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Procedia Social and Behavioral Sciences

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Procedia - Social and Behavioral Sciences 138 (2014) 289 – 297

The 9th International Conference on Traffic & Transportation Studies (ICTTS'2014)

An Optimization Model for Mitigating Bullwhip-Effect in a Two-Echelon Supply Chain

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Abstract

Bullwhip effect (BWE) is a conundrum, addressing the shift of a seemingly steady inventory demand into enhancing demand fluctuation in upstream supply chain. On upswing it can be very expensive in terms of stock out costs and capability on-costs while on the downtrend it can be costly in terms of stock carrying and obsolescence costs. To ameliorate the firm's efficiency, in this paper we propose an optimization model to mitigate the bullwhip effect in a two-echelon supply chain. The objective function is to minimize the sum difference between the actual order and the demand forecast of multiple products and the exponential smoothing technique, is performed to forecast demand of products. The model is further testified by an illustration of five products and it shows that the model facilitates to dig out an optimal set of parameters to mitigate the BWE.

Peer-review under responsibility of Beijing Jiaotong University(BJU), Systems Engineering Society of China (SESC).

Keywords: bullwhip effect; exponential smoothing; inventory management; supply chain management

1. Introduction

Bullwhip effect (BWE) is an observed phenomenon addresses the shift of a seemingly steady inventory demand into enhancing demand fluctuation in upstream supply chain. At the order side of supply chain It results in an amplified variation of information regarding demand. The supply chain management (SCM) conception has become more challenging since the start of the 20th century owing to the global contest in the world market. And BWE always has been remained and known as a hot and key advance research enigma amidst researchers, practitioners and academician since the commencement of 20th century.

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Peer-review under responsibility of Beijing Jiaotong University(BJU), Systems Engineering Society of China (SESC).
doi:10.1016/j.sbspro.2014.07.206

Bullwhip effect presents a continuous conundrum for managers to sort out in an international supply chain. In SCM an unevenness in order sizes surges as demand signs propagate upstream. It has a striking impact on firm's upswing as well as on downtrend, ensuing stock out costs, capability on-costs, and poor customer service owing to inaccessible reserves, stock carrying and obsolescence costs due to inordinate inventory. Unsettled planning for production and like high shipment costs.

Since BWE is the outcome of the lack of information transparency which is the upshot of the lack of coordination amidst the supply chain participants. Therefore right coordination is the key to reduce the BWE.

Isolated forecasting induces BWE, especially when demand forecasts modified primed on orders instead of customer demand and normally ruminates when collaborator works in isolation and try to optimize their personal objective role. Consequently, a very weak harmonization and lack of coordination exist amidst supply chain participants. The fixed charges and economies of scale urging mass sales passing at month's end, price forwarding, advance buying, stockpiling at the end of month/year to satisfy goals. And also owing to rational conduct of supply chain partners and gaming dearth i.e. limited supplies assigned in ratio to called for amounts instead of the capability to sell) etc.

In reality, bullwhip effect or whiplash effect adverts to an internal phenomena rather than extraneous where orders to the manufacturers lean to have bigger difference than sale to the vendees (i.e. variability in demand) and the uncertainty proliferates upswing in an augmented way i.e. variance magnification. BWE, at the firm level, is considered as a reaction to the external environment while the industry is regulated and molded by the natural world. It was posited that BWE is simply a phenomenon colligated with inadequate information flows and is an upshot of rational reaction by the participants.

The information about the exact order sizes to manufacturers, suppliers, and demands from potential customers, distributors, wholesalers, retailers, can help you in a usable way to increase reliability, delivery uptime, and reduce your operational costs.

In supply chain, "information flow" amid participants is a vital factor for coordination and directly impresses production plans, inventory control and delivery scheduling of single comrades in the supply chain. The paper addresses the proposed model to mitigate the bullwhip effect in a multi product supply chains. The objective function is to minimize the sum differences, which instances the BWE, between the actual orders and the demands forecast of each product. The exponential smoothing technique is executed to forecast demand of every product. The result shows that the model facilitates to dig out an optimal set of parameters to mitigate the BWE by setting parameters employing an optimization function. The remaining portion of the paper is organized as follows. In section 2 the literature review is narrated. Section 3 is dedicated to describe our optimization model for a two-echelon supply chain. An illustration and computational results are further presented in Section 4. In Section 5, the paper ends with conclusion.

2. Literature Review

The basic term bullwhip effect is not a new phenomenon and it has been one of the major challenges in supply chains as a magnified variation of information about demand at the order side of the supply chain. It is conceived as a sort of difference amplification of orders across demands. Simon (1952), Forrester (1958), are reckoned as pioneers who surveyed BWE through simulation analysis and named it as" Demand amplification". In 1961, Forrester exemplifies the effect in sequential analysis and remarks that it is an upshot of industrial organizations' dynamic or time changing conducts regarding policies and brings about features and unwanted demeanors in supply chain.

BWE was primitively struck by the Logisticians in unlike cases in the Procter & Gamble (P&G). Besides P&G, firms like Hewlett- Packard in the computer industry, these cases were introduced to educates globally via a simulation business game named the "Beer Distribution Game". Four actors in this game are required, who make autonomous inventory decisions without knowing about other chain players, banking merely on adjacent player as the only informant. The test depicts the fact that the impact of distorted information is one of the reasons of BWE and the orders' variances magnify as one proceeds in the supply chain. Sterman (1989) infers the process as a result of actor's irrational conduct or" misperceptions of feedback". A methodology posed by Jack (1961) for ascertaining manufacturing and inventory regarding the problem of bullwhip effect. The writer presented that conventional stock control routines primed on an Economic Order Quantity (EOQ) standard would lean to magnify demand variation by a supply chain. Burbidge (1984) was the pioneer to render a rigorous explanation of the BWE; “if demand for products is transmitted along a series of inventories using stock control ordering, then demand creation will increase with each transfer”.

Lee et.al (1997a) introduced the concept of BWE with an analytical frame. In Lee et.al (1997b), the implications of BWE to managers was elaborated. In an endeavor to key out the substantial grounds of bullwhip effect, this observed phenomenon comprises of two main categories, viz behavioral grounds and operational grounds. The behavioral grounds have chiefly been examined through case studies or tested in laboratory setting. A simulation instrument such as Beer game has been used in laboratory setting for empirical analysis of behavioral grounds. The bullwhip’s operational grounds encompass the sixteen main causes, viz. Demand forecasting, order batching , price fluctuation , rationing and shortage gaming (Lee. et.al. 2004), non-zero lead time (Heydari et.al. 2009) inventory policy (Aharon et.al. 2009), replenishment policy (Su et.al. 2008), improper control system, multiplier effect (Geary et.al. 2006), lack of transparency (Sohn et.al. 2008, Agrawal et.al. 2009), number of echelons, capacity limits (Alony et.al. 2007), lack of synchronization (Erkan et.al. 2008), misperception of feedback, local optimization without global vision, company processes (Moyaux et.al. 2007). These basic grounds of BWE, has urged researchers to stress on rendering techniques to mitigate the BWE. While analyzing the behavioral grounds, we recognized that both operational and behavioral grounds need to be conceived in an integrated way so as to mitigate or eradicate BWE.

In 2000, Chen et.al assessed the impact of demand forecasting on the bullwhip effect for an easy two-stage supply chain comprising of a single retailer and a single producer, In order to evaluate the mean and variance of the demand, the retailer employs a simple moving average forecast.

Chen et.al presumed that the retailers utilizes a forecasting technique called exponential smoothing and it was establish that the extent of the enhancement in variability depends on both the technique employed by the retailer for forecasting and the processing temperament of the customer demand. Jaksic and Rusjan (2008) expressed that definite policies for replenishment can be persuaders of BWE and advised that the BWE can be averted.via suitable choice and employ of definite parameters of rules , Rong, et.al analyzed the supply chain disruptions which induces reverse bullwhip effect (RBWE). They employed a simulation survey game viz. “Beer Distribution Game” and the reason was discovered that the participants modify their order placing demeanor which induces the BWE.

Bowman (1963) explicated a strategy with a feedback controller about relative inventory position that meliorated bullwhip demeanor. It was publicized that bullwhip effect can always be averted via proper selection of the feedback parameters.

3. Proposed Model for a Two-Echelon Supply Chain

The basic term bullwhip effect is not a new phenomenon and it has been one of the major challenges in supply chains as a magnified variation of information about demand at the order side of the supply chain. It is conceived as a sort of difference amplification of orders across demands. Simon (1952) and Forrester (1958) are reckoned as pioneers who surveyed BWE through simulation analysis and named it as” Demand amplification”. In 1961, Forrester exemplifies the effect in sequential analysis and remarks that it is an upshot of industrial organizations’ dynamic or time changing conducts regarding policies and brings about features.

3.1. Problem Description

The BWE addresses that the variance of orders is amplified as one moves up the supply chain. In other words there is usually a surge in the sum difference between the actual order and the demand forecast. The proposed model is viewed so as to analyze the capability of the exponential smoothing technique employed for forecasting demand. The intention of this model is to minify the sum difference to such an extent that will mitigate/eliminate the variance amplification i.e. BWE.. This technique is executed in order to mitigate or eradicate the happening of the BWE phenomenon. The advised model comprises of an individual retailer with multiple products and an individual producer. Twelve months for multiple products are considered as a planning horizon. The retailer compiles the orders from the producer at the start of each period t. Once the customer demand is noticed and satisfied, the retailer accumulates the unsatisfied demand in order that he could detect the new inventory level and forecast demand for the next period. A replenishment order $O_{i,t}$ is placed with the producer at the end of the period. The lead time for replenishment is stipulated amid the time for placing order and then compiling order by the retailer.

3.2. Denotations explanation

$O_{i,t}$ = Delivered order quantity of product i, primed on demand forecast for future period t , i=1,2,…,n; t=1,2,….m
$O_{i,t-1}$ = Formerly placed order quantity of product i for the period $(t-1)$.
$\widehat{D}_{i,t}$ = Demand forecast for future period for product i. i=1,2,…,n, t=1,2,….m
$\widehat{D}_{i,t-1}$ = Demand forecast for Former period for product i. i=1,2,…,n, t=1,2,….m
$D_{i,t}$ =customer demand for the present period for product i, observed from the preceding period, i=1,2,…,n, t=1,2,….m
$IP_{i,t}$ = Currently available inventory position of product i. i=1,2,…,n, t=1,2,….m, (stock on order plus net safety stock).
$IP_{i,t-1}$ = Inventory position of product i, for the former (previous) period $(t-1)$, i=1,2,…,n, t=1,2,….m
R_i = review interval for product i
$T_{i,L}$ = replenishment lead time for product i. i=1,2,…,n
K_i = desired service level time for product i. i=1,2,…,n
$R_i + T_{i,L}$ =a duration rather than just replenishment lead time T_L for product i
θ_i = exponential smoothing parameter for product i. i=1,2,…,n
δ_i = inventory position smoothing parameter for product i. i=1,2,…,n
η_i = order quantity smoothing parameter for product i. i=1,2,…,n
K_i = desired service level time for product i. i=1,2,…,n
$T_{i,L}$ = replenishment lead time parameter for product i. i=1,2,…,n

3.3. Objective Function

A surge in the sum difference between the actual orders quantity and the demand forecast amount is not tolerated. The objective function is to minimize the sum difference, i.e. the bullwhip effect, between the actual order and the demand forecast of every product. The exponential smoothing is performed to forecast demand of every product.

$$\min \sum_{i=1}^{n} \sum_{t=1}^{m} (O_{i,t} - \widehat{D}_{i,t})^2$$

3.4. Constraints

$$\hat{D}_{\mathrm{i,t}} = \hat{D}_{i,t-1} + \theta_i (D_{i,t} - \hat{D}_{i,t-1}), \quad i = 1, 2, \cdots, n, t = 1, 2, \cdots, m \tag{1}$$

$$IP_{i,t} = IP_{i,t-1} + O_{i,t-1} - D_{i,t}, \quad i = 1, 2, \cdots, n, t = 1, 2, \cdots, m \tag{2}$$

$$O_{i,t} = D_{i,t} + (1-\eta_i)(O_{i,t-1} - \hat{D}_{\mathrm{i,t}}) + \delta_i (\hat{D}_{\mathrm{i,t}}.T_{i,L} + K_i \hat{D}_{\mathrm{i,t}} \sqrt{R_i + T_{i,L}} - IP_{i,t}), \; i = 1, 2, \cdots, n, t = 1, 2, \cdots, m \tag{3}$$

$$\theta_i, \delta_i, \eta_i, K_i \in [0.1, 0.9], \quad i = 1, 2, \cdots, n \tag{4}$$

$$T_{i,L} \in [1, 30], \, integer, \quad i = 1, 2, \cdots, n, t = 1, 2, \cdots, m \tag{5}$$

Equation (1) is employed to estimate the demand forecast for future period for product i, while Equation (2) is about the currently available inventory position for product i, during period t. In equation (3), delivered order quantity of product i, primed on demand forecast for future period t is calculated by employing different parameters mentioned in section 2.2.

Constraint (4), represents the parameters, $\theta_i, \delta_i, \eta_i, K_i$, employed in computation for product i, and the value of each ranges from 0.1 to 0.9. e.g. if $\theta_i = 0$ then $\widehat{D}_{i,t} = \widehat{D}_{i,t-1}$, which intends that the demand remains the same throughout, whilst if $\theta_i = 1$ then $\widehat{D}_{i,t} = D_{i,t}$, which intends that the demand forecast equals to observed demand. These two extreme cases are either illogical or idealistic. Hence, here θ_i is purposely but logically assumed to belong to the interval of $[0.1, 0.9]$. That is the ratio of variance across the demand forecast. Likewise the same situation goes with the other three parameters, which means δ_i, η_i, K_i belong to the same interval of $[0.1, 0.9]$. Constraint 5, describes the replenishment lead time for product i, and the value ranges from 1 to 30. Similarly if $T_{i,L} = 0$, it depicts that there is no lead time. This is an idealistic consideration which is impracticable. Hence it is advised that the value ranges of $T_{i,L}$ must be adjusted from 1 to 30. It is obvious that the computed parameters prove a substantial capability to render a noticeable fit with the desired demand which shows the minimum bullwhip effect. Hence, it is to certify that the proposed model has revealed nifty capability to mitigate the bullwhip effect.

4. An illustration and computational results of proposed Model

To exemplify the proposed model, the following illustration is executed to appraise the smooth forecasting technique and to demonstrate the bullwhip diminution effect.

To testify the efficiency of the technique, we consider a retailer who collects orders of multiple products from manufacturer in a consumer market. The retailer attempts urgently to place orders for products in an extremely competitive market and hence follows a policy to avert overlooked collections. The retailer advances setting of products for a planning horizon agreeing to sale of multiple products. Since the retailer has to place orders for multiple products at manufacturer in accordance with the demand forecast for the entire products contingent for the planning horizon therefore, the retailer decides to cuts down its orders rate in accordance with its demand forecast.

To examine the efficiency and adaptability we execute the technique for multiple products. Table 1 denotes the exact value of types of specifics at the start of the planning horizon and table 2 displays the current customer demand for each of the five products during the planning horizon.

Innovating LINGO-11 to this model illustrates that the disparity amidst the orders and the demands is like an explicit illustration to the BWE. The intention of employing LINGO-11 is to evaluate the technique and to ameliorate the stable state exactness and also to eradicate the disparity so as to equate the order amount to the demand quantity.

Table. 1 The initial-stage data of Multiple products

Type of Specifics	Products				
	A	B	C	D	E
Review interval	3	5	3	4	2
Inventory position	500	300	400	200	250
Initial demand forecast	800	400	600	500	400
Initial order	500	800	900	400	300

Table. 2 Customer demand for multiple products

Months	Product				
	A	B	C	D	E
Jan	1000	1000	1200	600	500
Feb	800	1000	600	700	600
March	950	700	1000	700	700
April	500	600	700	800	700
May	800	1000	820	650	750
June	600	800	680	850	800
July	750	900	850	700	1000
Aug	1200	850	600	750	700
Sep	1000	600	750	1050	800
Oct	900	650	950	900	900
Nov	1500	850	900	1000	850
Dec	800	900	1000	850	1200

Table. 3 Variables including parameters employed for calculation

Product	parameters				
	θ_i	δ_i	η_i	K_i	I_L
A	0.1256	0.3374	0.6603	0.4119	1.000
B	0.4652	0.2791	0.9000	0.2567	1.000
C	0.3088	0.2919	0.6527	0.1045	1.000
D	0.9000	0.3283	0.5109	0.1005	1.000
E	0.9000	0.2322	0.6988	0.2713	1.000

Table. 4 Orders placed to producer for multiple products

Months	Product				
	A	B	C	D	E
Jan	1222	900	1002	734	550
Feb	1041	1212	578	954	778
March	909	650	937	816	873
April	401	438	790	816	739
May	628	1174	782	535	758
June	646	852	643	865	857
July	753	919	831	754	1222
Aug	1305	853	608	726	548
Sep	1216	434	679	1286	664
Oct	878	554	1042	1076	1035
Nov	1489	959	1056	970	925
Dec	986	1024	1057	682	1491

By employing LINGO-11, we obtain the optimum results. Table 3 shows the requisite parameters employed for various products and their values obtained during analysis while Table 4 depicts the resulting quantity of inventory orders placed to producer for five different products during the planning horizon. Table 5 displays the resulting amount of demand forecast for five different products and Table 6 renders the bullwhip effect for multiple products during the planning horizon.

Table. 5 Demand forecast for multiple products

Months	Product				
	A	B	C	D	E
Jan	825	679	785	590	490
Feb	822	828	728	689	589
March	838	769	812	699	689
April	796	690	777	790	699
May	796	834	791	664	745
June	772	818	756	831	794
July	769	856	785	713	979
Aug	823	853	728	746	728
Sep	845	736	735	1020	793
Oct	852	696	801	912	889
Nov	933	767	832	991	854
Dec	917	829	884	864	1165

Table. 6 BWE for multiple products

Months	Products				
	A	B	C	D	E
Jan	157609	48841	47089	20736	3600
Feb	47961	147456	22500	70225	35721
March	5041	14161	15625	13689	33856
April	156025	63504	169	676	1600
May	28224	115600	81	16641	169
June	15876	1156	12769	1156	3969
July	256	3969	2116	1681	59049
Aug	232324	0	14400	400	32400
Sep	137641	91204	3136	70756	16641
Oct	676	20164	58081	26896	21316
Nov	309136	36864	50176	441	5041
Dec	4761	38025	29929	33124	106276
Sum	**1095530**	**580944**	**256071**	**256421**	**319638**

The scope of the result reflects that smaller the sum difference, the lower will be the BWE. As Table 6 indicates, the optimum sum differences for Product A to E are kept as low as 1095530, 580944, 256071, 256421 and 319638, respectively, with the total objective value 2508604. The Monthly data also represents some interesting findings, such as zero BWE for Product B in August, and the 2nd and 3rd lowest BWE for Product C and E, both in May.

5. Conclusion

In this article we innovate the conception of BWE and empirically analyze its grounds in order to mitigate its detrimental impact on the supply chain. In our proposed optimization model, we have sought to execute the exponential smoothing technique to forecast demand of multiple products and to bring down the BWE in supply chains. The variables include a few parameters in the formulations of demand forecast and actual order. The objective function is the sum differences of the actual orders and demand forecasts for all products. Ultimately an illustration with five products is executed to testify the effectiveness of the proposed model. We conceptualized that the work demonstrated in this paper is complementary to the creative part on BWE. It is also axiomatic that this technique is helpful for the decision makers to reduce uncertainty and to consistently achieve the targets against the BWE problem.

Acknowledgements

The authors are grateful to the reviewers whose comments ameliorate the quality of the paper. The writers would like to recognize the financial aid rendered by National Science Foundation of China (Grant No. 61164003).

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