

Countering Bullwhip Effect in Supply Chain Management: A Literature Review

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ABSTRACT

In the present era of globalization, managing the supply chain has become a tedious task for every organization. Rapid changes in the demand of the customers, product shrinkage life cycle, a huge variety of products available, and presence of global-standard products have made it more difficult to carry out operations of the supply chain. Organizations look for techniques to streamline the supply chain, which includes production, inventory, and logistics. Although the term supply chain is only three-decade old, the magnitude and scope present in it lure the researchers. The amplification of demand as supply chain moves from customer to supplier is considered as the bullwhip effect. This distortion results in the disturbance of entire supply chain activities. This phenomenon is common across all types of supply chain within all types of industries. The present study tries to summarize the plethora of recent research being conducted to counter the bullwhip effect in supply chain. The study also categorizes research on various aspects such as techniques and methodology used to counter the bullwhip effect. It also provides the basic framework for researcher to look for recent development in various areas of research to counter the bullwhip effect.

Keywords: Bullwhip Effect, Supply Chain Management, Literature Review, Techniques to Mitigate Bullwhip Effect

INTRODUCTION

Supply chain management (SCM) has been an area of interest for the researchers due to the fact that it has a wide application in the industry. The current study deals with a particular problem of SCM known as the bullwhip effect. The amplification of demand as we move up in supply chain is considered as “Bullwhip Effect”, also known as whiplash, whipsaw, and Forrester effect. Forrester (1961) studied the industrial dynamics using simulator DYNAMO to show that the amplification of demand increases as we move up in supply chain. Later, Sterman (1989) used a BEER distribution game to implement it in a better and exhaustive way. The behavioral aspect of the bullwhip effect has been considered in the mentioned studies as both of the studies used simulator. The operational aspect of the bullwhip effect using mathematical models and cases is defined elaborately and then this amplification phenomenon is named as the bullwhip effect (Lee et al., 1997).

Demand forecasting, order batching, price fluctuation, and rationing & gaming are being identified as four main reasons for causing the bullwhip effect (Lee et al., 1997). Rationing and gaming is also termed as Houlihan effect named after Houlihan in 1987. Order batching is termed as Burbidge effect coined in 1991. Besides these effects, there are many other theories described in different ways which either result in the bullwhip effect or contribute to its enhancement. Information flow, lead time, promotional effect, inventory management, marketing, number of echelons, material delay, etc., also contribute to the bullwhip effect. The detailed study of these will be summarized in the latter half of the study.

So far, the literature available is already categorized in terms of various theories viz. OR theory that deals with optimization, filter theory to filter out noise, control theory to stable dynamic behavior of production, inventory, demand, etc., simulation theory to do what-if analysis, and operational theory to deal with the day-to-day operations

such as forecasting, inventory management, production scheduling, etc. (Geary et al., 2006).

The bullwhip effect can be understood in many ways. Svensson (2005) defined the bullwhip effect on the basis of rubber band principle. The study used construct of principle of speculation and postponement to explain the bullwhip effect. The generic categories used to redefine the bullwhip effect in value chain system are time dependence, functional dependence, and relationship dependence. Geary et al. (2006) gave 10 different principles to trim down the bullwhip effect out of which four were published in the prior studies (Lee et al., 1997) viz. demand signal processing, order batching, rationing & gaming, and price variations. Some of the authors (Towill et al., 2007) emphasized on appropriate lens to reduce the bullwhip effect that is categorized into three types, namely filter lens, variance lens and shock lens.

Miragliotta (2006) gave taxonomy on the basis of layers and mechanisms to deal with the bullwhip effect. Layers include a physical layer comprising of input variable, state variable, transfer function, and output. Such reconstruction of layer acts as an observer to monitor the system and control the layer, which deals with the required actions in order to attain the desired objectives. Metters (1997) also used the simulation technique to demonstrate the impact of the bullwhip effect on the profitability of organization. The study found that a decrease in the variance of seasonal variations and the ratio of variance to mean can increase the profit of an organization by more than 10% in a month. Disney and Towill (2003) emphasized on vendor managed inventory with APIOBPCS (automatic pipeline, inventory and order-based production control system), which resulted in the elimination of Houlihan effect, i.e., rationing and gaming effect and Burbidge effect, i.e., batch order effect. It is also an effective tool to deal with the fluctuations arising due to price and promotional effects. Bullwhip is categorized on the basis of shipment bullwhip, manufacturing bullwhip, and order bullwhip (Jin et al., 2017). Wu and Katok (2006) explored the role of communication in the bullwhip effect and concluded that communication when combined with learning results in depletion of the bullwhip effect and it increases the performance of supply chain. The literature review on variables causing the bullwhip effect with respect to trend and direction is done by Wang and Disney (2016). In another study, the financial data is studied to seek the performance of firm and its relationship with bullwhip effect (Mackelprang & Malhotra, 2015).

There exists a scope in which the researcher can analyze and define the approach to mitigate the bullwhip effect. The present study makes an attempt to categorize the various research techniques, data types, and methodologies used to measure and mitigate the bullwhip effect. This categorization leads to the path by which a researcher can analyze a supply chain to deal with the bullwhip effect. The objective of the paper is to carry out structured literature review that not only categorizes the situations but different techniques that a researcher follows to deal with the bullwhip effect. Rest of the study is organized as follows: Section 2 deals with the methodology. Section 3 categorizes data and research techniques used in various studies on the bullwhip effect. Section 4 deals with the miscellaneous techniques by which the bullwhip effect has been studied and Section 5 deals with scope and conclusion.

METHODOLOGY

Although summarizing the plethora of the research being already done in the field is quite a difficult task, the present study is an attempt to summarize the available literature. The research protocol being followed is summarized as follows:

- Research journal portals Proquest, Science Direct, and Emerald have been explored to collect the literature available on the bullwhip effect as these have the greatest coverage of the literature in the field of operations management and the SCM.
- The keywords used in order to search are the bullwhip effect, causes of the bullwhip effect, mitigation of the bullwhip effect, etc.
- Filter on time period was applied to get the research from the last one decade only.
- Screening of papers is done to get the relevant papers that are specifically related to the bullwhip effect.
- The selected papers are studied thoroughly and using reference the second phase of search of literature was carried out.
- Final studies are found to be 138 in number belonging to 18 different journals.

The journals considered are related to a wide variety of disciplines suggesting the scope and applicability of the bullwhip effect. Computer science, logistics, operations, supply chain, operational research, mathematics,

management, banking and finance, engineering, manufacturing, and retails are the few areas to mention in the list. Table 1 lists 18 different types of journals of the domain along with the number of articles being referred from each and the graphical representation of the table is provided by Fig. 1. Fig. 2 displays the papers reviewed in the present study in the chronological order of publishing.

Table 1: Different Journals With the Number of Papers Being Studied

Journal Name	Number of Papers
Applied Mathematical Modeling	5
Benchmarking: An International Journal	2
Computers & Industrial Engineering	5
Computers and Operations Research	2
European Journal of Operational Research	31
Expert System with Applications	6

Journal Name	Number of Papers
IFAC Information Control Problems in Manufacturing	3
Industrial Management and Data System	2
International Journal of Logistics Management	3
International Journal of Operations & Production Management	3
International Journal of Physical Distribution and Logistics Management	8
International Journal of Production Economics	47
Journal of Operations Management	4
Management Science	3
Procedia Engineering	3
Procedia Social and Behavioral Sciences	2
Supply Chain Management: An International Journal	6
Transportation Research	3
Total	138

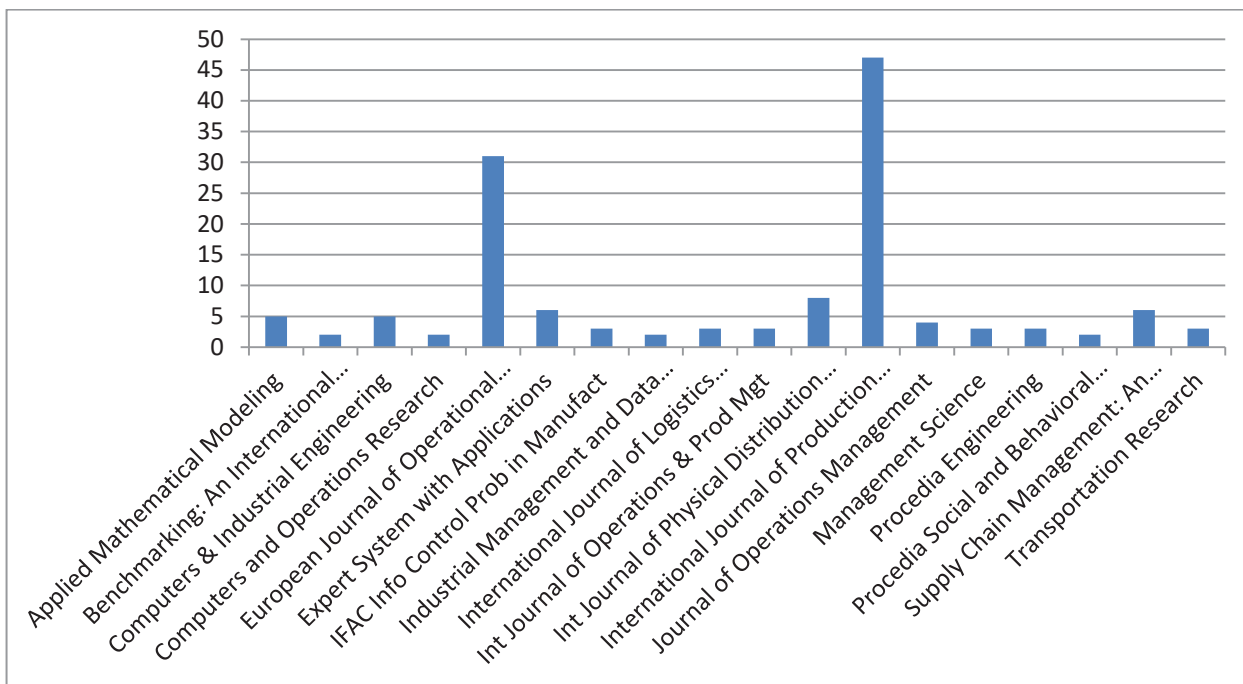


Fig. 1: Bar Graph of the Journal With the Frequency of the Papers

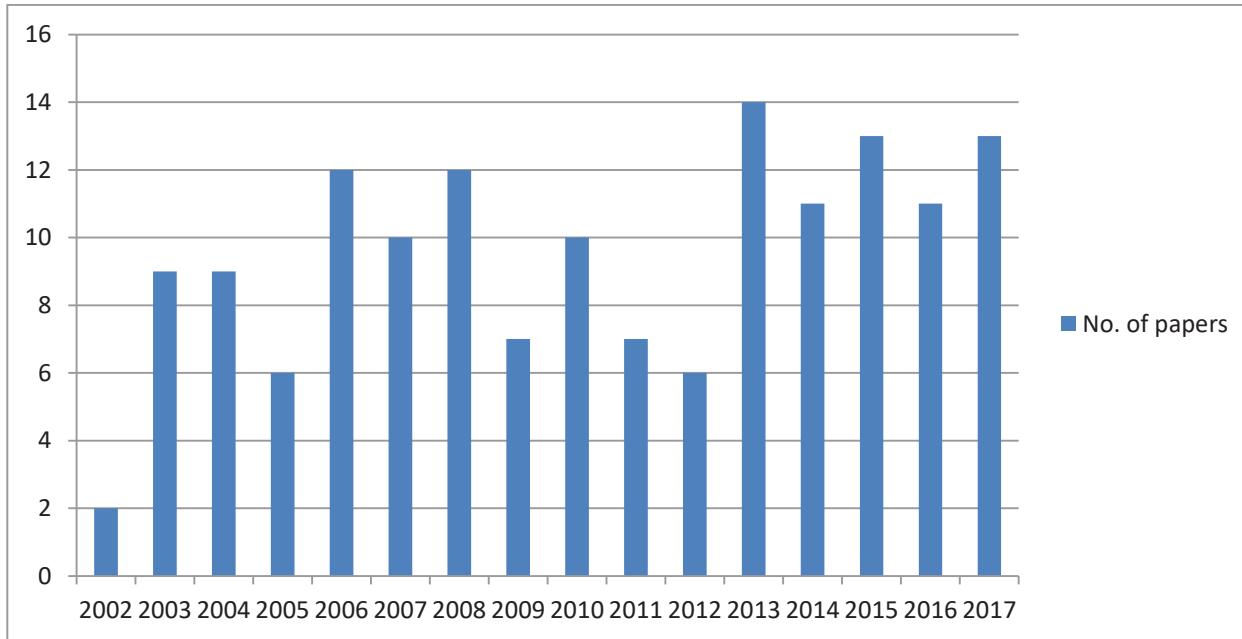


Fig. 2: Year-Wise Distribution of the Papers

CATEGORIZATION ON THE BASIS OF DATA AND TECHNIQUES

In this section, the categorization is done on the basis of data or techniques which are used in reviewed studies to counter the bullwhip effect. The bullwhip effect is visible across all the industries and, thus, has been a subject of study along all the management disciplines. Numerous authors have studied various case studies across industry and with-in the industry (Gupta & Saxena 2019a). The bullwhip effect is experienced in all types of sectors—automobile sector (Chiang et al., 2016; Seles et al., 2016) retail sector (Hamister & Suresh, 2008; Kelepouris et al., 2008), telecom sector (Mahmoudi & Lamothe, 2006), etc.

The automatic pipeline input-output based production control system has an entire area of research in control theory approach. Over 200 papers have already been published using the control theory approach in order to deal with the bullwhip effect. It was first applied by John who developed IOBPCS system in 1994. Since then, S. R. Disney and D. R. Towill enhanced this control engineering approach to a great extent.

Quite a few studies using soft computing techniques have also been visible which are using fuzzy theory (Shore & Venkatachalam, 2003), genetic algorithm (Zarandi et al., 2008; Wu et al., 2011), and ant colony (Nia et al., 2014) to deal with the bullwhip effect. The details of all studies are given in Table 2.

Table 2: Categorization on Basis of Data and Research Techniques

Research Technique	Study/Research Papers
Primary data	Svensson (2003), Kaipia et al. (2006), Hamister & Suresh (2008), Kocoglu et al. (2011), Akkermans & Voss (2013), Qrunfleh & Tarafdar (2013), Cao et al. (2014), Lee et al. (2014), Seles et al. (2016)
Secondary data	Fransoo & Wouters (2000), Disney et al. (2006), Chang et al. (2007), Ketzenberg et al. (2007), Kelepouris et al. (2008), Zhou et al. (2010), Babai et al. (2013), Tosun et al. (2013), Zotteri (2013), Sodhi et al. (2014), Duan et al. (2015), Mackelprang & Malhotra (2015), Udenio et al. (2015), Chiang et al. (2016), Lin et al. (2016), Isaksson & Seifert (2016), Seles et al. (2016), Trapero & Pedregal (2016), Ali et al. (2017), Jin et al. (2017)

Research Technique	Study/Research Papers
Simulation/hypothetical data illustration	Metters (1997), Kelle & Milne (1999), Dejonckheere et al. (2002), Dejonckheere et al. (2003), Disney & Towill (2003), Lummus et al. (2003), Smaros et al. (2003), Disney et al. (2004), Machuca & Barajas (2004), Pujawan (2004), Zhang (2004), Chandra & Grabis (2005), Sheu (2005), Disney & Towill (2006), Kim et al. (2006), Mahmoudi & Lamothe (2006), Potter & Disney (2006), Wu & Katok, (2006), Chang et al. (2007), Hsieh et al. (2007), Hong & Ping (2007), Luong & Phien (2007), Ouyang (2007), Bayraktara et al. (2008), Caloiero et al. (2008), Duc et al. (2008), Hamister & Suresh (2008), Jaksic & Rusjan (2008), Kim & Springer (2008), Ouyang & Daganzo (2008), Su & Wong (2008), Wright & Yuan (2008), Agarwal et al. (2009), Haughton (2009), Ryu et al. (2009), Sucky (2009), Duc et al. (2010), Ouyang & Li (2010), Wanga et al. (2010), Sodhi & Tang (2011), Wu et al. (2011), Zhang & Burke (2011), Adenso et al. (2012), Ciancimino et al. (2012), Fu et al. (2012), Hussain et al. (2012), Kristianto et al. (2012), Nepal et al. (2012), Ancarani et al. (2013), Chatfield & Pritchard (2013), Li (2013), Li & Liu (2013), Nielsen (2013), Salcedo et al. (2013), Sandhu et al. (2013), Tangsuecheeva & Prabhu (2013), Buchmeister et al. (2014), Dominguez et al. (2014), Fu et al. (2014), Hassanzadeh et al. (2014), Li et al. (2014), Tanweer et al. (2014), Chan et al. (2015), Costas et al. (2015), Costantino et al. (2015), Fu et al. (2015), Ma et al. (2015), Sadeghi (2015), Sourish & Kumar (2015), Wang et al. (2015), Aslam & Ng (2016), Babai et al. (2016), Chiang et al. (2016), Khosroshahi et al. (2016), Li et al. (2016), Goodarzi et al. (2017), Haines et al. (2017), Huang et al. (2017), Minner & Transchel (2017), Naim et al. (2017), Sirikasemsuk & Loung (2017), Sy (2017)
Optimization model	Kelle & Milne (1999), Disney & Towill (2003), Pujawan (2004), Sheu (2005), Gaalman & Disney (2006), Dhahri & Chabchoub (2007), Li (2008), Su & Wong (2008), Dobos (2011), Fu et al. (2012), Li & Liu (2013), Salcedo et al. (2013), Tangsuecheeva & Prabhu (2013), Fu et al. (2014), Sodhi et al. (2014), Tanweer et al. (2014), Nagarajaa et al. (2015), Aslam & Ng (2016), Dai et al. (2016), Khosroshahi et al. (2016), Dai et al. (2017), Minner & Transchel (2017)
Fuzzy/Soft computing algorithm	Shore & Venkatachalam (2003), Liang & Huang (2006), Su & Wong (2008), Zarandi et al. (2008), Wu et al. (2011), Tosunet al. (2013), Jaipuria & Mahapatra (2014), Nia et al. (2014), Chan et al. (2015), Sadeghi et al. (2016)
Theoretical/conceptual paper	Christopher & Lee (2004), Lee et al. (2004), Hull (2005), Svensson (2005), Geary et al. (2006), Towill et al. (2007), Song et al. (2009), Lin et al. (2016), Wang & Disney (2016)

Research Technique	Study/Research Papers
Case-based study	Fransoo & Wouters (2000), Miragliotta (2006), Ravichandran (2006), Chang et al. (2007), Caridi et al. (2010), Christopher & Holweg (2011), Akkermans & Voss (2013), Jaipuria & Mahapatra (2014), Lee et al. (2014), Udenio et al. (2015), Seles et al. (2016)

Primary Data

Svensson (2003) studied the bullwhip effect on guidelines of the principle of speculation and postponement. The study used factor analysis on the primary data to conclude that the bullwhip effect occurring in intra-organization is due to the flow of inbound and outbound logistics. Structural equation modeling is used in the study of Qrunfleh & Tarafdar (2013) to conclude that the supply chain partnership has a full mediation effect on relationship between lean supply chain strategy and responsiveness, whereas postponement has partial mediation effect on relationship between agile supply chain strategy and responsiveness. Structural equation modeling with Guanxi was used on primary data to prove that Guanxi has a positive impact on mitigating the bullwhip effect (Cao et al., 2014). Akkermans and Voss (2013) explored the bullwhip effect in service industry using primary data. Primary data-based study conducted on Turkey manufacturing industries (Kocoglu et al., 2011) in which structural equation modeling was used to show supply chain performance as a function of supply chain integration and information sharing. Indian automobile sector has also been explored on the basis of supply chain analytics (Raghavendra & Nijaguna, 2016). Retail sector pricing strategy is also discussed (Hamister & Suresh, 2008), which is also based on primary data and study concluded that when the demand is serially correlated on daily basis, low pricing results in decrease of the bullwhip effect and increase in profitability. A European electronic industry has been explored in primary data-based study (Kaipia et al., 2006) and the bullwhip effect is explored using planning nervousness, which is a function of varying and lack of planning process, multi-decision-making phases, long planning horizons, and delay in information flow.

Secondary Data

A study on Indian sectors which was based on secondary data was carried out to analyze the bullwhip effect and it has

been found that not all sectors are experiencing the same bullwhip effect (Gupta & Saxena, 2019a). Ravichandran (2006) carried out two case studies on Indian scenario to manage the bullwhip effect. Enterprise resource planning and vendor managed inventory are effective tools to counter the bullwhip effect. Greek retail companies were studied (Kelepouris et al., 2008) on the basis of secondary data and it was found that the information sharing reduces the bullwhip effect and an increase in lead time increases the bullwhip effect, whereas Duc et al. (2008) illustrated that the bullwhip effect does not necessarily increase with the increase of lead time. It was suggested that the augmented collaborative planning, forecasting, and replenishment model is better than CPFR model because it also contained information such as demand fluctuation and replenishment besides point of sales information for the retail industry (Chang et al., 2007).

Forecast accuracy may result in the decrease of the bullwhip effect but in order up to policy, the bullwhip effect always exists (Chiang et al., 2016). The study also concluded that aggregate forecasting results in decrease of the bullwhip effect but in US auto industry it does not. The bullwhip effect across the United States on various industries such as manufacturing, wholesale, mining, retail, etc., was computed (Isaksson & Seifert, 2016) and a significant bullwhip effect has been found among them based on secondary data and bullwhip ratio was used to conclude the result. Monthly data of US industries was explored and intra-industry bullwhips have been explored

in case of manufacturing, shipping, and ordering (Jin et al., 2017). A case study is analyzed on oil sector (Hull, 2005) which concluded that an emphasis must be given to economics and administrative work if supply flow does not depend on customer demand to avoid the reverse bullwhip effect. The food supply chain is studied which measured the bullwhip effect at outlet level, product level, and echelon level (Fransoo & Wouters, 2000). Telecom sector is studied for the bullwhip effect (Mahmoudi & Lamothe, 2006) and simulation is performed on capacity planning, stock and information system, and as these variables increase the bullwhip effect decreases.

Simulation technique and illustrated data is used in 48% of the papers. In fact mathematical modeling studies also used simulated data to illustrate their models besides other studies based on simulators. The bullwhip effect caused by human interaction can be taken under study by simulators. Next most frequently used technique is optimization model with a 14% share in which model minimizes the total supply chain cost. Real-life secondary data such as financial measure, demand, order, and inventory are also studied to compute the bullwhip effect in 13% of studies. Fuzzy and other computing algorithms are gaining popularity in recent times to counter the bullwhip effect and are found in 7% of the studies. There is a dearth of studies that are based on primary data. Also, the case studies are found to be less in number. Fig. 3 shows the percentage of each research technique.

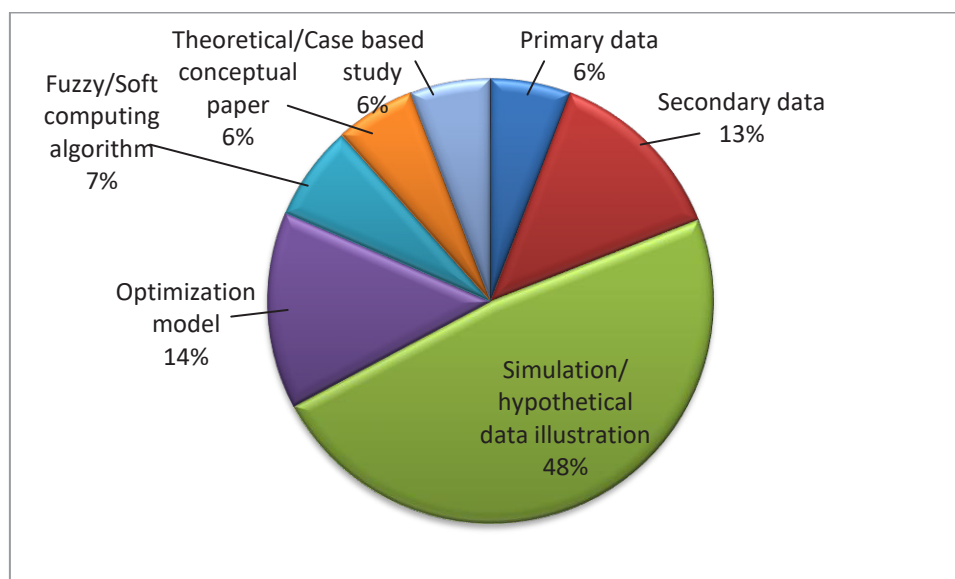


Fig. 3: Pie Chart Showing the Percentage of Research Techniques Used to Deal With Bullwhip Effect

Fuzzy/Genetic Algorithm

Using genetic algorithm, forecasting accuracy increases which minimizes the shortages and total cost of supply chain. Controller is used with demand following ARMA and it has been found that equal weight to inventory and ordering variance results in optimization of the bullwhip effect (Gerard & Disney, 2009). Two-stage ant colony optimization (TACO) is used to deal with inventory lot size problem and establish a relationship between the bullwhip effect and replenishment (Su & Wong, 2008). Agent-based model and simulation are also effective ways to study the bullwhip effect across a supply chain. Simulation agent, function agent, and control agent are used in a study (Wu et al., 2011). Adaptive fuzzy smoothing constant is developed in a vendor managed inventory to reduce the bullwhip effect and determine the information about order policy (Kristianto et al., 2012). Fuzzy vendor managed inventory is explored using various techniques such as ant colony optimization, genetic algorithm, and differential evolution to minimize the total cost of supply chain as objective function and then make the comparisons (Nia et al., 2014). Fuzzy vendor managed inventory is explored using simulation with genetic algorithm that results in decrease of bullwhip effect (Lin et al., 2010). Fuzzy agent-based system to minimize the total cost for reduction of the bullwhip effect is suggested (Zarandi et al., 2008). A fuzzy logic model with analytical hierarchical process to seek the information-sharing capability in supply chain is explored (Shore & Venkatachalam, 2003). Discrete wavelet transformation is used with artificial neural network (ANN) and it has been found that forecasting in this case is better than ARIMA (Jaipuria & Mahapatra, 2014). Central control approach results in decrease in the bullwhip effect as compared to decentralized internal model control approach (Salcedo et al., 2013). Fuzzy time series forecasting has been suggested to remove supply chain disruption (Chan et al., 2015). In case of automotive supply chain to mitigate the bullwhip effect and simultaneously the cost reduction, genetic algorithm is explored (Tosun et al., 2013). Fuzzy demand inventory model along with backorder and discount is studied using hybrid imperialist competitive algorithm to find near-optimal solution (Sadeghi et al., 2016).

TECHNIQUES TO DEAL WITH BULLWHIP EFFECT

This section deals with the techniques that are used in various studies to mitigate the bullwhip effect. Impact of replenishment strategies is studied in E-shopping scenario

using causal root diagram (Li et al., 2016), comparison between the economic order quantity, and target stock level has been done using simulation and later has been found as better approach. Green bullwhip effect is transferring environment requirement and can be a force for positive change; Lee et al. (2014) proved this using case-based research. Holt-Modigliani-Muth-Simon model is used to show that the total cost in centralized system is less than that of decentralized system (Dobos, 2011). Fluctuations of flow variables are decreasing along the supply chain but inventory fluctuation increases causing the bullwhip effects.

Nepal et al. (2012) studied bullwhip effect in terms of product life cycle and concluded that as the steps in product life cycle change, the bullwhip effect as well as the net stock amplification increases. Regression analysis is used to show that sharing upstream disruption information results in decrease of bullwhip effect; however, disruption information shared in downstream does not have such benefit (Sarkar & Kumar, 2015). The quantification of the bullwhip effect in case of information shared and not shared when lead time is stochastic in nature is also studied (Kim et al., 2006).

Dominguez et al. (2014) illustrated with the help of simulation that using collaboration and smooth replenishment approach bullwhip effect can be reduced in divergent supply chain network as linear supply chain is a rare phenomenon. Blos et al. (2015) studied ISO norms. Risks are identified corresponding to norms and then mitigating disruption techniques are developed. Udenio et al. (2015) studied the supply chain during the recession and emphasized that it is important to analyze the entire supply chain, destocking may be a way to counter the bullwhip effect during the credit crisis. The bullwhip effect is explored under various scenarios. The bullwhip effect has been experienced in various types of supply chain. It also has been explored under various conditions such as different types of information systems and types of warehousing. In some studies, the reverse bullwhip effect has also been noticed. The various scenarios under which the bullwhip effect has been experienced is given in Fig. 4. There are a large number of techniques that researchers have used to counter the bullwhip effect. Different techniques have been used in different scenarios. Present research categorizes the various research techniques used by various researchers in their study. The categorization of techniques used to mitigate the bullwhip effect are illustrated in Fig. 5. The broad identified areas are statistics, soft computing, price and demand, mathematical model, simulation, control engineering, and end-to-end visibility in supply chain.

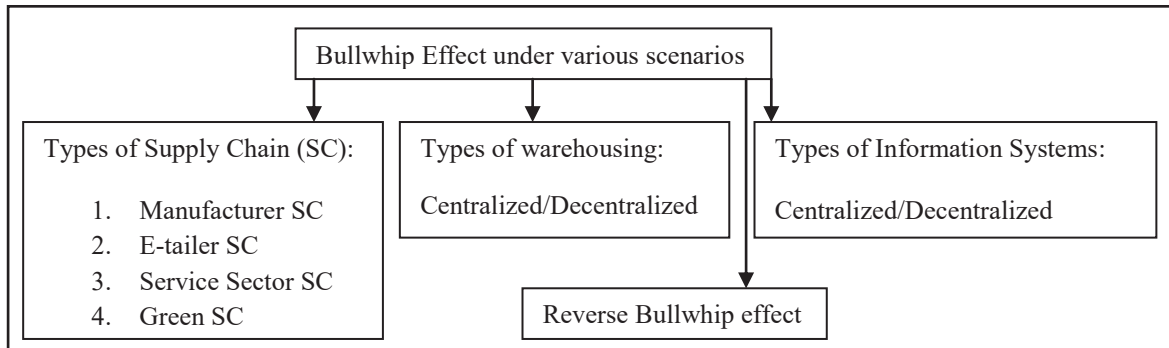


Fig. 4: Bullwhip Effect Under Various Scenarios

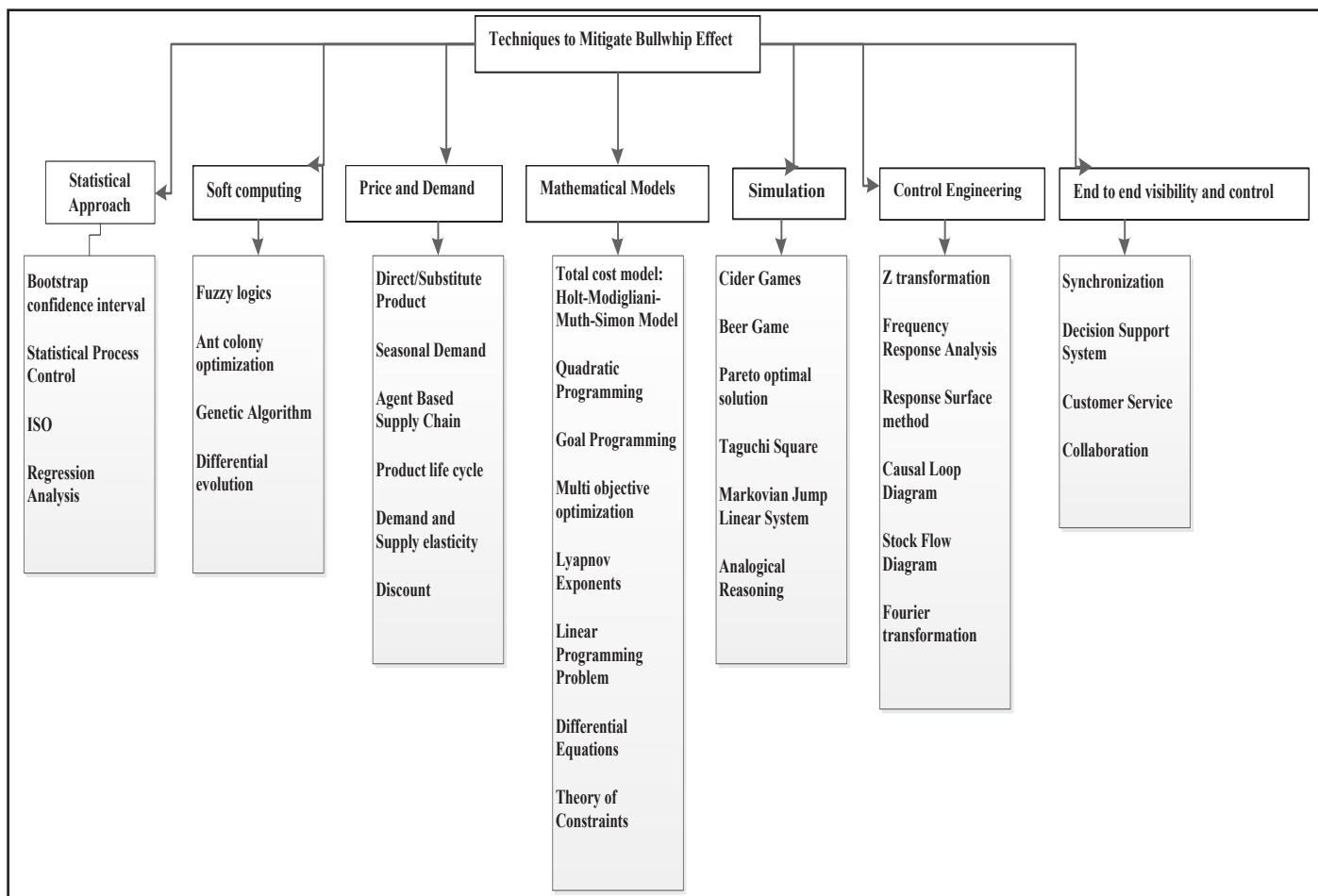


Fig. 5: Techniques to Deal With Bullwhip Effect

Visibility and control in supply chain can be increased through synchronization (Christopher & Lee, 2004). An increase in end-to-end pipeline time results in lack of visibility. An effective literature about the visibility, quality, accuracy, and freshness of information across the supply chain has also been referred to (Caridi et al., 2010). Bootstrap method is non-parametric and free from distribution assumption and, hence, provides a

better interval bullwhip effect approach rather than the point of estimation of the bullwhip effect (Hsieh et al., 2007). The bullwhip effect decreases as the seasonal lead time decreases; the result is derived on the basis of order up to inventory policy for stationary autoregressive moving average demand process (Nagarajaa et al., 2015). Statistical process control forecasting system with inventory variance ratio is better technique to cater

the bullwhip effect rather than moving average and exponential smoothing (Costantino et al., 2015).

Song et al. (2009) developed a quantitative method to measure the bullwhip effect using Fourier transformation, which is based on inventory entropy. Technique not only shows the amplitude but also the frequency for time series data. Customer service is measured by fill rate and by maintaining the higher fill rate both bullwhip and inventory variances can be minimized (Disney et al., 2006). Babai et al. (2016) found that if the demand is highly positively correlated then it will lose its value to reduce the bullwhip effect. Nielsen (2013) concluded that the autocorrelation within the time series demand weakens the bullwhip effect whereas cross-correlation with the ordering time series increases the bullwhip effect. Luong (2007) stated that the bullwhip effect still exists in the case of per autocorrelation among demand. Both upstream and downstream information systems in supply chain are important: the upstream will streamline the supply chain while the downstream information system helps to build better customer demand (Haines et al., 2017). Model predictive control technique is used to track inventory and customer demand, the cost function has been minimized using quadratic programming (Fu et al., 2014).

High customer demand per order results in the bullwhip effect although small demand per order increases the operational cost but decreases the bullwhip effect (Wang et al., 2015). Besides the famous beer game simulator, another simulator such as cider games is also applied when the number of factors affecting bullwhip increases (Adenso et al., 2012). NetLogo agent programming language version 5.0 is used to build simulator in study when the return of excessive goods is permitted to cause the bullwhip effect (Chatfield & Pritchard, 2013). Inventory and warehousing decisions play a big role in study of the bullwhip effect. The combination of various inventory and warehousing decision factors affecting the bullwhip effect is studied simultaneously in many studies (Gupta & Saxena, 2019b). Third-party warehousing is not having an impact on the bullwhip effect even if it is not decreasing the inventory cost and it depends on other factors also (Duc et al., 2010). Control engineering approach is also used to mitigate the bullwhip effect, such researches are taken under optimization problem using z transformation. Naim et al. (2017) suggested the analogical reasoning with control engineering to mitigate the behavioral aspect of the bullwhip effect.

Kim and Springer (2008) suggested the generic stock management model using stock-flow diagram to measure

and reduce the endogenous supply chain volatility. By using the theory of constraints, bullwhip can be reduced significantly (Costas et al., 2015). Taguchi square technique is used to run the simulation in which demand is considered as normally distributed. In another study, simulation modeling uses design of experiment technique to measure supply chain performance in terms of fill rate and inventory reduction in a scenario when information is shared and not shared in steel industry (Sandhu et al., 2013).

Response Surface Method/Frequency Response Analysis

Response surface method by Hassanzadeh et al. (2014) is used to find the main causes of the bullwhip effect in centralized and decentralized supply chains. Caloiero et al. (2008) also used response surface plot technique to find the impact of the bullwhip effect on supply chain and concluded that the bullwhip effect can be minimized at high inventory oscillations but the cost is high so supply chain needs the balance between the two. Frequency domain analysis is used to express the bullwhip effect in the absence of known customer demand and on the basis of various inventory replenishment policies (Ouyang & Li, 2010).

Operations Research

Goal programming uses ARIMA forecasting technique parameters in decision-making for various aspects such as demand, inventory management (Dhahri & Chabchoub, 2007), etc. Markovian jump linear system is used to analyze and quantify the bullwhip effect, but it requires the experience of assuming the state transition probability (Ouyang & Daganzo, 2008). Multi-object optimization is used to minimize inventory, backlog, and the bullwhip effect. A simulated Pareto optimal solution is used to explain the result.

Marketing and Promotional Effect

Many studies explored the role of product promotion on the bullwhip effect. Salesperson incentives create a bullwhip effect and the magnitude of effect is more if the consumer demand is stable, whereas weaker in variable consumer demand (Zotteri, 2013). The bullwhip effect reduces during the promotional period but increases before and after the promotional period (Trapero & Pedregal, 2016). By only controlling the marketing initiative, the

bullwhip effect can be reduced significantly (Lummus et al., 2003). Changes in EOQ in case of quantity discount and promotions scheme to avoid the bullwhip effect is also explored in one study (Gupta, 2012).

Pricing

Pricing policy affects the amplification of demand in supply chain. The number of times the price is increased, it seems to have a direct decrease in the bullwhip effect; but in totality, it increases the bullwhip. Increase in number of price of substitute product results in increase of the bullwhip effect (Duan et al., 2015). Supply and demand elasticity identifies the severity of the bullwhip effect; moreover, the performance between two supply chains can also be judged by elasticity (Hull, 2005). Iso-elastic demand function shows the reverse bullwhip effect whereas linear and logarithmic function do not exhibit the reverse bullwhip effect (Ozelkan & Cakanyildirim, 2009). The bullwhip effect in case of complementary product is explored (Ma et al., 2015) when price of one product affects the demand of other product in two different parallel supply chains. Price variance of manufacturer has an impact on the bullwhip effect (Sodhi et al., 2014) and discount is really a bad idea. The bullwhip effect for price-sensitive demand is studied that includes the stochastic covariance of price and demand in a vector time series process (Zhang & Burke, 2011).

Finance

The bullwhip effect has a great financial aspect on a supply chain. Cash flow bullwhip is identified on the basis of independent variables such as inventory, lead time, demand, etc. (Goodarzi et al., 2017); and using the response surface method, the bullwhip effect is measured. Cash flow bullwhip from cash conversion cycle is developed and it is found that as the cash conversion cycle increases, there is less cash to perform financial operations because it is directly proportional to the number of days of inventory and, hence, results in an increased bullwhip effect (Tangsucheeva & Prabhu, 2013).

APIOBPCS

The literature available to mitigate the bullwhip effect using APIOBPCS is found to be huge. The study of the literature review is already available only catering these automatic control systems. Lin et al. (2016) studied 225 papers that used order-based production control system

in the study. Using simulation, it has been verified that vendor managed inventory (VMI) reduces bullwhip across supply chain (Disney & Towill, 2003). Transfer function of different types such as constant, linear, and quadratic is applied on exponential smoothing constant which is included in APIOBPCS (Dejonckheere et al., 2002). Supply chain model is built on basis of flow of material and information (Fu et al., 2012). Model predictive control strategy (MPCS) is used and extended prediction self-adaptive control (EPSAC) is implemented with MPCS which outperform the tradition ordering policies (OUT and APIOBPCS) on reducing the bullwhip effect (Fu et al., 2015). The bullwhip effect can also be minimized by selecting suitable batch size. Economy of scale is achieved on the basis of production package and transportation. The batch size which is multiple of average demand is suggested using an output-based production control system (Potter & Disney, 2006). If a decision support system is built on basis of APIOBPCS, then boom and bust can be avoided so the only uncertainty left is because of the market and, hence, the bullwhip effect can be reduced (Disney & Towill, 2006). The application of APIOBPCS is also used in closed-loop supply chain to see the impact of product returns and remanufacturing uncertainties on the bullwhip effect and it has been found that as the returns increase, bullwhip effect decreases (Zhou et al., 2017). Information sharing is explored in APIOBPCS in case of OUT policy and demand smoothing policy and it has been found that information sharing reduces the bullwhip effect (Dejonckheere et al., 2004). APIOBPCS is applied to European Confectionary data and it has been found that this model has a tendency to cope up with the uncertainty in demand and has the capability to mitigate the bullwhip effect (Zhou et al., 2010). APIOBPCS is found to be better than beer games, lean, agile, leagile, OUT and HMMS (Holt, Modigliani, Muth and Simon) algorithms (Disney et al., 2004). *MATLAB*, *iThink*, *Vensim*, *Arena*, and *Simul8* are the common packages used for dynamic modeling. Hussain et al. (2012) used Taguchi design of experiment in APIOBPCS model to see the impact of its parameter on bullwhip effect. OUT always results in the bullwhip effect irrespective of the demand forecasting technique, control system engineering is suggested to counter bullwhip effect (Dejonckheere et al., 2003).

SCOPE AND CONCLUSION

The present study summarizes and categorizes a huge amount of research present in area of the bullwhip effect that was carried out in last two decades. The research started with the seminal study of industrial dynamics, simulations, and mathematical models to identify the

reasons that cause the bullwhip effect in SCM. A large number of studies have been done to mitigate the bullwhip effect in supply chain and present study categorizes the various methods which have been adopted by researchers to deal with the bullwhip effect. Then, the study also categorizes the bullwhip effect on basis of research techniques used by various researchers. SCM being an interdisciplinary approach is very vast and large number of techniques belong to different types of the research area is suggested to deal with the bullwhip effect. Economist, financial manager, operations managers, marketing managers, etc., have their views on the bullwhip effect. The present study gives the synoptic view for all. Thus, the present study would work as a direction for the people belonging to these areas. The researchers can get an extensive literature being summarized at one place in order to refer to the various journals for the study of the bullwhip effect. The year-wise increase in the number of studies on the bullwhip effect depicts that the problem is yet to be addressed in an efficient manner. In the present study, various tools, techniques, and methods to mitigate the bullwhip effect have also been extensively summarized. Using simulation techniques researchers can emphasize on modeling and addressing the problems related to the entire supply chain whereas most of the secondary and primary data-based studies are based on the single echelon supply chain. The bullwhip effect in different supply chains (green supply chain, centralized and decentralized supply chain, reverse supply chain, etc.) has been categorized so the researcher needs to identify the domain to which the problem pertains to so that it can be addressed in an efficient manner. Techniques to mitigate the bullwhip effect not only belong to the management but also the mathematicians, scientists, statisticians, engineers, etc., have their role to play.

The categorization of research on basis of associated subjects such as finance, marketing, inventory and operations management, economics, human resources and organizational behavior, etc., is kept as future scope of the research. The categorization of studies on basis of various sectors is also kept as future scope of the research. The bullwhip effect is very complex phenomenon, which not only occurs due to the decision-making of operations and supply chain manager (behavioral aspect) but also depends upon how the operations are carried out in the supply chain (operational aspect). The categorization of literature on the basis of behavior and operations is also kept as future scope of the study.

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