Journal of Optimization in Industrial Engineering
Vol.16, Issue 1, Winter & Spring 2023, 105–118
DOI:10.22094/JOIE.2023.1966193.1981

Research Article

A Dynamics Approach for Modeling Inventory Fluctuations of the Pharmaceutical Supply Chain in COVID 19 Pandemic

Parvaneh Tavakol [a], Bijan Nahavandi [b,*], Mahdi Homayounfar [c]

[a] *PhD Candidate, Department of Industrial Management, Bandar-e- Anzali International Branch, Islamic Azad University, Bandar-e-Anzali, Iran*
[b] Assistant Professor, Department of Industrial Management, Science and Research Branch, Islamic Azad University, Tehran, Iran
[c] Assistant Professor, Department of Industrial Management, Rasht Branch, Islamic Azad University, Rasht, Iran

Received 31 August 2022; Revised 05 April 2023; Accepted 10 April 2023

Abstract

Considering the importance of inventory management in the pharmaceutical industry, especially during the Covid-19 pandemic, this paper investigates a five-echelon pharmaceutical supply chain including component suppliers, manufacturers, retailers, distributors and consumers in order to identify various variables of the inventory management systems and analyze their behavior. Conducting the research, first, based on the reviewing the literature, 29 drivers of bullwhip effect (BWE) in supply chain were extracted. Next, systems dynamics as a powerful approach for modeling complex systems, especially supply chains, is applied to simulate the dynamics of the pharmaceutical supply chain. So, the interactions of the main variables of the system were translated to the dynamic hypotheses and constitute the causal loop diagram. Then, stock and flow diagram was formulated in form of the differential equations. To validate the proposed model, some structural and behavioral validation test were implemented which indicated model's accuracy. Finally, 4 potential scenarios based on the extent of improvement in information quality, safety stock and lead time were developed and manipulated to analyze their effects on inventory gap, as the main indicator of BWE. The results indicate that the best scenario for the component supplier and manufacturer is 5% increase in the information quality, 10% increase in the safety reserve and 5% decrease in lead time. While for the medicine distributor and medicine retailer; 5% increase in information quality, 5% increase in the safety reserve and 10% reduction in lead time, minimizes stock gap in the shortest time.

Keywords: Supply Chain; Inventory Management; Bullwhip Effect; System Dynamics; Delphi

1. Introduction

A supply chain is a network of suppliers, manufacturers, distributors, retailers, and customers that are connected by information, financial and material flows and converts raw materials and components into finished products that are shipped to the customers (Costantino et al., 2015a; Costantino et al., 2016; Shaban et al., 2018; Hu, 2019). A supply chain should be adequately planned and managed to match demand and supply at the lowest cost (Costantino et al., 2016). The efficiency of supply chain systems typically depends on management decisions and coordination, which has become a complicated challenge to overcome in the complexity and turbulence of the supply chains in new business environment (Hu, 2019).
Demand variability, particularly in the upstream echelons, has a considerable effect on the efficiency and effectiveness of the supply chain. Due to the inventories' importance in economic activities and their important role in understanding the business processes, and prediction and coordination of inventory management components, inventory fluctuations which have different mechanisms in every supply chain, are intensively studied in the literature (Hu, 2019; Pastore et al., 2020b). It could be found that moving toward upstream in the supply chain, demand fluctuation tends to increase (Pastore et al., 2020). This amplification (called Bullwhip effect) has a great impact on performance of supply chain, because upstream supply chain participants are misinformed about the demand nature. This misinforming has a significant impact on supply chain performance and can lead to undesirable outcomes such as high forecasting error, inventory surplus, inefficient use of production capacity, low service level, uncertain production planning, difficulty in forecasting policy and scheduling programs, and poor supplier/customer relationships and more (Duc Tai et al. 2019; Pastore et al., 2020; Aslani Khiavi and Skandari Dastghiri, 2021). Indeed, BWE is one of the basic obstacles to achieve coordination in supply chains and reduction of this phenomenon has an important role in supply chain harmony (Sadeghi, 2014).
There are considerable researches of inventory-related theory that minimize the inventory costs in simple inventory systems but when these optimal practices are applied together in a supply chain system, they create the bullwhip effect (Fig. 1), that is, order variability is amplified as moving up the supply chain (Costantino et al., 2015b). This phenomenon takes place by a similar pattern to bullwhip oscillation. When a bullwhip is shaken, the fluctuations grow as it gets closer to the end of the whip (Kadivar and Akbarpour Shirazi, 2018).

*Corresponding author Email address: bijan.nahavandi@srbiau.ac.ir

Fig. 1. Demand variability in supply chain

The Bullwhip Effect, through which the supply chain amplifies the variability of orders as they pass through the various echelons of the system, is a popular phenomenon in the operations management discipline due to its costly implications in production and distribution systems (Ponte et al., 2020a). Bullwhip effect is caused by fluctuations in data or information which is supplied to companies that are further up the supply chain. The fluctuations in information or distorted data leads to inaccurate demand forecasting by companies' factors contribute to the bullwhip effect such as lead-time, type of inventory policy, and information on demand forecasting (Kumara et al., 2020; Ghaffari et al., 2014).

On the other hand, supply chain's BWE causes to increase in production costs of downstream and upstream echelons, and also cause to the loss of resources (Zhou et al., 2019). Therefore, both supply chain practitioners and researchers have been interested in learning the reasons for and solutions to lessen the effects of this phenomena (Duc Tai et al. 2019). See Wang and Disney (2016) and Pastor et al. for more details (2019).

Over the years, a significant number of researches and techniques such as the control theory including simulation, mathematical, and statistical techniques have been utilized to measure the bullwhip effect in supply chain (Aslani Khiavi and Skandari Dastghiri, 2021). Despite the number of researches conducted for reducing BWE, there is still a considerable gap for improvement. Iran manufacturing industries especially pharmaceutical industry face material constraints in their supply chains in the past years due to the sanctions and extraordinary usage in the COVID 19 pandemic. The COVID-19 pandemic caused to the bullwhip effect (BWE) in the global scale and influenced economy of all the countries in the world. It has been the most essential challenge since the 2nd world war, which disrupted interactions among global supply chains' players (Scarpin et al., 2022). These may negatively impact on order and holding costs of inventory. Therefore, the need to study the factors affecting inventory management and bullwhip effect in the supply chain to reduce demand shortages, surpluses and fluctuations of medicines as strategic products which are related to human lives is an undeniable necessity. According to statistics of Iran health ministry, pharmaceutical and related costs in Iran account for about 30% of the total cost of health care system and about 50% of the cost of outpatient health care, so medicine is of special importance in the health system

There are many research areas on BWE in supply chain management during the last decade time, but the present study contributes to the literature as following:

- Among the studies focused on demand fluctuations, never paid to COVID 19 pandemic in a system dynamics model.
- The pharmaceutical supply chains which experience large product fluctuations in all of the world, are not considered from the inventory management perspective and any research is made to reduce their BWE in the under developed countries
- A few researches in the BWE literature empirically investigated supply chains with 4 echelons.

Motivated by the current literature, this paper intends to investigate the impact of various variables on the bullwhip effect in the four-echelon supply chain including Retailers, Distributors, Manufacturer, and Suppliers. Researches on the BWE are classified into six categories: (i) quantification of the bullwhip effect, (ii) identifying the causes of the BWE, (iii) observing the bullwhip effect empirically (iv) reducing the bullwhip effect, (v) simulating the system behavior and (vi) on experimental validation of the bullwhip effect. In this study, system dynamics methodology is utilized in the simulation process and scenario analysis to reduce bullwhip effect to provide an in-depth understanding of BWE causes and their behaviors. This study also examines the sanctions effect on supply chain performances in term of BWE. The reminder of the paper is organized as follows. Section 2 presented the essential concepts on BWE together with an overview on the literature about this phenomenon. The research methodology is described in Section 3. Section 4 illustrates the findings of simulation process. Finally, conclusions and insights for further research are presented in Section 5.

2. Literature Review

Bullwhip effect was first introduced by Forrester (1958; 1961). He was the first scholar who discussed its causes and possible remediation in context of production-distribution system using "industrial dynamics" approach (Goodarzi and Farzipoor Saen, 2020). Then, Sterman (1989) illustrated this effect through a well-known, role-playing simulation known as the "beer game" at MIT and showed that the irrational behavior of players and misconceptions about demand information can induce BWE (Kadivar and Akbarpour Shirazi, 2018). Since then, many researchers have studied the bullwhip effect both from empirical and analytical standpoints, modelling this phenomenon, understanding its influencing factors and looking for possible remedies (Pastore et al., 2020). In addition, extensive research has been conducted to investigate the causes of the bullwhip effect and to propose mitigation and avoidance solutions for this problem. In the last two decades, different efforts to explain and reduce the BWE have emerged and continue to grow (Wang and Disney 2016). This subject has been examined in many empirical and theoretical researches. Particularly, several authors identified the bullwhip effect's prevalence in actual businesses, and provided insights into the primary factors amplifying demand fluctuation (Pastore et al., 2020). The bullwhip effect's most recent studies are mentioned in the following.

Shabany Moghadam and Fazel Zarandi, (2022) suggested a new agent-based structure to facilitate the cooperation and coordination among major components of a four-echelon supply chain and manage the dynamics of BWE. Aslani Khiavi and Skandari Dastghiri (2021) proposed a model of Inverse Network DEA, to measure the relative magnitude size of the bullwhip effect, when a series of uncertain demands are made in a specific time interval. The results show that time is an unfair factor in the size of the bullwhip effect. The findings indicate that cross-sectional planning is possible at different times according to different conditions. Ponte et al. (2020b) explored the impact of quantity discounts on the dynamic behavior of production and distribution systems by studying key operational and economic metrics. In a three-echelon supply chain, they revealed that the discount generally increases the bullwhip effect, which especially harms the manufacturer. The discount also reduces the retailer’s purchase costs, but increases its inventory- and capacity-related costs. Mirab Samiee et al. (2020) investigated the role of demand forecasting accuracy on the amount of the bullwhip effect-related cost, taking an intervened demand process with stochastic perturbations into account. They conducted a simulation study on a two-echelon supply chain to investigate the association between forecasting accuracy and the bullwhip effect-related cost. Zhu et al. (2020) investigated affecting factors on bullwhip effect in the oil and gas supply chain using case study evidence from six companies in North America. Regarding the factors that drive or mitigate the bullwhip effect in different types of companies in the oil and gas supply chain, seven propositions are developed and several additional findings are obtained. Pastore et al. (2020) studied a two-echelon single-product supply chain with final demand distributed according to a known AR (1) process but with unknown parameters. The results show that the bullwhip effect is affected by unknown parameters and is influenced by the frequency with which parameter estimates are updated. Michna et al. (2020) quantified the bullwhip effect when both random demands and random lead times are estimated using the industrially popular moving average forecasting method. They obtained an expression that reveals the impact of demand and lead time forecasting on the bullwhip effect. they draw a number of conclusions on the bullwhip behavior with respect to the demand auto-correlation and the number of past lead times and demands used in the forecasts. To better understand the Bullwhip Effect in closed-loop systems. Ponte et al. (2020a) obtained expressions for the order and inventory variance amplification in four archetypes that differ in the structure of information transparency. They proved the existence of an optimal return rate, and derived its expression in the four closed-loop supply chain archetypes. The optimal rate is dependent on the node’s cost structure, the lead times, and the variability of demand. Dominguez et al. (2020) analyzed the bullwhip effect and inventory performance of a multi-echelon closed loop supply chain with variable remanufacturing lead times under different scenarios of return rate and information transparency in the remanufacturing process. The results showed that ignoring such variability generally leads to an overestimation of the dynamic performance. They observed that enabling information transparency generally reduces order and inventory variability.

Zhou et al. (2019) proposed an optimization model of time-of-use pricing for the user-side microgrid from the perspective of power supply chain management. The objective of their model was to minimize the total cost of the power supply chain and optimize the charging-discharging behaviors of end-users. The results indicates that optimal time-of-use pricing can support the charging-discharging behaviors of residential users and reduce the cost of the entire electric power supply chain. Dominguez et al. (2019) investigate the dynamic behavior of a closed-loop supply chain with capacity restrictions both in the manufacturing and remanufacturing lines. Based on the findings, capacity constraints in both remanufacturing and manufacturing lines can be adopted as a fruitful bullwhip-dampening method, even if they need to be properly regulated for avoiding a reduction in the system capacity to fulfil customer demand in a cost-effective manner. Pastore et al. (2019) identified the bullwhip effect in a European automotive spare parts chain with the aim of shedding some light on how demand variability propagates in different groups of products. The results showed that the bullwhip effect is larger for fast moving products rather than for slow movers. Gaalman et al. (2019) studied the relationship between lead times and the bullwhip effect produced by the order-up to policy. The results indicate that a positive demand impulse response leads to a bullwhip effect that is always increasing in the lead time when the order-up-to policy is used to make supply chain inventory replenishment decisions. By using the zeros and poles of the z-transform of the demand process, we reveal when this demand impulse is positive.

Lin et al. (2019) established a system dynamics model, by taking the multi-echelon hybrid supply chain for a logistics equipment company in China. They analyzed the oscillation characteristics of service flow and product flow and proposed the performance metrics of bullwhip effect in multi-echelon hybrid supply chain. They found that bullwhip effect of multi-echelon hybrid supply chain could be smoothened by incorporating forecast smooth factor, control percentage coefficient and order lead time. Nakade and Aniyama (2019) analyzed the bullwhip effect of weighted moving average forecast under stochastic lead time. Under a general setting they expressed a performance measure on bullwhip effect theoretically. Numerical results give effects of parameters of forecasting and the lead time distribution on the bullwhip effect. Ojha et al. (2019) used simulation to investigate the impact of information sharing on both the Bullwhip Effect (BWE) and the Order Fulfillment Performance (OFP) in a multi-echelon supply chain system. The results indicate that using information sharing to coordinate orders in the supply chain generally reduces the negative effects of the bullwhip effect. In addition, the information type has the opposite impact on managing the bullwhip effect.

Kadivar and Akbarpour Shirazi (2018) investigated the measure of the bullwhip effect in three different supply-chains; (I) with a central warehouse, (II) with a cross-docking system, and (III) without any distribution systems to discover which supply chain helps reduce the bullwhip effect more. It was found that factors such as lead time, market share of each retailer, autoregressive coefficient and moving average parameter contribute to the selection of the most effective distribution system. Braz et al. (2018) compared the causes and mitigating factors of the bullwhip effect in forward supply chains and closed-loop supply chains. To this end, they employed a systematic literature review that combines bibliometric and content analyses. The studies examined indicate that the causes of the bullwhip effect in closed-loop supply chains are similar to those in forward supply chains. Regarding mitigation, they found that the primary mitigating factor is related to increasing the product return rate. Zhao et al. (2018) employed a simulation method model to explore the effect of single strategy and combined scenarios on mitigating bullwhip effect (BE) in three-echelon SC. Novel scenario simulation is designed to stimulate recovery activities of electronic waste, decrease solid material depletion and promote clean production. Results show that positive recovery activities are optimal solution in green SC among single strategies; simulated scenarios alleviate the BE largely especially the combination of higher recovery ratio and information transparency reinforcement.

Ponte et al. (2017) studied the interaction between four widely used inventory models in five different contexts depending on the customer demand variability and the safety stock. The results show that the concurrence of distinct inventory models in the supply chain may alleviate the generation of inefficiencies derived from the Bullwhip Effect. The experiments via an agent-based system proved to be a powerful and risk-free approach for business exploration and transformation. Wang and Disney (2017) investigated the amplification of order and inventory fluctuations in a state-space supply chain model with stochastic lead-time, general auto-correlated demand and a proportional order up-to replenishment policy. They identified the exact distribution functions of the orders and the inventory levels. We give conditions for the ability of proportional control mechanism to simultaneously reduce inventory and order variances. Minner and Transchel (2017) analyzed the impact of perishability on order variability and the bullwhip effect in supply chains and proposed a dynamic ordering policy for the upstream supply stage, taking into account negative correlation of retailer orders between periods. Ma and Bao (2017) investigated the impact of retail prices variability in the two-echelon supply chain on the bullwhip effect. The results indicate that it's inadvisable to conduct large fluctuation on price. Besides, demand dates that are more historical may actually reduce the bullwhip effect. We also find that the bullwhip effect will be bigger when the competition becomes fiercer. Sy (2017) used the system dynamics modeling to examine the effects of integrating product returns and recovery options to the traditional downstream flow in the production-distribution system. The recovery options of remanufacture, cannibalization and refurbish were found to have the most significant effects to the resulting degree of bullwhips and inventory variances.

Costantino et al. (2016) evaluated and compare the smoothing OUT with the traditional OUT, both integrated with the Holt-Winters (HW) forecasting method, in a four-echelon supply chain. The results show that the smoothing OUT replenishment rule is superior to the traditional OUT, in terms of the bullwhip effect, inventory variance ratio and average fill rate, especially when the seasonal cycle is small. Dai et al. (2016) developed an analytical model to systematically investigate the relationships between the bullwhip effect, information distortion and supply chain costs with different levels of information quality. Based on the results the bullwhip effect is magnified along the chain when higher-quality information on inventory shrinkage, but the magnification of the bullwhip effect does not necessarily result in higher costs. They demonstrated that higher-quality information increases the benefits of information sharing. Wang and Disney (2016) reviewed the bullwhip effect literature which adopts empirical, experimental and analytical methodologies. Assumptions and approximations for modelling the bullwhip effect in terms of demand, forecast, delay, replenishment policy, and coordination strategy are considered. Ghaffari et al. (2014) proposed a model using differential equations to study BWE in a supply chain network with multiple retailers and distributors. For reducing the bullwhip effect, they proposed a robust control method and an inventory replenishment policy. Table 1 summarized the recent researches on BWE.

Despite this consistent body of knowledge concerning the bullwhip effect in supply chains, few studies have investigated the reduction of bullwhip effect phenomenon in a four-echelon supply chain, in the pharmaceutical industry and in the presence of Covid 19 and sanctions. This paper addresses the propagation of demand variability, contributions investigating other approaches are not reviewed in the following. The same holds for the contributions related to other causes of the bullwhip and make some scenarios to diminish its effect. So, this research gives substantial insights into its causes and potential mitigating actions. Still, none of the studies mentioned above are considered these contributions. This is the gap this research aims to fill.

Table 1
Recent studies on BWE in supply chains

Research	Method	Case Study	Objective	SC	Echelon	Main Variable
Malekinejad et al. (2022)	ISM, SEM	Automotive engine oil industry	Reducing BWE	CL	-	10 factors
Scarpin et al. (2022)	Regression models	Airline industry	investigate the effect of the COVID-19 crisis on the BWE and ripple effect	-	-	Centrality, Finance proxies (Leverage ratios and Solvency ratios)
Giri and Glock (2022)	ARMA	Manufacturing/remanufacturing industry	Effect of order-quantity batching on the performance	CL	3	Price of the product
Shabany Moghadam and Fazel Zarandi (2022)	ABM, Game theory	NA	Facilitating cooperation and coordination among SC components	-	4	Information sharing
Yang et al. (2021)	Literature review	NA	Investigating Behavioral and psychological factors	-	-	Social interaction, individual traits and emotion
Hosseini Bamakan et al. (2021)	Fuzzy cognitive map	Pharmaceutical industry	Bullwhip Effect Reduction	-	-	13 Factors
Ponte et al. (2021)	Simulation	NA	Effect of price and lead time on BWE	CL	2	Price, lead time and batching
Nguyen et al. (2021)	Simulation, Regression analysis	Hard goods retailer	Connecting all SC upper tiers to the storefront	-	3	Historical average demand, demand estimates, lead time
Ponte et al. (2020a)	MOP	Manufacturer of military optical products	Studying the impact of information transparencies, return rates, and lead time on performance	CL	4	Information transparencies, return rates, and lead time
Zhu et al. (2020)	NA	Oil and gas supply chain	Exploring factors that impact BWE	-	4	Storage capacity, demand forecasting, long-term contracts
Mirab Samiee et al. (2020)	Simulation	NA	Demand forecasting	-	2	Demand Forecasting
Ponte et al. (2020b)	Simulation	NA	Quantity discounts	-	3	Quantity discounts
Pastore et al. (2020)	AR	NA	Demand distribution	-	2	Demand parameter uncertainty
Michna et al. (2020)	Moving Average	NA	Quantifying the bullwhip	-	-	Lead times
Goodarzi and Farzipoor (2020)	DEA	Pharmaceutical industry	Bullwhip effect evaluation	-	2	Efficiency
Dominguez et al. (2020)	Simulation/ ANOVA	NA	Inventory performance	CL	3	Lead time, return rate and information transparency
Zhou et al. (2019)	Simulation	Power Generation System	Minimizing the total cost and optimizing the charging-discharging behaviors of end-users.	-	-	Energy Cost
Dominguez et al. (2019)	Simulation	NA	Investigate the dynamic behavior of SC	CL	-	Capacity restrictions
Pastore et al. (2019)	Regression	spare parts industry	Analyzing demand variability propagations	-	5	Demand variability
Gaalman et al. (2019)	ARMA	NA	Lead Time variability	-	-	Lead time
Lin et al. (2019)	System dynamics	Logistics equipment company	Performance metrics of bullwhip	Hybrid	4	Forecast smooth factor, control percentage and order lead time
Hu (2019)	Differential equations	NA	Investigating BWE in supply chains	-	-	Delivery delays
Nakade and Aniyama (2019)	Moving Average	NA	BWE forecasting	-	-	Lead time

Research	Method	Case Study	Objective	SC	Ech elon	Main Variable
Ojha et al. (2019)	Simulation	Managing order fulfillment	Investigate the impact of information sharing on BWE and order fulfillment	-	-	Information sharing and information type
Kadivar and Akbarpour (2018)	ARMA	NA	Impact of different distribution systems on BWE	-	4	Type of distribution systems
Braz et al. (2018)	Literature review	NA	Comparing the mitigating factors of the BWE	CL	-	Many Factors
Zhao et al. (2018)	System dynamics	Electronics industry	Reducing BWE	-	3	Electronic waste, solid material and clean production
Ponte et al. (2017)	ABM	NA	Interaction of Inventory Policies across the Supply Chain	-	4	Inventory Policies
Wang and Disney (2017)	ARMA and Simulation	NA	Investigating the amplification of inventory fluctuations	-	-	Lead-Time
Minner and Transchel (2017)	Simulation	NA	Analyzing the impact of perishability on order variability and BWE	-	2	Inventory depletion, stock-out management, and service level requirement
Ma and Bao (2017)	Simulation	Air conditioning	Impact of retail prices variability on BWE	-	2	price, market share, lead time, and autoregressive coefficients
Sy (2017)	System dynamics	3 case studies	Identifying effective policies for managing inventory, production and distribution	-	3	Integrating product returns and recovery options
Costantino et al. (2016)	Holt-Winters Simulation	NA	Investigating the impact of smoothing OUT on the seasonal SC performances	-	4	Smoothing OUT replenishment rule
Trapero and Pedregal (2016)	Recursive estimation algorithms	Chemical industry	Analyzing potential metrics for measuring BWE	-	3	A time-varying extension of the BWE metric
Dai et al. (2016)	Simulation	NA	examining the relationships among the BWE, information distortion and supply chain costs	-	2	Inventory inaccuracy; Information quality
Wang and Disney (2016)	Literature review	NA	Reviewing BWE's Progress, trends and directions	-	-	BWE
Khosroshahi et al. (2016)	Moving average	Pipeline supply chain	Quantify the BWE	-	3	Service levels
Dominguez et al. (2015)	Simulation, ANOVA	NA	Investigation the impact of SC structure on BWE	-	-	Number of echelons, nodes and distribution of links
Fu et al. (2015)	Simulation	NA	Quantifying BWE	-	4	ordering policy
Udenio et al. (2015)	System dynamics	Manufacturing industry	Analyzing the strong sales dip	-	1	Structural, operational, and behavioral
This research	System dynamics	Pharmaceutical industry	Reducing medicine shortage	-	5	Information Quality, Safety Stock and Lead Time

3. Research Methodology

This study employed system dynamics approach advocated by Forrester (1961) as a method to investigate the dynamic effects in large non-linear systems to model a 5-echelon supply chain involves in component producer, manufacturer, distributor, retailer and Consumer, in the pharmaceutical industry in COVID-19 pandemic and evaluate different scenarios of reducing bullwhip effect. The computer simulation was implemented in Vensim PLE software. It is operated by a cause-and-effect feedback relationship in four variables (state variable, rate variable, auxiliary variable and constant variable) and five types of parameters (initial value, rate, constant, table function and auxiliary variable). parameter and initial conditions to quantify most variables and eliminate ambiguity. Bullwhip effect especially in pharmaceutical industry shows complicated, uncounted and changing.

Pure mathematics methods fail to express dynamic interactions and relevant system behavior. So, system dynamics modeling is appropriate for studying the bullwhip effect. A list of criteria that constitute BE is illustrated in Table 2. SD model has been widely adopted to model complicated systems. Furthermore, the applying SD model to describe BE is a new field of study.

Table 2
Derivers of the Bullwhip Effect

Indicator	**References**
Purchase Cost	Lee et al. (1997), Zotteri (2013), Pastore et al. (2019)
Order Batching	Lee et al. (1997), Chen et al. (2000), Holland and Sodhi (2004), Hussain and Drake (2011), Li et al. (2014), Braz et al. (2018), Pastore et al. (2019), Zhu et al. (2020)
Inventory Class	Brandimarte and Zotteri (2007), Zotteri (2013), Pastore et al. (2019), Dominguez et al. (2020)
Lead Time	Chen et al. (2000), Li et al. (2014), Matamoros et al. (2011), Zhao et al. (2018), Pastore et al. (2019), Gaalman et al. (2019), Ponte et al. (2020a), Zhu et al. (2020), Dominguez et al. (2020), Ponte et al. (2020b)
Product Type	Zotteri (2013), Pastore et al. (2019)
Promotions	Lee et al. (1997), Gavirneni (2006), Zhang and Burke (2011), Pastore et al. (2019)
Information Type	Ojha et al. (2019)
Information Distortion	Braz et al. (2018), Zhao et al. (2018), Ojha et al. (2019), Jiang and Ke (2019), Zhou et al. (2019), Goodarzi and Farzipoor Saen (2020), Ponte et al. (2020b)
Information Transparency	Ponte et al. (2020a), Dominguez et al. (2020)
Structured Inventory Control Process	Chong (2013), Braz et al. (2018), Zhao and Zhu (2018)
Return Rate	Corum et al. (2014), Dominguez et al. (2015), Cannella et al. (2016), Zhu et al. (2017), Braz et al. (2018), Zhao et al. (2018), Ponte et al. (2020a), Dominguez et al. (2020)
Inventory Policy	Cheng (2009); Dominguez et al. (2020)
Safety Stock	Zhao et al. (2018)
Demand Quantity	Li et al. (2014), Zhao et al. (2018), Ponte et al. (2020b)
Distribution Rate	Zhao et al. (2018)
Transportation System	Zhao et al. (2018)
Customer Demand Change	Li et al. (2014), Haines et al. (2017), Zhao et al. (2018), Pastore et al. (2019)
Order Backlog	Haines et al. (2017), Zhao et al. (2018), Ponte et al. (2020b)
Inventory Arrival Rate	Haines et al. (2017), Zhao et al. (2018)
Number of Echelons	Braz et al. (2018)
Rationing	Li et al. (2014), Braz et al. (2018)
Shortage Game	Li et al. (2014), Braz et al. (2018); Zhu et al. (2020)
Price Fluctuations	Lee et al. (1997), Chen et al. (2000), Li et al. (2014), Chong (2013), Trapero and Pedregal (2016), Braz et al. (2018), Zhu et al. (2020), Ponte et al. (2020b)
Demand Forecast Updating	Lee et al. (1997), Chong (2013), Zhu et al. (2020)
Forecasting Error	Metters (1997), Chen et al. (2000), Chong (2013), Braz et al. (2018), Ponte et al. (2020b)
Difference with Desired Inventory (Inventory Gap)	Lee et al. (1997), Chong (2013), Yuan and Zhu (2016), Ma and Bao (2017), Braz et al. (2018)
Monopoly of Marketing Channel	Chong (2013)
Stability of Supplier's Quality	Chong (2013)
Quantity Discount	Ponte et al. (2020b), Zhu et al. (2020)
Investment Accelerator Effect	Wang and Disney (2016), Zhu et al. (2020)

To verify the proposed model, we used two categories of validation tests, namely structural and behavioral tests including Model boundary, system behavior, sensitivity analysis and behavior reproduction which are the most important verification tests. Steps of simulation in system dynamics model is presented in Figure 1.

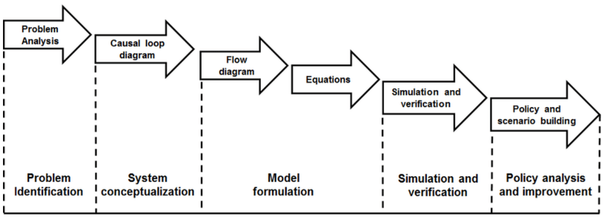

Fig. 1. Steps to build a system dynamics model

4. Research Findings

As previously discussed, the main objective of this research is to reduce demand amplification in the pharmaceutical supply chain. In this section, we will initially consider a 5-echelon supply chain model for the exposition of our supply chain model and BWE.

4.1. Dynamic hypothesis

The following are the casual-loop diagrams and their relevant dynamics hypothesis. First feedback loop shows the cause-and-effect relationships related to the component supplier of Sobhan-Darou Company. In the modeling the BWE, the lowest chain is the supplier of components (elements whose combination produce the medicine), the increase in demand components from medicine manufacturers increases the production rate of component production, which leads to increase in production and inventory of the components. This inventory is reduced due to the transfer of component from the supplier to the medicine manufacturer. Increase in the component shipment to the manufacturer will increase the manufacturer's received components and reduce its components demand. These relationships are displayed as Figure 2.

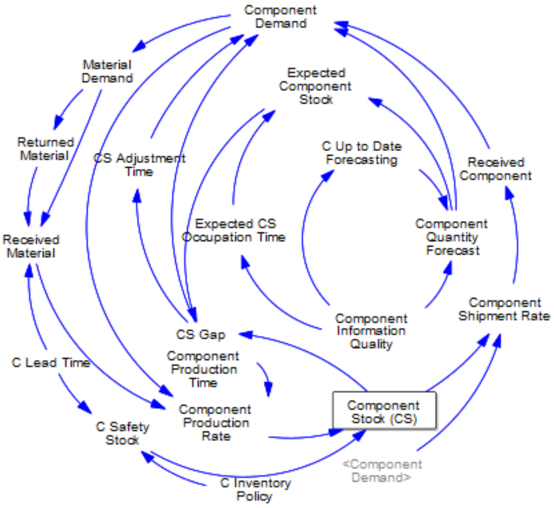

Fig. 2. Cause and effect diagram of component supplier

The manufacturer of medicine is the second part of the designed supply chain. As shown in Fig. 3; in the manufacturer's circle, the increase in medicine orders from distributors increases the production rate of manufacturer, which consequently increases the manufacturer's inventory. Medicine inventory is reduced due to the shipment of medicine from the manufacturer to the distributors. Increasing the transfer of the medicine to the distributors will increase the received medicine by the distributor s and decrease its demand.

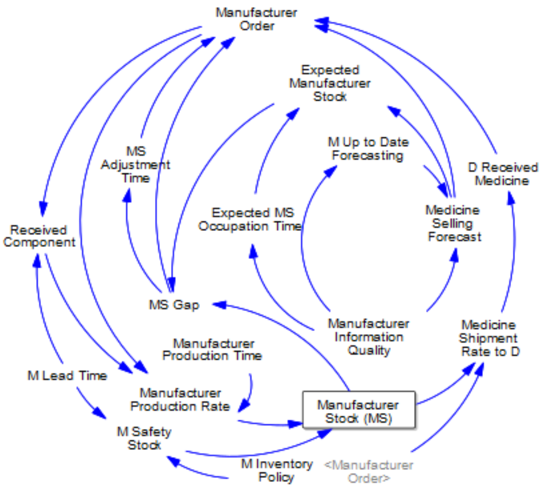

Fig. 3. Cause and effect diagram of Manufacturer

Fig. 4 illustrates the cause-and-effect circles of distributor in pharmaceutical SCM. As shown in the Fig.; the distributor of medicine products is known as the third part of the supply chain. In the distributor's circle, the increase in medicine orders from retailers (pharmacies) leads to increase in the medicine received by the distributor, which consequently increases the distributor's inventory. The distributor's inventory is reduced by shipment of pharmaceutical products to retailers. Increasing the medicine shipment from the distribution company to the retailers increases the medicine received by retailers and reduces the demand for pharmaceutical products from them. These characteristics are shown through the mechanism of pharmaceutical products distribution.

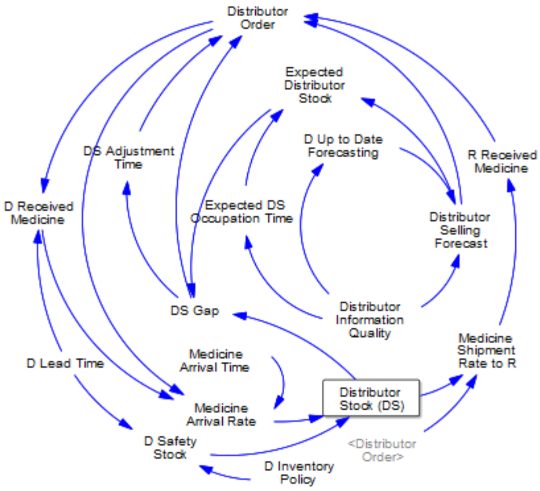

Fig. 4. Cause and effect diagram of distributor

Fig. 5 shows the retailers' causal loops diagram as another part of the supply chain. In the retailer circle, an increase in demand of customers (consumers) causes an increase in the amount of medicine received by retailers (pharmacies), which consequently increases the inventory of retailers. Drug inventory of retailers is reduced by selling medicine products to customers. Increasing the sale of the medicine to the customers will increase the received medicine by them and decrease the demand for the medicine. These characteristics are displayed through the mechanism of sale of pharmaceutical products.

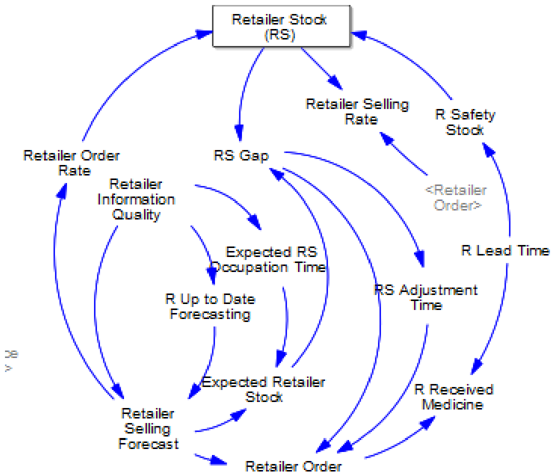

Fig. 5. Cause and effect diagram of retailer

The following figure shows the cause-and-effect diagram of consumers in pharmaceutical SCM. As shown in Fig. 6; In the proposed model, consumers (customers) are known as the fifth part of the supply chain. In the circle of consumers, the increase in prevalence of diseases, especially the Covid-19 pandemic, the quality of domestic medicines, the price fluctuations of foreign medicines that are affected by sanctions and the prohibition of medicine import, will change the demand rate of domestic medicine by customers where effects on the consumption of domestic medicines. In addition, the Covid-19 pandemic caused some consumers shift from pharmaceutical products to herbal and non-chemical medicines, which reduced the demand of domestic medicines. These characteristics are displayed as below.

According to the examined cause and effect diagrams (Fig. 2, 3, 4, 5 and 6) for 5 echelons in the pharmaceutical supply chain, that is; component suppliers, manufacturers, distributors, retailers (pharmacies) and customers, the overall cause and effect diagram of the research is developed as Fig. 7.

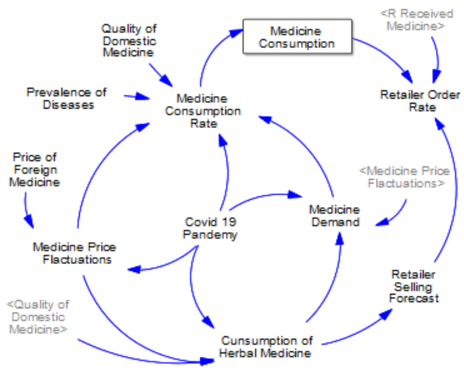

Fig. 6. Cause and effect diagram of consumers

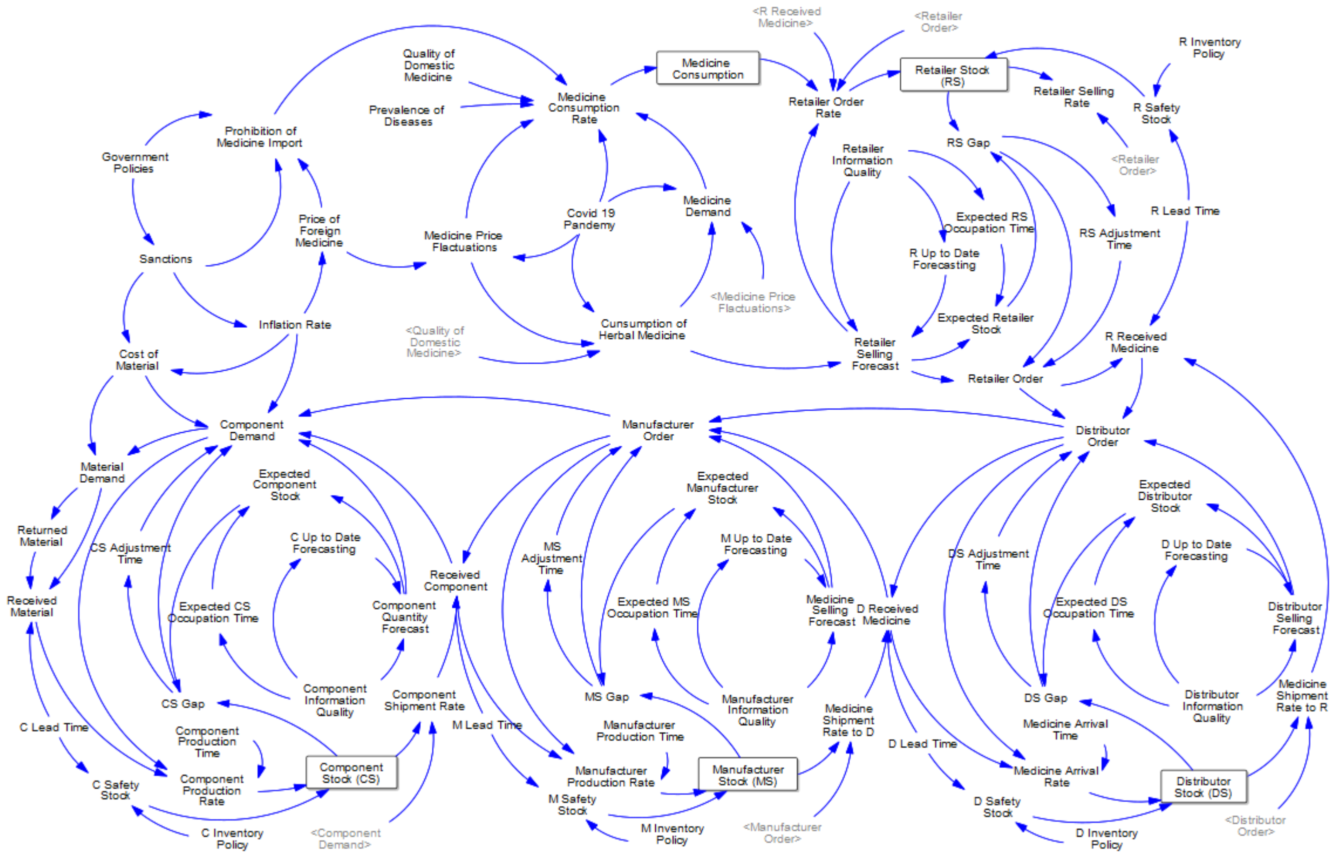

Fig. 7. Cause and effect diagram of pharmaceutical SCM

4.2. Stock and flow diagram

This research uses parameters and variables that have widely studied and recommended for SD models to establish proper means for simulating supply chain behavior. According to the causal loop diagrams described in the previous section, the stock and flow diagram of the research model is shown in Fig. 8. This model consisted of 9 Constant, 5 stock variables, 9 flow variables and 56 auxiliary variables.

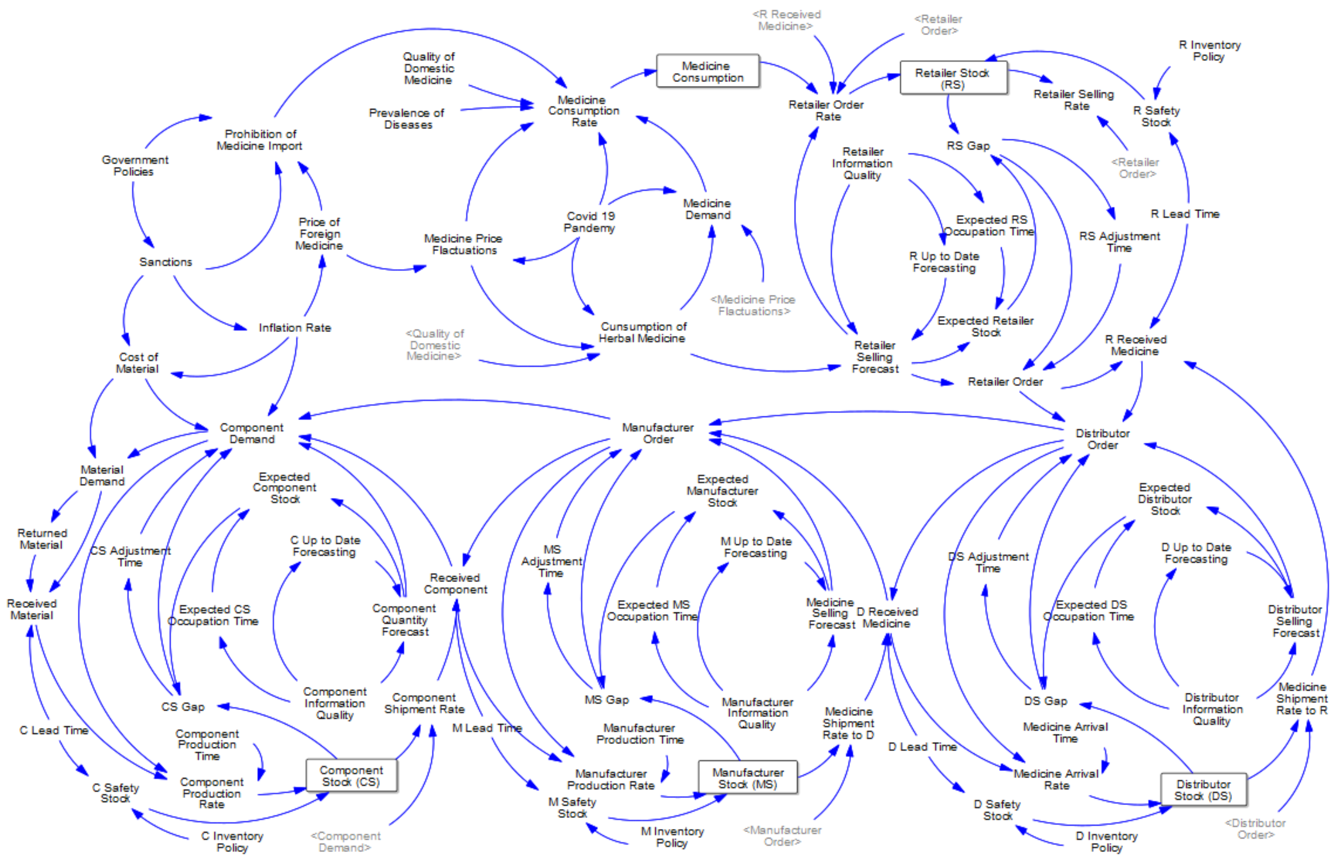

Fig. 8. Stock and flow diagram of pharmaceutical SCM

4.3. Validity tests

The model's validity is tested in terms of the congruency of its structure, components and elements with the real system.

Structural validity tests. In this research, due to the inaccessibility to real data about some variables, three validation methods namely experts' judgments, model structure validation and model dimensions' consistency have been used to validate model structure. (A) The boundary adequacy test examines the suitability of model boundaries based on its design purpose. In other words, the limits of the model must be in accordance with the purpose of its design and include all the factors and parts affecting the behavior of the investigated variable, and the definition of endogenous and exogenous variables should be in accordance with the objectives of the model. This aspect of model validation is qualitative and is possible through the study of diagrams and flow charts by experts. For this purpose, the state-flow diagram was explained to the research participants and the final model was confirmed. (C) Dimensions consistency test examines the correctness of the different variables included in the stock & flow charts that are related to each other through differential equations. The "Units are OK" message, appeared in the Vensim window while running the simulation which indicates the accuracy of the inputs, outputs and differential equations. (C) Model structure assessment test validates the completeness of the simulated model, and ensures all the defined variables are utilized in differential equations. Providing any error instead of the confirmation window in this section indicates the simulation is incomplete. In this case, Vensim software displays no error in simulation process.

Behavioral tests. (A) Integration error test. This test aims to validate the consistency of model's behavior. Therefore, in addition to the initial simulation of the model, another simulation was done in a limited time horizon and the results were compared for several main variables. Based on the results the behavior of the main variables is similar and the integration error can be ignored. (B) Behavior regeneration test. In this test, the behavior obtained from the simulation of the main variables is compared with their reference behavior, and if the error percentage is small, it can be claimed that the model has behavioral validity. For this purpose, we compare the results of the simulation of some variables with their predicted values using root mean square errors (RMSE). Empirically, it has been stated that to confirm the system's behavior, this index should be less than 0.1. Considering the number of variables in the model, for example, the value of the RMSE index of the manufacturer's stock has been calculated, which was equal to 0.04. (C) Sensitivity analysis. To evaluate the sensitivity analysis of the main variable, several exogenous key variables are selected and their effect is evaluated for two extreme values. SyntheSim sensitivity analysis is applied in this research which verified the model's validity.

4.4. Scenario analysis

In the current research, 4 scenarios are considered according to the policies and facilities of each echelon. It is necessary to explain that the scenarios about the information quality, safety stock and lead time of the echelons have been proposed due to the availability of their data. Table 3 details these scenarios.

Table 3
Stock Gap of the SC echelons

Scenario	Information Quality	Safety Stock	Lead Time
Base Run	-	-	-
Scenario 1	5 Percent ↑	5 Percent ↑	5 Percent ↓
Scenario 2	5 Percent ↑	10 Percent ↑	5 Percent ↓
Scenario 3	5 Percent ↑	5 Percent ↑	10 Percent ↓

In the Base Run scenario, the information quality, safety stock and lead time of the echelons is considered exactly same as the values of the simulated model. In scenario 2, it is assumed that the information quality will increase by 5%, the safety stock will increase by 5%, and the lead time will reduce by 5%. In scenario 3, it is assumed that there will be 10% increase in the information quality, 5% increase in the safety stock, and 5% reduction in the lead time. Scenario 4 assumed that the information quality will increase by 5%, the safety stock will increase by 5%, and the lead time will be reduced by 10%. Fig. 9 shows the result of the scenarios in reducing the stock gap of component supplier, manufacturer, distributor and retailer.

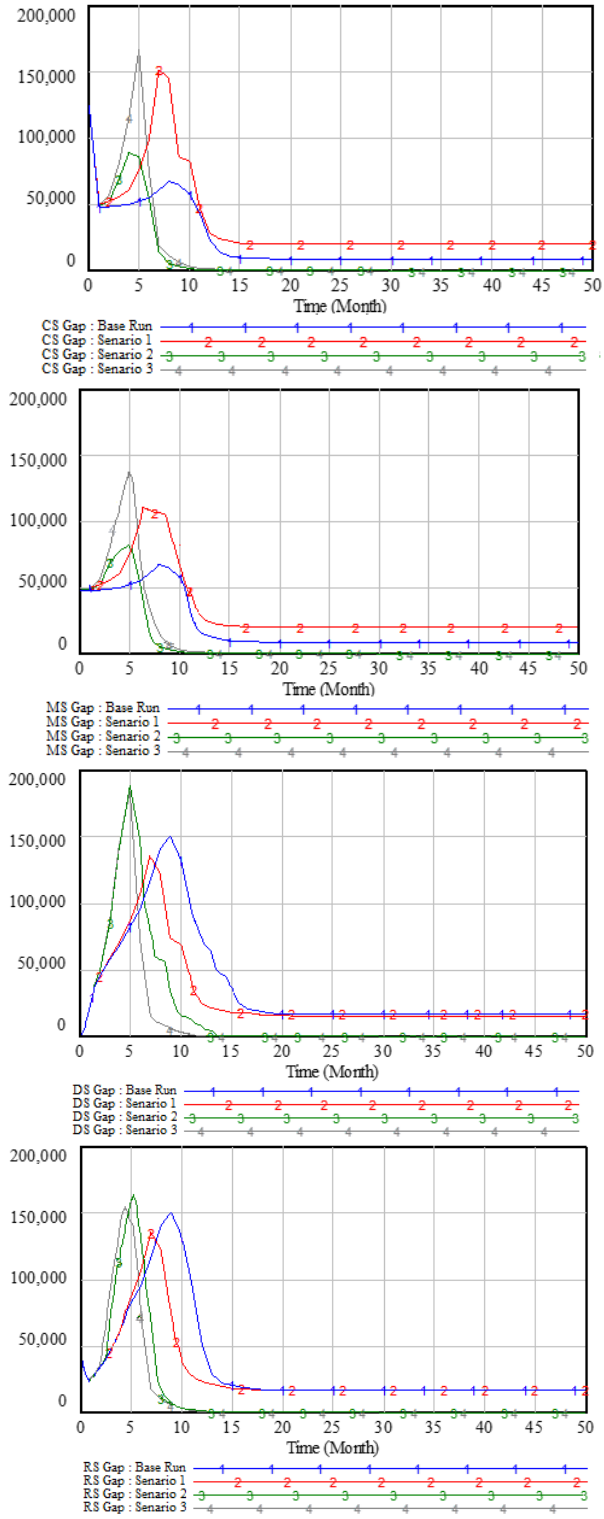

Fig. 9. Behavior of the stock gap for supply chain player

According to the proposed 4 scenarios for the echelons of the supply chain and analyzing the results, it was found that the best scenario for the component supplier and Medicine manufacturer is a 5% increase in the information quality and a 10% increase in the safety reserve and a 5% decrease in lead time. While for the medicine distributor and medicine retailer, a 5% increase in the quality of information, a 5% increase in the safety reserve and a 10% reduction in lead time, minimizes stock gap in the shortest time. It should be noted that the behavior of the variable in BWE comprises the delay concept which must be incorporated in modelling at different period time.

5. Conclusion

The establishment of supply chain management approaches is always associated with two basic features of integration and coordination of the components. The importance of this approach in recent decades have led researchers to concentrate on this field of study. In this research, after designing inventory management dynamic model and simulating it, the efects of change in the information quality, safety stock and lead time have been studied on inventory fluctuations of pharmaceutical industry. Haychen et al. (2000), Dejonkhar et al. (2004), Chartfield et al. (2004) and Chartfield and Pritchard (2017) also investigated the BWE and its drivers such as lead time, information sharing, and quality. According to their study, with the fixed reserve of each member of the supply chain, increasing changes in customer demand will increase the whip effect from downstream to upstream in the supply chain, but it will be accompanied by a decrease in the overall effect of the BWE whip. That is, if the safety stock increases by 5 units, it will reduce the changes in customer demand and the BWE of the whole supply chain. The variance of the final customer's demand is also increasing. This increase in variance is associated with an increasing trend as we move up the supply chain and go to the upstream.

The suggestions for future studies are as follows: The reaction of the supply chain in the BWE is different based on different demand forecasting methods, which can be investigated as a subject of future research.

It is suggested to pay attention to the issue of closedness of flows in the form of the concept of the closed-loop supply chain in the model. According to the results of this research, demand fluctuations at different echelons of the supply chain have on the evaluation of the BWE. it is suggested to implement integrated information systems in the entire chain and to share the information supply and capacity. According to the results of this research, the fluctuations of the safety stock at different levels of the supply chain have the greatest impact on the evaluation of the leather BWE, it is suggested to design the ordering system process.

References

Aslani Khiavi, S., & Skandari Dastghiri, S. (2021). The Design of Inverse Network DEA Model for Measuring the Bullwhip Effect in Supply Chain with Uncertain Demands. *Journal of Optimization in Industrial Engineering*, 14(1), 93-104.

Brandimarte, P., & Zotteri, G. (2007). Introduction to distribution logistics, *John Wiley & Sons*.

Braz, A.C., Mello, A.M., de Vasconcelos Gomes, L.A., & Nascimento, P.T. (2018). The bullwhip effect in closed-loop supply chains: A systematic literature review. *Journal of Cleaner Production*, 202, 376-389.

Cannella, S., Bruccoleri, M., & Framinan, J.M. (2016). Closed loop supply chains: What reverse logistics factors influence performance? *International Journal of Production Economics*, 175, 35-49.

Chen F., Drezner, Z., Ryan, J.K., & Simchi-Levi, D. (2000). Quantifying the Bullwhip Effect in a Simple Supply Chain: The Impact of Forecasting. *Management Science*, 46(3), 436-443.

Chong, L. (2013). Controlling the bullwhip effect in a supply chain system with constrained information flows. *Applied Mathematical Modelling*, 4, 1897-1909.

Costantino, F., Gravio, G.D., Shaban, A., & Tronci, M. (2015a). The impact of information sharing on ordering policies to improve supply chain performances. *Computers & Industrial Engineering*, 82, 127–142.

Costantino, F., Gravio, G.D., Shaban, A., & Tronci, M. (2015b). A real-time SPC inventory replenishment system to improve supply chain performances. *Expert Systems with Applications*, 42, 1665–1683.

Costantino, F., Gravio, G.D., Shaban, A., & Tronci, M. (2016). Smoothing inventory decision rules in seasonal supply chains. *Expert Systems with Applications*, 44, 304-319.

Corum, A., Vayvay, Ö., & Bayraktar, E., (2014). The impact of remanufacturing on total inventory cost and order variance. *Journal of Cleaner Production*, 85, 442-452

Dai, H., Li, J., Yan, N., & Zhou, W. (2016). 3Bullwhip effect and supply chain costs with low- and high-quality information on inventory shrinkage. *European Journal of Operational Research*, 250(2), 457-469.

de Lima, D.P., Fioriolli, J.C., Padula, A.D., & Pumi, G. (2018). The impact of Chinese imports of soybean on port infrastructure in Brazil: A study based on the concept of the Bullwhip Effect. *Journal of Commodity Markets*, 9, 55-76.

Dominguez R., Cannella S., & Framinan, J.M. (2015). On returns and network configuration in supply chain dynamics. Transportation Research Part E: Logistics and Transportation Review. *Transportation Research Part E: Logistics and Transportation Review*, 73, 152-167.

Dominguez, R., Ponte, B., Cannella, S., & Framinan, J.A. (2019). On the dynamics of closed-loop supply chains with capacity constraints. *Computers & Industrial Engineering*, 128, 91-103.

Dominguez, R., Cannella, S., Ponte, B., & Framinan, J.A. (2020). On the dynamics of closed-loop supply chains under remanufacturing lead time variability. *Omega*, 97, 102106.

Duc Tai, P., Ton Hien Duc, T., & Buddhakulsomsiri, J. (2018). Measure of bullwhip effect in supply chain with price-sensitive and correlated demand. *Computers & Industrial Engineering*, 127, 408-419.

Fu, D. (2015). Quantifying and mitigating the bullwhip effect in a benchmark supply chain system by an extended prediction self-adaptive control ordering policy. *Computers & Industrial Engineering*, 81, 46-57.

Gaalman, G., Disney, S.M., & Wang, X. (2019). When the Bullwhip Effect is an Increasing Function of the Lead Time. *IFAC Papers OnLine*, 52-13, 2297–2302.

Gavirneni, S. (2006). Price fluctuations, information sharing, and supply chain performance. *European Journal of Operational Research*, 174, 1651-1663.

Giri, B.C., & Glock, C.H. (2022). The bullwhip effect in a manufacturing/remanufacturing supply chain under a price-induced non-standard ARMA (1,1) demand process. *European Journal of Operational Research*, 301(2), 458-472.

Goodarzi, M., & Farzipoor Saen, R. (2020). How to measure bullwhip effect by network data envelopment analysis? *Computers & Industrial Engineering*, 139, 105431.

Haines, R., Hough, J., & Haines, D. (2017). A Metacognitive Perspective on Decision Making in Supply Chains: Revisiting the Behavioral Causes of the Bullwhip Effect. *International Journal of Production Economics*, 184, 7-20.

Holland, W., & Sodhi, M.S. (2004). Quantifying the effect of batch size and order errors on the bullwhip effect using simulation. *International Journal of Logistics Research and Applications*, 7(3), 251-261.

Hosseini Bamakan, S.M., Malekinejad, P., Ziaeian, M., & Motavali, A. (2021). Bullwhip effect reduction map for COVID-19 vaccine supply chain. *Sustainable Operations and Computers*, 2, 139-148.

Hu, Q. (2019). Bullwhip effect in a supply chain model with multiple delivery delays. *Operations Research Letters*, 47(1), 36-40.

Hussain, M., & Drake, P.R. (2011). Analysis of the bullwhip effect with order batching in multi- echelon supply chains. *International Journal of Physical Distribution & Logistics*, 41(8), 797-814.

Jiang, Q., & Ke, G. (2019). Information Sharing and Bullwhip Effect in Smart Destination Network system. *Ad Hoc Networks*, 87(1), 17-25.

Kadivar, M., & Akbarpour Shirazi, M. (2018). Analyzing the Behavior of the Bullwhip Effect considering Different Distribution Systems. *Applied Mathematical Modelling*, 59, 319-340.

Ghaffari, M., Javadian, N., & Tavakkoli-Moghaddam, R. (2014). Controlling the Bullwhip Effect in a Supply Chain Network with an Inventory Replenishment Policy Using a Robust Control Method. *Journal of Optimization in Industrial Engineering*, 16, 75-82.

Khosroshahi, H., Moattar Husseini, S.M., & Marjani, M.R. (2016). The bullwhip effect in a 3-stage supply chain considering multiple retailers using a moving average method for demand forecasting. *Applied Mathematical Modelling*, 40(21–22), 8934-8951.

Kumara, A., Shankarb, R., & Aljohani, N.R. (2020). A big data driven framework for demand-driven forecasting with effects of marketing-mix variables. *Industrial Marketing Management*, 90, 493-507.

Lee, H.L., Padmanabhan, V., & Whang, S. (1997). The bullwhip effect in supply chains. *Sloan Management Review*, 38, 93–102.

Lee, H.L., Padmanabhan, V., & Whang, S. (1997). Information distortion in a supply chain: The bullwhip effect. *Management Science*, 43, 546–555.

Li Q., Disney, S.M., & Gaalman, G. (2014). Avoiding the bullwhip effect using Damped Trend forecasting and the Order-Up-To replenishment policy. *International Journal of Production Economics*, 149, 3-16.

Lin, W., Ren, H., Peng, Q., Ye, S., Jiang, Z., Wang, K. (2019). An Analysis of the Bullwhip Effect in Multi-echelon Hybrid Supply Chain. *IFAC Papers OnLine*, 52(13), 2419–2424.

Ma, J., & Bao, B. (2017). Research on bullwhip effect in energy-efficient air conditioning supply chain. *Journal of Cleaner Production*, 143, 854-865.

Malekinejad, P., Ziaeian, M., & Hosseini Bamakan, S.M. (2022). A communication model for reducing the bullwhip effect in closed-loop supply chain. *Advances in Industrial and Manufacturing Engineering*, 5, 100086.

Matamoros. O., Mauricio, M., Ricardo, F.C., Isaías, T.P., & Ignacio, C.M. (2011). Fractal characterization of an after-sales spare parts supply chain in telecom industry. *International Journal of Physical Sciences*, 6(10), 2462-2469.

Metters, R. (1997). Quantifying the bullwhip effect in supply chains. *Journal of Operations Management*, 15, 89–100.

Michna, Z., Disney, S.M., & Nielsen, P. (2020). The impact of stochastic lead times on the bullwhip effect under correlated demand and moving average forecasts. *Omega*, 93, 102033.

Minner, S., & Transchel, S. (2017). Order variability in perishable product supply chains. *European Journal of Operational Research*, 260(1), 93-107.

Mirab Samiee, Z., Rostamzadeh, M., & Fatahi Valilai, O. (2020). An Analysis of the BWE-Associated Costs: The issue of Demand Forecasting Accuracy. IFAC Papers online, 53(2), 10836-10842.

Nakade, K., & Aniyama, Y. (2019). Bullwhip Effect of Weighted Moving Average Forecast under Stochastic Lead Time. *IFAC Papers OnLine*, 52(13), 1277–1282.

Nguyen, D.T., Adulyasak, Y., & Landry, S. (2021). Research manuscript: The Bullwhip Effect in rule-based supply chain planning systems–A case-based simulation at a hard goods retailer. *Omega*, 98, 102121.

Ojha, D., Sahin, F., Shockley, J., & Sridharan, S.V. (2019). Is there a performance tradeoff in managing order fulfillment and the bullwhip effect in supply chains? The role of information sharing and information type. *International Journal of Production Economics*, 208, 529-543.

Pastore, E., Alfieri, A., Zotteri, G., & Boylan, J.E. (2020). The impact of demand parameter uncertainty on the bullwhip effect. *European Journal of Operational Research*, 283 (1), 94-107.

Pastore, E., Alfieri, A., & Zotteri, G. (2019). An empirical investigation on the antecedents of the bullwhip effect: Evidence from the spare parts industry. *International Journal of Production Economics*, 209, 121-133.

Ponte, B., Dominguez, R., Cannella, S., & Framinan, J.M. (2022). The implications of batching in the bullwhip effect and customer service of closed-loop supply chains. *International Journal of Production Economics*, 244, 108379.

Ponte, B., Framinan, J.M., Cannella, S., & Dominguez, R. (2020a). Quantifying the Bullwhip Effect in closed-loop supply chains: The interplay of information transparencies, return rates, and lead times. *International Journal Production Economics*, 230, 107798.

Ponte, B., Puche, J., Rosillo, R., & de la Fuente, D. (2020b). The effects of quantity discounts on supply chain performance: Looking through the Bullwhip lens. *Transportation Research Part E*, 143, 102094.

Ponte, B., Sierra, E., de la Fuente, D., & Lozano, J. (2017). Exploring the Interaction of Inventory Policies across the Supply Chain: An Agent-based Approach, *Computers and Operation Research*, 75, 335-348.

Potter, A., & Disney. S.M. (2006). Bullwhip and batching: an exploration. *International Journal Production Economics*, 104(2), 408-418.

Sadeghi, A. (2014). Measuring and Analyzing the Bullwhip Effect in a Two-Product and Two Echelon Supply Chain Using Control Theory Approach. *Journal of Optimization in Industrial Engineering*, 15, 55-63.

Scarpin, M.R.S., Scarpin, J.E., Musial, N.T.K., & Nakamura, W.T. (2022). The implications of COVID-19: Bullwhip and ripple effects in global supply chains. *International Journal of Production Economics*, 251, 108523.

Shaban, A., & Shalaby, M.A. (2018). Modeling and Optimizing of Variance Amplification in Supply Chain Using Response Surface Methodology. *Computers & Industrial Engineering*, 120, 392-400.

Shabany Moghadam, F., & Fazel Zarandi, M.H. (2022). Mitigating bullwhip effect in an agent-based supply chain through a fuzzy reverse ultimatum game negotiation module. *Applied Soft Computing*, 116, 108278.

Sterman, J.D. (1989). Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision-Making Experiment. *Management Science*, 35, 321-339.

Sy, C. (2017). A policy development model for reducing bullwhips in hybrid production-distribution systems. *International Journal Production Economics*, 190, 67-79.

Trapero, J.R., & Pedregal, D.J. (2016). A novel time-varying bullwhip effect metric: An application to promotional sales. *International Journal of Production Economics*, 182, 465–471.

Udenio, M., Fransoo, J.C., & Peels, R. (2015). Destocking, the bullwhip effect, and the credit crisis: Empirical modeling of supply chain dynamics. *International Journal of Production Economics*, 160, 34-46.

Wang, X., & Disney, S.M. (2016). The bullwhip effect: Progress, trends and directions. *European Journal of Operations Research*, 250(3), 691–701.

Wang, X., & Disney, S.M. (2017). Mitigating variance amplification under stochastic lead-time: The proportional control approach. *European Journal of Operational Research*, 256(1), 151-162.

Yang, Y., Lin, J., Liu, G., & Zhou, L. (2021). The behavioural causes of bullwhip effect in supply chains: A systematic literature review. International *Journal of Production Economics*, 236, 108120.

Yuan, X.G., & Zhu, N. (2016). Bullwhip Effect Analysis in Two-Level Supply Chain Distribution Network Using Different Demand Forecasting Technology. *Asia-Pacific Journal of Operational Research*, 33(3), 1650016.

Zhang X., & Burke G.J. (2011). Analysis of compound bullwhip effect causes. *European Journal of Operational Research*, 210, 514-526.

Zhao, S., & Zhu, Q. (2018). A risk-averse marketing strategy and its effect on coordination activities in a remanufacturing supply chain under market fluctuation. Journal of Cleaner production, 171, 1290-1299.

Zhao, Y., Cao, Y., Li, H., Wang, S., Liu, Y., Li, Y., & Zhang, Y. (2018). Bullwhip effect mitigation of green supply chain optimization in electronics industry. *Journal of Cleaner Production*, 180, 888-912.

Zhou, L., & Disney, S.M. (2006). Bullwhip and inventory variance in a closed loop supply chain. *Spectrum*, 28(1), 127-149.

Zhou, K., Wei, S., & Yang, S. (2019). Time-of-use pricing model based on power supply chain for user-side microgrid. *Applied Energy*, 248, 35–43.

Zhu, T., Balakrishnan, J., & da Silveira, G.J.C. (2020). Bullwhip Effect in the Oil and Gas Supply Chain: A Multiple-case Study. *International Journal of Production Economics*, 224, 107548.

Zotteri, G. (2013). An empirical investigation on causes and effects of the Bullwhip-effect: Evidence from the personal care sector. *International Journal of Production Economics*, 143(2), 489-498.

This article can be cited: Tavakol, P., Nahavandi, B., & Homayounfar, M. (2023). A Dynamics Approach for Modeling Inventory Fluctuations of the Pharmaceutical Supply Chain in COVID 19 Pandemic. *Journal of Optimization in Industrial Engineering, 16*(1), 105-118. doi: 10.22094/joie.2023.1966193.1981