forecasting on this effect[17]. Among them Chen et al (2000a) evaluate and compare the impact of exponential smoothing and moving average methods on bullwhip effect in a simple two-echelon supply chain, including a retailer and a producer[6]. Chen et al (2000b) have also studied the effects of two factors, demand forecasting and order preparation time, on the bullwhip effect in a two-echelon supply chain, and extended it for multi-echelon chains[7]. Zhang (2004) studied the effect forecasting methods on bullwhip effect in a simple inventory system and came to the conclusion that the forecasting methods affects on bullwhip effect[19]. Carbonneau et al (2006) investigated the impact of application of learning methods, such as neural networks, recursive neural networks and support vectors machines, for forecasting, on the bullwhip effect and compared it with traditional methods such as moving average and linear regression[4]. Bayraktar et al (2008) investigated the effect of exponential smoothing method on the bullwhip effect in electronic supply chain management. They have developed a simulation program to select the best exponential smoothing parameters in supply chain[2].

Other researchers have studied the effect of other factors on bullwhip effect. Disney and Towill (2003) compared the expected performance of a VMI supply chain to the traditional serially linked supply chains with emphasis on their impact on the bullwhip effect[9]. Chatfield et al (2004) investigated the effect of random preparation time, information sharing and the quality of shared information in a periodic order-up-to level inventory system[5]. Machuca and Barajas (2004) using a web-based supply chain simulator, studied the effect of EDI on reducing bullwhip and average cost of inventory[15]. Kelepouris et al (2008) studied the way replenishment parameters and information sharing influence bullwhip effect and design a model for two-echelon supply chain[13]. Jakšič and Rusjan (2008) also studied impact of replenishment policies on bullwhip effect[11]. Agrawal et al (2009) investigated the effect of preparation time and information sharing on bullwhip effect in a two-echelon supply chain[1]. Bottani et al (2010) in their paper studied the effect of EPC Network and RFID technology on the reduction of bullwhip effect and consequently the safety stock of a three-echelon supply chain in Italian Fast Moving Consumer Goods[3].

This paper is focused on studying the impact of some factors on bullwhip effect in a three-echelon supply chain. The paper is organized as follow. In the second section, the studied issue and the desired parameters and assumptions are described. Next, the scheme used for this paper is described. Testing and analyzing the model has been studied in the forth section. Finally, conclusion and suggestions for future research are presented.

2. Modelling And Analysis

2.1. Problem Definition

This paper has studied the impact of a wide range of factors on the bullwhip effect in a supply chain. The supply chain and considered factors are shown in Figure 1.

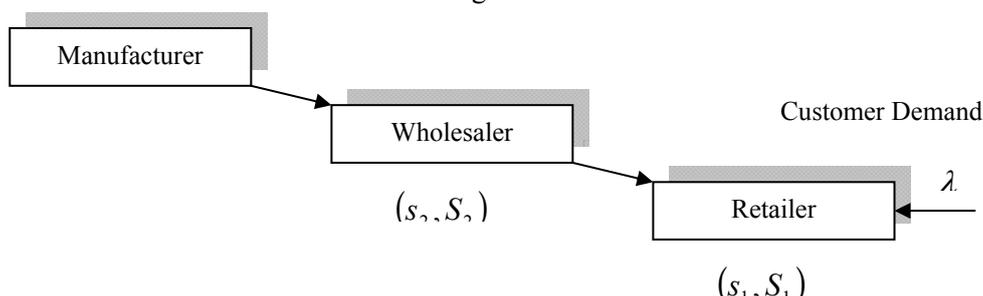


Figure 1. The Three-Echelon Supply Chain

In this supply chain, customer demand is based on a Poisson process with a rate of λ that enters retailers. The inventory policy of retailers is Constant Review (s_1, S_1) . Also, if the lack of inventory, deficient demand is lost. While retailer's inventory level reaches s_1 , $S_1 - s_1$ is ordered. This order is sent to wholesaler and it will supplied with the lead time of LT_1 .

The wholesaler's demand is based on the retailer's demand and his inventory policy is Constant Review (s_1, S_1) , too. By reaching the re-ordering point, the wholesaler sends his order to manufacturer and it will supplied with the lead time of LT_2 . The manufacturer's demand is based on the wholesaler's orders.

Each echelon's of chain uses one of Moving Average, Exponential Smoothing and Regression methods for forecasting demand. With the assumption that none of the components uses the same method for forecasting, six different combinations of the three forecasting methods are described in Table 1.

Table 1. Different combinations of the forecasting methods in the supply chain

Senario	Retailer	Wholesaler	Manufacturer	Senario	Retailer	Wholesaler	Manufacturer
1	(1)	(2)	(3)	4	(2)	(3)	(1)
2	(1)	(3)	(2)	5	(3)	(1)	(2)
3	(2)	(1)	(3)	6	(3)	(2)	(1)
		(1) Moving Average	(2) Exponential Smoothing			(3) Regression	

Considering the above factors evaluated in this study that their impact on the bullwhip effect is desired, include the following six elements: Demand rate (λ), LT_1 , LT_2 , Ordering Policy (Table 1), Forecasting parameters consisting Exponential Smoothing coefficient (α) and the number of periods in Moving Average method (n). Since this study is to investigate the effect of these factors on the bullwhip effect, therefore, to measure the bullwhip effect, we use the ratio of the manufacturer's orders variation to the variance of the demand at the lowest level of the chain. The studied problem is shown in figure 1.

$$\text{bullwhip effect} = \frac{\text{Supplier's order variance}}{\text{variance of the demand at the lowest level of the chain}} \quad (1)$$

Another important point in this regard is the ordering policy of retailer and wholesaler. According to studies done in this field, each of the (s_1, S_1) and (s_2, S_2) are calculated as follow.

2.2. Design of Experiment

In the present study and to evaluate the impact of each of the six factors considered on the bullwhip effect, factor design and simulation are used. Considering the relatively high number of factors were considered, therefore a 2^6 experimental design is used to identify factors and estimate regression function. Table 2 shows each of the factors studied and their upper and lower limits of initial 2^6 design.

Table 2. Considered factors and their limits in initial 2^6 design

Factor	λ	LT_1	LT_2	Forecasting Policy	α	n
Upper	1	1	10	(2)	0.15	2
Lower	100	30	60	(6)	0.65	10

For LT_1 , period time (T) is equal to 30 days and for LT_2 it is 60 days. The positive and negative levels of forecasting policy are randomly selected among the six scenarios considered in Table 1. Accordingly, our 2^6 factor design consists of 64 experiments that in each experiment, the considered factors are set in their upper or lower limits as shown in table 2. Each experiment consists of 4 iterations. Also to estimate the bullwhip effect in each experiment, 100 demands according to the demand rate λ is created and the bullwhip effect is calculated based on it and with regard to the level of other factors. Calculated bullwhip effect in each of the combination treatments are shown in Table 3.

Table 3. The results of designed experiments bullwhip effect

					λ							
					+				-			
					LT_1							
					+		-		+		-	
					α							
+		-		+		-		+		-		
Forecasting scenario	+	LT_2	n	+	642036.42	641686.97	610478.21	609460.43	642.4	641.65	610.31	609.23
				-	685208.61	684862.56	687296.01	652915.04	685.39	648.87	687.62	652.87
				+	265397.14	265244.19	232404.28	231647.17	265.28	265.36	267.26	231.74
				-	270439.36	270190.27	272125.84	236488.30	270.76	270.00	237.21	236.47
				+	305378.51	261312.08	268743.62	121233.67	303.19	262.89	301.90	225.26
				-	305193.47	259752.05	300782.73	225338.56	303.25	260.39	302.20	260.41
	-	LT_2	n	+	159929.35	155548.59	124561.66	121447.27	161.87	154.90	124.49	121.17
				-	159032.86	155106.74	157923.41	121554.55	159.26	153.93	124.65	121.29

2.3. Results analysis

In order to analyze experimental data the software DOE ++ is used. The results are shown in Table 4.

Table 4. ANOVA table

P Value	F Ratio	Mean Squares [Partial]	Sum of Squares [Partial]	Degrees of Freedom	Source of Variation
Model	63	1.16E+11	1.85E+09	8490.7608	3.34E-302
Main effects	6	8.86E+10	1.48E+10	6.79E+04	
2-Way Interaction	15	2.41E+10	1.61E+09	7387.0078	3.65E-256
3-Way Interaction	20	3.39E+09	1.70E+08	779.2567	4.14E-172
4-Way Interaction	15	1.66E+08	1.11E+07	50.9202	1.50E-58
5-Way Interaction	6	6.40E+07	1.07E+07	49.0287	3.25E-36
6-Way Interaction	1	7.74E+06	7.74E+06	35.5983	1.15E-08
Residual	192	4.18E+07	2.18E+05		
Pure Error	192	4.18E+07	2.18E+05		
Total	255	1.16E+11			

In this case the estimated regression function will be a six degrees function with 64 statements that analyzing and estimating it will have great difficulty. Therefore, in order to analyze the regression function Stepwise regression was used. Based on this method the estimation of the regression function will be as follows:

$$y = 7656.02 - 1841.01 * \text{senario} - 126.145\lambda + 25.99 * lt_1 - 289.66 * lt_2 + 159.64 * n + 2105.79 * \alpha + 63.27 * \text{senario} * \lambda - 6.43 * \text{senario} * lt_1 + 70.47 * \text{senario} * lt_2 - 29.37 * \text{senario} * n - 877.98 * \text{senario} * \alpha + 1.09 * \lambda * lt_1 + 5.12 * \lambda * lt_2 - 2.918 * \lambda * n + 53.19 * \lambda * \alpha + 0.27 * lt_1 * lt_2 + 4.9 * lt_1 * n - 99.05 * lt_1 * \alpha - 4.15 * lt_2 * n + 71.51 * lt_2 * \alpha + 70.21 * n * \alpha$$

For this model we have $R-Sq = 96.85$ and $R-Sq(adj) = 96.56$ which shows the estimated model significantly explained the variability in the dependent variable. Now, if the values of different function's variables be given, the expected bullwhip effect can be estimated by above Eq.

2.4. Conclusion

The bullwhip effect is one of the challenging problems, in front of supply chain management. The intensification of demands variation during the supply chain's stages, create some Destructive effects on the performance of supply chain. So, the Knowledge of management about bullwhip effect provides a weapon for managers to prevent its negative effects. In this paper, an algorithm based on designed experiment and regression analysis is developed to approximation of a function that express the bullwhip effect of a three echelon supply chain based on its effective factors. The approximated function's goodness of fit is validated via its coefficient of determination (R^2). The approximated bullwhip effect function can be used to estimate the bullwhip effect of a three echelon supply chain in a given situation. This methodology can be used in approximation of bullwhip effect functions in systems with different structures and managers can applied this function to balance their decisions based on its impact on supply chain's bullwhip effect. The complementary researches can be done on the supply chains with different structures, like 4 echelon or multi

layer echelons, or change other assumptions, are considered in this paper, on the inventory policy, lead time, and etc.

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