A literature review on bullwhip effect in supply chain

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***Abstract* - The Bullwhip Effect is a major problem in supplier and forecast driven industries. Information distorted in one end of supply chain creates larger variations and inefficiencies at upper stage of supply chain. If Customer demand is slightly fluctuated then Supplier Demand is highly fluctuated compared to Customer Demand means variability of orders increases as move up in the supply chain from Customer to Manufacturer to Supplier. Optimal ordering policies, Information sharing strategy, choosing proper forecasting method can reduce bullwhip effect.**

***Index Terms* –Bullwhip effect, Demand fluctuation, Supply chain management**

I. INTRODUCTION

Bullwhip effect highly causes upper stages of supply chain. Various researches have done in previous years to controlling bullwhip effect. The objective of this research paper is to understand the nature of bullwhip effect and study the different controls, models, policies and methodologies implemented to reduce bullwhip effect in past recent years. There are about 40 recent research papers studied and reviewed in this paper.

The bullwhip effect can be explained as an occurrence detected by the supply chain where orders sent to the manufacturer and supplier create larger variance then the sales to the end customer. These irregular orders in the lower part of the supply chain develop to be more distinct higher up in the supply chain. This variance can interrupt the smoothness of the supply chain process as each link in the supply chain will over or underestimate the product demand resulting in exaggerated fluctuations [41].

II. LITERATURE REVIEW

S.M. Disney and D.R. Towill (2001) presented a discrete control theory model of a generic model of a replenishment rule. From this model, an analytical expression for bullwhip is derived that is directly equivalent to the common statistical measure often used in simulation, statistical and empirical studies to quantify the bullwhip effect. The way to minimise the bullwhip problem with given policy is to increase the average age of forecasts and reduce the rate at which inventory correction are accounted for in the production distribution-ordering algorithm [1].

Roger D. H. Warburton et al. (2004) used new solution to the supply chain equations to develop optimal ordering policies that reduce the Bullwhip Effect, and generally improve inventory management. A surge in demand depletes inventory, and they have determined the critical parameters that replenish the inventory without any overshoot. Managerially useful ordering strategies have emerged from the mathematics. The replenishment delay emerges as responsible for much of the rich and complex behaviour associated with the inventory response [2].

J. Dejonckheere et al. (2004) examined the beneficial impact of information sharing in multi-echelon supply chains. They compare a traditional supply chain, in which only the first stage in the chain observes end consumer demand and upstream stages have to base their forecasts on incoming orders, with an information enriched supply chain where customer demand data (e.g. EPOS data) is shared throughout the chain. Two types of replenishment rules are analysed: order-up-to(OUT) policies and smoothing policies (policies used to reduce or dampen variability in the demand).In the traditional supply chain, such a smoothing policy can lose its dampening abilities at higher levels of the chain, whereas in the information enriched chain, smoothed order rates may be realised by all levels in the chain [3].

HX Sun and YT Ren(2005) shown the quantification results of the bullwhip effect for simple, two-stage, supply chains consisting of a single retailer and a single manufacturer. Order-up-to inventory policy is assumed. The modelling results of three important forecasting methods (moving average, exponential smoothing, and minimum mean square error) are studied. A comparison is made between these forecasting methods, and some practical guidelines are developed to help managers to select a forecasting method that yields the greatest desired benefit. Results shown that increase in variability will be greater for longer lead times. However, the size of the impact does depend on the forecasting methods [4].

Jeon G. Kim et al. (2006) included stochastic lead time and provide expressions for quantifying the bullwhip effect, both with information sharing and without information sharing. They estimated the mean and variance of lead-time demand (LTD) from historical LTD data, rather than from the component period demands and lead time. Nevertheless, they also calculated the variance amplification like Chen et al., but with gamma lead times.They analysed that bullwhip effect is caused by human intervention and by disruptions in information flow in the supply chain [5].

Andrew Potter and Stephen M. Disney et al. (2006) considered scenarios where orders are placed only in multiples of a fixed batch size, for both deterministic and stochastic demand rates. They derive a closed form expression for bullwhip when demand is deterministic. This is validated through a simple model of a production control system. An expression for bullwhip in a ‘‘pass on orders’’ scenario with stochastic demand is also derived and validated. Using simulation the impact of changing batch size on bullwhip in a production control system is shown. It has been shown that bullwhip levels from batching can be reduced if the batch size is a multiple of average demand [6].

Diana Yan Wu and Elena Katok. (2006) investigated the effect of learning and communication on the bullwhip effect in supply chains. Using the beer distribution game in a controlled laboratory setting, they test four behavioural hypotheses – bounded rationality, experiential learning, systems learning, and organizational learning – by systematically manipulating training and communication protocols. This result indicates that while training may improve individuals’ knowledge and understanding of the system, it does not improve supply chain performance unless supply chain partners are allowed to communicate and share this knowledge. The bullwhip effect is caused by insufficient coordination between supply chain partners [7].

S. Gearya et al. (2006) described 10 published causes of bullwhip effect, all of which are capable of elimination by re-engineering the supply chain. To re-engineer the supply chain to systematically remove all avoidable causes of uncertainty requires smooth material flow, smooth and transparent information flow, time compression of all processes, holistic controls and the abolition of all interfaces, especially those causing functional silos to exist [8].

Sunil Agrawal et al. (2007) analyzes a two echelon (warehouse–retailer) serial supply chain to study the impact of information sharing (IS) and lead time on bullwhip effect and on-hand inventory. The results are compared with the previous research work and an easy analysis of the various bullwhip effect expressions under different scenarios, is done to understand the impact of IS on the bullwhip effect phenomenon. It is shown that some part of bullwhip effect will always remain even after sharing both inter as well as intra echelon information. Further, with the help of a numerical example it is shown that the lead time reduction is more beneficial in comparison to the sharing of information in terms of reduction in the bullwhip effect phenomenon [9].

YanfengOuyang (2007) characterized the stream of orders placed at any stage of the chain when the customer demand process is known and gave an exact formula for the variance of the orders placed. The paper also derives robust analytical conditions, based only on inventory management policies, to predict the presence of the bullwhip effect and bound its magnitude. The general framework proposed in this paper allows for any inventory replenishment policies, any ways of sharing and utilizing information, and any customer demand processes. Even with shared information the bullwhip effect will arise as long as the inventory gain is positive. To completely eliminate the bullwhip effect, suppliers have to seek policies that have negative inventory gains [10].

LIU Hong and WANG Ping (2007) focused on the impact of difference demand forecasting technology on the bullwhip effect and establishing the two-level supply chain bullwhip effect theory models and simulation models on the basis of AR(1) stationary demand process. For l=value of lead time and l*=critical value of lead time, When the lead time $l < l^*$, [1]MA forecasting method will be better than MSE-optimal method for decreasing the bullwhip effect. [2]When $l > l^*$,MSE-optimal forecasting method is better than the MA for decreasing bullwhip effect. [3]When $l < l^*$, EWMA forecasting method will be better than MSE-optimal method for decreasing the bullwhip effect. [4]When $l > l^*$, MSE-optimal forecasting method is better than the EWMA for decreasing bullwhip effect [11].

Huynh TrungLuong and Nguyen HuuPhien(2007) conducted research to fill this gap by first dealing with AR(2) demand process and investigating the behaviour of the developed measure with respect to autoregressive coefficients and order lead-time. Extension to the general AR(p) demand process is then considered. When both first-order and second-order autoregressive coefficients are positive, the bullwhip effect exists and it will increase as lead-time goes up. However, in other value ranges of autoregressive coefficients, the behaviour of bullwhip effect is very complicated and it is very interesting to note that the bullwhip effect does not always exist and it is not always correct that the bullwhip effect will increase when lead-time increases [12].

Liwei Baiet al. (2008) proposed a control technique for reducing the bullwhip effect, or more generally the demand variability in supply chains. The method is effective and easy to implement in practical management and supply chain systems. The idea is to stabilize the inventory control policy to dampen the effect of propagation by imposing a correlated control to the original order. When there are more stages in a supply chain, the impact of bullwhip effect would become more significant [13].

Truong Ton HienDuc et al. (2008) quantified the impact of the bullwhip effect for a simple two-stage supply chain with one supplier and one retailer. Assuming that the retailer employs a base stock inventory policy, and that the demand forecast is performed via a mixed autoregressive moving average model, ARMA (1,1), they investigate the effects of the autoregressive coefficient, the moving average parameter, and the lead time on the bullwhip effect.The bullwhip effect does not always exist, but its existence depends on the values of autoregressive and moving average coefficients of the ARMA model. In fact, the bullwhip effect occurs only when the autoregressive coefficient of the demand process is larger than the moving average parameter. The bullwhip effect does not always increase when the lead time L increases [14].

David Wright and XinYuan(2008) provided a simulation of the effect of improved forecasting methods, and finds that Holt’s and Brown’s methods substantially mitigate the bullwhip effect across a range of performance metrics. It is shown that a relatively slow adjustment of stock levels, combined with a slightly more rapid adjustment of supply line levels provides the most stability when combined with either Holt's or Brown's forecasting method [15].

Marlene Silva Marchena (2010) showed that for certain types of demand processes, the use of the optimal forecasting procedure that minimizes the mean squared forecasting error leads to significant reduction in the safety stock level. This highlights the potential economic benefits resulting from the use of this time series analysis [16].

Ling-Tzu Tseng et al. (2011) proposed a prediction system based on an evolutionary least-mean-square algorithm to estimate the downstream demand, which consequently enables the batch ordering of manufacturer to close the estimated inventory level to cope with the bullwhip effect by taking into account the holding and backorder costs [17].

BelarminoAdenso-Dıaz et al. (2011) presented an analysis of the influence of factors identified as significant with regard to the bullwhip effect in forward chains on the appearance of the bullwhip effect in environments of reverse logistics and its pattern of evolution along the chain. They do so by using a simulator that extends the logic of the Beer Game to this type of environment. The adjustment controllers are the factors that increase bullwhip more significantly and there is also an important influence of the final demand variance, followed by the forecasting technique used, the final demand variability, the delays between the chain's links and shared information being available [18].

SunongWua et al. (2011) applied ABMS (Agent-based model and simulation), as one of the scientific and dynamic research methods for complex system, to establish a supply chain model and determine its abundant bullwhip effect phenomenon under swarm platform. The ABMS has been developed based on Agent modelling, of which its modelling and simulation is worked out as one of the scientific and dynamic research methods for complex system. It proves the ABMS is the effective way to study the bullwhip effect in complex supply chain [19].

Surjeet Dalal and Dr. Vijay Athavale (2012) proposed case-based multi-agent systems that acquire the conclusion on origin of solving ancient times trouble solving incident. The multi-agent system is the budding procedure of Artificial Intelligence system. It is used to tenacity real time exertion faced in the business actions. The multi-agent system is self-possessed of the numerous intelligent agents that are autonomous, proactive and decision-taking power.
The case-based multi-agent system executes the activities in efficient way to reduce the bullwhip effect [20].

Ahmed Shaban et al. (2012) investigated the impact of various classical ordering policies on ordering and inventories in a multi-echelon supply chain through a simulation study. In addition a proposed ordering policy that relies on information sharing in a decentralized way is proposed to mitigate the bullwhip effect.A proposed ordering policy that relies on information sharing in a decentralized way is to proposed to mitigate the bullwhip effect and overcome the problems of the classical ordering policies. The simulation results show that the proposed ordering policy succeeds to mitigate the bullwhip effect and achieve an acceptable performance in terms of variance of inventory level as well [21].

Francesco Costantino et al. (2013) considered a simulation approach to study the effect of demand seasonality on the bullwhip effect and inventory stability in a four-echelon supply chain that adopts a base stock ordering policy with moving average method. The results show that high seasonality levels reduce the bullwhip effect ratio, inventory variance ratio, and average fill rate to a great extent, especially when the demand noise is low [22].

A.S.M. Tanvir Hasan et al. (2013) followed three steps to resolve bullwhip effect. First, identify the causes. Fishbone diagram helps to classify the core reasons of it. The second part is to analyze the causes and discuss the effect of these causes and try to recommend some probable solutions. The third and last part is to observe the practical situation of bullwhip effect. Here, a case study is to be studied and apply the following solution of this supply chain system and observe how these solutions resolve the bullwhip phenomenon. Here lead time of an order can amplify the variability [23].

Dean C. Chatfield and Alan M. Pritchard Prabhu (2013) determined if returns impact the level of bullwhip effect observed in a multi-stage supply chain. They build a hybrid agent/discrete-event simulation model of a supply chain and execute it under various conditions of demand variance, lead-time variance, information sharing, and return allowance. We find that permitting returns significantly increases the bullwhip effect. As a result, applying models that assume returns are permitted will systematically overestimate the bullwhip effect for supply chains that restrict returns [24].

Borut Buchmeistera et al. (2014) simulated a simple three-stage supply chain using seasonal (SM) and deseasonalized (DSM) time series of the market demand data in order to identify, illustrate and discuss the impacts of different level constraints on the BE. The results are presented for different overall equipment effectiveness (OEE) and constrained inventory policies.At higher OEE level manufacturers have less variability in production processes; the BE is stronger in DSM than in SM [25].

Qing Cao et al. (2014) drawn on both operations strategy literature as well as marketing strategy literature to propose a conceptual model that links Guanxi, the bullwhip effect, and business performance in an empirical study. Guanxi has a positive impact on business performance and also reduces the bullwhip effect [26].

Marly Mizue Kaibara de Almeida et al. (2014) provided results of trust and collaboration that lead to the mitigation of the bullwhip effect in supply chain management through a systematic literature review. The analysis found that few studies focused on addressing behavioral aspects to reduce the bullwhip effect. Most of them focused on operational and quantitative aspects. These results indicate the need for studies on behavioral aspects in mitigating the bullwhip effect, where trust and collaboration among those involved in the supply chain need to be developed and organized [27].

YongruiDuanYuliang Yao JiazhenHuo (2015) used a large-scale, product-level dataset collected from a supply chain dyad, They examined the effect of own and substitute products on a focal product's bullwhip effect and estimate the existence and magnitude of the bullwhip effect at the product level. It is known that Price is a major driving factor of the bullwhip effect [28].

Xiangyu Li (2015) put forward some weakening measures aimed at reasons of Bullwhip Effect including strengthening information sharing (EC system, EDI system as well as direct information exchange with consumers through the Internet), adjusting structure of supply chain, preventing shortage game (reducing order batches, shortening time in advance, changing discount method, changing stock allocation mechanism as well as keeping stable price) and strengthening inventory control [29].

Ahmad Sadeghi (2015) considered a two-product and two-echelon supply chain in order to quantify the bullwhip effect. Demands of the products are correlated and are represented by a first order vector autoregressive model. Retailer uses "order up to" ordering policy for replenishment of stocks and utilizes exponential smoothing forecast method to predict demand in lead-time period. According to the mentioned assumptions, an equation is derived for bullwhip effect measurement and then a numerical example is presented for a better perception of the bullwhip effect behaviour when the parameters change. A comparison of the bullwhip effect measure has been done when two main forecasting methods i.e. exponential smoothing and moving average are used and empirical results are provided. At last, a cost analysis is conducted based on shortage and holding cost under different bullwhip effect measures[30].

Tunay Aslan (2015) simulated a generalized supply chain model with safety stock regulations to expose the bullwhip effect. A seasonal demand model which fits Poisson distribution is utilized to generate orders from customers to retailers, continuously to distributors and a single factory. Orders are reconstructed in phase space and investigated chaotic behaviour variations. Although it is assumed that increasing fluctuations of demand cause chaos and unpredictability, it is seen that predictability increases in bullwhip effect. The implications are included for giving ideas of nonlinear dynamics of bullwhip effect [31].

Hongyan Dai et al. (2015) build analytical models to investigate the influence of inventory inaccuracy on the bullwhip effect and supply chain costs under different levels of information quality. They also quantify the effects of information quality associated with different information sharing Mechanisms. The theoretical results are numerically validated. They show that a larger bullwhip effect does not always correspond to greater information distortion and poorer supply chain performance [32].

Matloub Hussain et al. (2015) investigated the impact of capacity constraints and safety stock on the backlog bullwhip effect in a model of a two-tier supply chain. Simulation experiments together with Taguchi design of experiments are performed to study non-linear impacts of capacity constraints in a two-tier supply chain. This research gives supply chain operations managers and designers a practical way to develop a trade-off between capacity and safety stock at different echelons and to take better decisions about their capacity and safety stocks [33].

Yao "Henry" Jin et al. (2015) investigated whether different patterns of data aggregation influence bullwhip effect measurement. Design/methodology/approach – Utilizing weekly, product-level order and sales data from three product categories of a consumer packaged goods manufacturer, the study uses hierarchical linear modelling to empirically test the effects of data aggregation on different measures of bullwhip. The author's findings lend strong support to the masking effect of aggregating sales and order data along product-location and temporal dimensions, as well as the dampening effect of seasonality on the measurement of the bullwhip effect [34].

Riffat Faizan and Adnan ul Haque (2015) found that one of reasons behind aforementioned inefficiencies is barriers in communication within departments functioning in supply chain. In addition to that, obstacles in operations were due to other factors including; price fluctuation, rationing, demand forecasting updates, order batching, and short game. The study showed that unrealistic expectations are develop among partners involved in supply chain due to inaccurate demand forecasting. On time delivery and dispatching was affected due to inadequate planning and increasing cost of labour for increasing [35].

B. Sravani and Dr. G. Padmanabhan (2015) investigated the selection of appropriate forecasting parameters in reducing bullwhip effect. Demand forecasting is one of the main causes of bullwhip effect. It is examined at 24 different sceneries in each echelon of three levels supply chain to determine the optimal parameters. Minitab software using Holt-winters forecasting technique has been used for the present work. The results revealed that increase of smoothing parameter levels had significant impact on bullwhip effect [36].

XunWang and Stephen M.Disney (2015) provided a review of the bullwhip literature which adopts empirical, experimental and analytical methodologies. Early econometric evidence of bullwhip is highlighted. Findings from empirical and experimental research are compared with analytical and simulation results. Assumptions and approximations for modeling the bullwhip effect in terms of demand, forecast, delay, and replenishment policy and coordination strategy are considered. They identified recent research trends and future research directions concerned with supply chain structure, product type, price, competition and sustainability [37].

Shahed Mahmud et al. (2015) focused on developing a genetic algorithm model for reducing the bullwhip effect in a single product, multi-stage supply chain. The flexibility of this proposed model is the ability to identify optimal ordering quantity for each stage of supply chain. The study has proposed a procedure to reduce the bullwhip effect based on different cost data, improving information sharing levels, and contributions and operational efficiency by identifying optimal ordering quantity in order to perfect match with the demand and supply in the supply chain network [38].

Nathan Craig et al. (2016) used analytical models and laboratory experiments to study the impact of a supplier's service level on demand from retailers, by testing this relationship in the field. They found increases in historical fill rate to be associated with statistically significant and managerially substantial increases in current retailer orders (i.e., demand, not just sales).They explored the drivers of this demand increase, including changes in retailer assortment and order frequency and discussed features of a retail buyer's decision context identified through field work that may explain the magnitude of the relationship [39].

Junhai Ma and Xiaogang Ma (2016) established the supply chain model with two retailers which followed the different first-order autoregressive models and employed the order-up-to inventory policy in order to consider the market competition. The bullwhip effect was measured under the MA forecasting method. According to the analysis of the expression for the bullwhip effect using algebraic analysis and numerical simulation, they investigated what sources lead to the bullwhip effect and how those sources affect the bullwhip effect. It is interesting to note that market competition and the consistency of demand volatility between two retailers are also two important factors leading to the bullwhip effect apart from autoregressive coefficient, lead time and the span of forecast [40].

III. COMMON CAUSES OF BULLWHIP EFFECT

1) Increase in Inventory
2) Inability to predict actual demand
3) Failure in fulfilling Customer demand
4) Increase raw material fluctuation and costs
5) Lead time increases
6) Ordering cost increases
7) Information distortion in upper stage

IV. TO REDUCE BULLWHIP EFFECT

- *Implement information sharing policy along the supply chain.*
  - Actual Customer demand information can be given to suppliers and manufacturers.
  - Information will improve upstream demand forecasting in the supply chain.
- *Use past accurate and also stable forecasting method*
  - Industries can use data past sales data and point of sale to estimate demand.
  - Use ERP solution such as SAP, Oracle and implement B2B communication in the chain.
- *Work with firms upstream and downstream in the supply chain*
  - Decide the proper lead time for fulfilling orders.
  - Decide the actual prices of products and not fluctuate it if it is not required.

V. FUTURE WORK PLAN

1) Measure bullwhip effect in glass manufacturing industries which dependent highly on many numbers of Suppliers.
2) Collect the demand and orders data of highly demanded products of the company and measure the behaviour of bullwhip effect.
3) Select accurate and also stable forecasting method for each product and implement it in actual production to simulate reduction in bullwhip effect.

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