Supply Chain Management by Means of Simulation

Borja Ponte, David de la Fuente, Raúl Pino, Rafael Rosillo, and Isabel Fernández

***Abstract*—Several changes in the macro environment of the companies over the last two decades have meant that the competition is no longer constrained to the product itself, but the overall concept of supply chain. Under these circumstances, the supply chain management stands as a major concern for companies nowadays. One of the prime goals to be achieved is the reduction of the Bullwhip Effect, related to the amplification of the demand supported by the different levels, as they are further away from customer. It is a major cause of inefficiency in the supply chain. Thus, this paper presents the application of simulation techniques to the study of the Bullwhip Effect in comparison to modern alternatives such as the representation of the supply chain as a network of intelligent agents. We conclude that the supply chain simulation is a particularly interesting tool for performing sensitivity analyses in order to measure the impact of changes in a quantitative parameter on the generated Bullwhip Effect. By way of example, a sensitivity analysis for safety stock has been performed to assess the relationship between Bullwhip Effect and safety stock.**

***Index Terms*—Artificial Intelligence, bullwhip effect, simulation, supply chain management.**

I. INTRODUCTION

A supply chain encompasses all participants and processes involved in satisfying customer demands around some products. The supply chain management covers, therefore, activities related to provisioning, production and distribution of the product, all of them placed between an upper node, which we will call factory, and a lower node, which we call shop retailer.

Thus, we must consider two main flows along it: the materials flow, including the distribution of the product from the factory to the shop retailer (downstream flow) and the information flow, which refers to transferring orders from the customer by the remaining members (upstream flow).

Analyzing the supply chain, Forrester [1] noted that small changes in customer demand are highly amplified along the supply chain, leading it to larger variations in demand supported by the different levels, as they are further away from customer. This is called the Bullwhip Effect (or Forrester Effect), which, according to the subsequent research by Lee et al. [2], is due to four main causes: errors in the forecasts of demands, inadequate lot sizing, variations in product prices over time, and the rationing policy for fear of stock breakage.

There have been several changes in the last two decades in the macro environment of the companies that have set up a new business perspective. This has led to the perception that competition is no longer limited to the product itself, but what really competes is the overall concept of the supply chain. From this perspective, the production function is considered to have a strategic role as a source of competitive advantage, so that the practices related to the supply chain management now represent one of the main concerns of business.

In these circumstances, it is especially emphasized the importance of proper management of the supply chain regarding different objectives. One of them is undoubtedly reducing the Bullwhip Effect. In fact, Disney and Towill [3] demonstrated that the Bullwhip effect leads the supply chain to unnecessary costs that can represent, in some cases, more than 30% of the total costs thereof. That is to say, the Bullwhip Effect can be considered as one of the main causes of inefficiencies in supply chain management, which is produced by the conducts of the various players involved in it.

In this context, this work proposes the application of modern simulation techniques to the study of Bullwhip Effect in a supply chain.

The authors recently studied the subject through a multiagent approach in [4], and now, they proposes the use of simulation tools to complement the analysis. To develop the model, we have used the software ARENA 11.0. From this perspective, we will do simultaneously a comparative evaluation of the two alternatives, in order to assess the potential of each one and to open new ways of research of this problem.

The presented document is divided into four sections besides this introduction. Section 2 shows a review of the most relevant and recent literature on the subject. Section 3 describes the model which we have created, with the various elements that compose it. Section 4 presents the results of applying the model on different series. Finally, Section 5 presents the conclusions according to the planned objectives.

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II. Background: Bullwhip Effect Reduction Through Simulation Tools

Firstly, we outline the traditional solutions proposed to mitigate the Bullwhip Effect. In the second and third, we briefly describe the most recent applications of multiagent methodology and simulation techniques to its reduction.

A. Traditional Solutions to the Bullwhip Effect.

Each supply chain has its own characteristics, mainly conditioned by the type of product which is offered to the consumer and by the market conditions in which it moves, and that unquestionably complicates the analysis of valid methodologies for reducing the Bullwhip Effect. However, it is possible to find some common problems to all of them, and several authors have proposed general strategies to be adapted to each particular supply chain. These traditional solutions to Bullwhip Effect are mainly based on collaboration among the various members of the supply chain, often sharing some information. Thus, some practices that are carried out in some companies and which have been successful in reducing the Bullwhip Effect are:

- Use of Information Technology systems, such as electronic data interchange [5].
- Postponement, which is based on a redesign of products with the aim that the differentiation takes place in nodes near the customer [6].
- Efficient Consumer Response (ECR). These are associations of companies to synchronize the supply chain [7].
- Vendor Managed Inventory (VMI). The supplier controls the inventory of the consumer, deciding on delivery times and quantities [8].
- Collaborative Planning, Forecasting and Replenishment (CPFR). It means that members of the supply chain can develop, in a collaborative way, business plans and processes [9].

B. Multiagent Systems in the Supply Chain Management.

The supply chain management is a highly complex problem, conditioned by multiple agents, each of which has to serve a large number of variables. In the last two decades, authors have looked for different ways to optimize the management by using new techniques based on Artificial Intelligence. Several authors have approached the supply chain as a network of intelligent agents. These are called multiagent systems.

Fox et al. [10] were pioneers in the proposal of the organization of the supply chain as a network of cooperating intelligent agents. In their work, each agent executes one or more functions of the supply chain, coordinating their actions with other agents. Later, Shen et al. [11] developed the tool MetaMorph II, which, through an agent-based architecture, integrates partners, suppliers and customers with a lead company through their respective mediators within a supply chain network via the Internet.

Kimbrough et al. [12] studied whether a structure based on agents could be valid for the supply chain management, and they reached the conclusion that the agents were able to effectively play the well known Beer Game [13], reducing the Bullwhip Effect. Moxaux et al. [14] used a multiagent system for modeling the behavior of each company in the supply chain. The paper proposes a variant of the Beer Game, which they called "Quebec Wood Supply Game".

Liang y Huang [15] developed, based on a multiagent architecture, a model which allowed predicting the order quantity in a supply chain with several nodes, where each one of them could use a different system of inventory. De la Fuente and Lozano [16] presented an application of Distributed Intelligence to reduce the Bullwhip Effect in a supply chain, based on a genetic algorithm. Zarandi et al. [17] introduced Fuzzy Logic in the analysis.

Wu et al. [18] applied the multiagent methodology to establish a supply chain model and to analyze in detail the Bullwhip Effect created along the chain, considering the non existence of information exchange among different members. One of the last studies in that regard is the one by Saberi et al. [19]. It develops a multiagent system, and which links the various agents that form it, emphasizing the collaborative aspect. Recently, Ponte and De la Fuente [4] proposed a multiagent model for managing the supply chain, based on collaboration between the various members, showing that this alternative allows a great reduction of Bullwhip Effect.

We can conclude that several changes in the last decades have become the supply chain in a complex system that requires modern methodologies for its analysis, seeking to optimize their management.

C. Supply Chain Simulation.

Digital simulation is a technique that allows imitating in a computer the behavior of a real system. Although it has been used for several decades, the continuous evolution of computers increases significantly its applications. It allows studying, in highly complex systems, the effect of small changes, which in real conditions it would not be feasible to analyze.

Manyem and Santos [20] simulated a supply chain of only two stages, with the aim of studying the propagation of Bullwhip Effect between two consecutive levels and, thus, the impact of this phenomenon in the profitability of the companies. They focused on the consequences of increasing the lead time, demonstrating that it introduced a great uncertainty to the chain, which meant severe disruption of performance.

Merkureyev et al. [21] simulated, using ARENA 5.0, a supply chain of four levels and described the impact on the Bullwhip Effect of the two supply chain information management policies (centralized and decentralized information) combined with two management policies inventory (policy min-max and stock-to-demand). Of these combinations, four different models emerged, concluding that the Bullwhip effect appeared in all cases, but not to the same extent, demonstrating that centralized information policy and the policy of stock-to-demand work best in Effect terms Bullwhip reduction.

Boute and Lambrecht [22] simulated the supply chain through a large spreadsheet, oriented to analyze the relationship between the level of customer service and the Bullwhip Effect. To do this, they studied various changes in the parameters that define replenishment policies at different levels. The authors concluded that the Bullwhip Effect can be reduced, even increasing fluctuations in inventories, but at the cost of lowering the level of customer service.

So, in contrast with multiagent systems, we refer in this section to simulations that do not introduce intelligence to the model so that agents do not have decision-making capacity in search of an optimal solution, but merely they follow a sequence of planned operations. We can conclude, after studying the literature, that these simulations are mainly used to analyze the consequences of the change of certain variables on the Bullwhip Effect, which also allows us to propose new solutions. We also noticed that there are not, compared to other techniques, many studies about the applications of supply chain simulation to analyze the Bullwhip Effect.

III. MODEL

To prepare the base model, we have considered a traditional supply chain with linear structure, which consists of five main levels: Consumer, Shop Retailer, Retailer, Wholesaler and Factory. Fig. 1 shows the graphical representation of the levels, indicating the materials flow, which occurs from the top of the chain (Factory) to the lower levels (Consumer). Therefore, it is called downstream flow. The information flow is considered to be in the opposite way, which is called downstream flow.

To implement the model, we have used ARENA 11.0 (developed by Rockwell Software).

The model is based on four Communication Channels (one between Consumer and Shop Retailer, other between Shop Retailer and Retailer, other between Retailer and Wholesaler, and the last between Wholesaler and Factory). Each one is similar to that shown in Fig. 2, which corresponds to a screenshot of the Channel Communication between the Shop

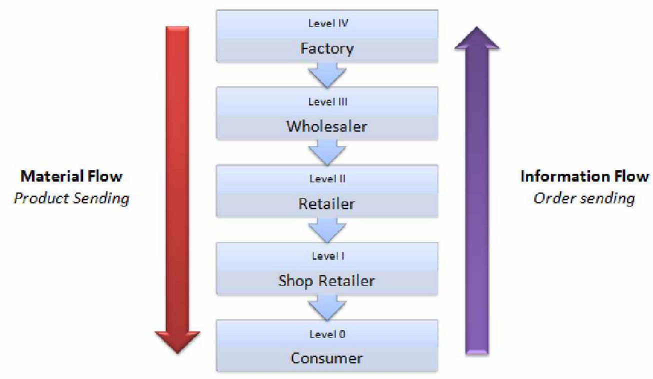

Fig. 1. Supply Chain Structure.

Retailer and the Retailer. In each one of them, the simulation begins with the level receives the order made by the previous one. Orders placed by level n+1 of the supply chain in period t (*O,t,n+1*) will mean the demand in the same period of the previous level (*D,t,n*), which is the main link connecting the different levels. It is expressed in (1).

$$D_t^n = O_t^{n+1} \tag{1}$$

Then, demand is stored in an external file for later analysis. Next, it evaluates whether the stock available at the level (*IS,t,n*), which has been planned according to the forecast of the demand, is sufficient to satisfy demand (*D,t,n*). If it is sufficient, it decreases the retailer's stock (*FS,t,n*) and it sends the material (*Y,t,n*). The stockout would be zero (*SO,t,n*). If it is not enough, stockout is generated in the level, which will be repaired in the next period, leaving the retailer's inventory to zero. In either case, it closes the communication between the two levels of the supply chain until the next period. Obviously, the initial stock of each level (*IS,t,n)* coincides with the sum of the final stock of this level in the previous period (*FS,t-1,n*) and the order made in the previous period (*O,t-1,n*). All this is expressed in (2), (3), (4), and (5).

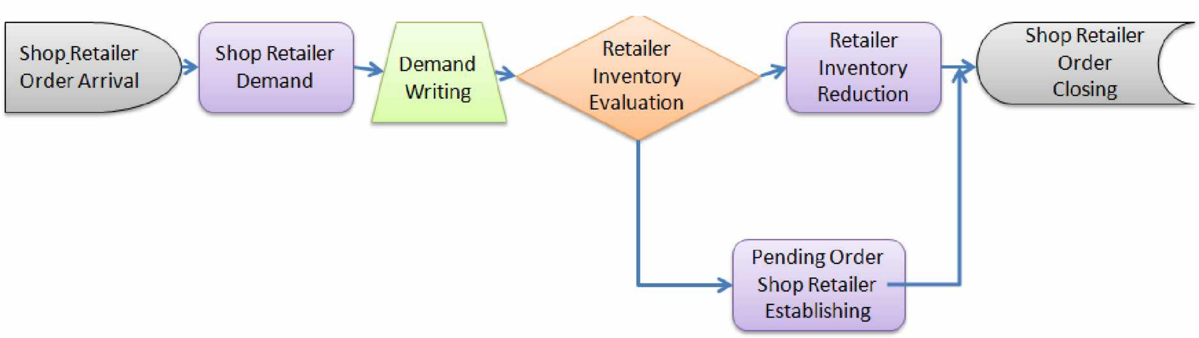

Fig. 2. Example of the Communication Channel between Shop Retailer and Retailer in the developed model.

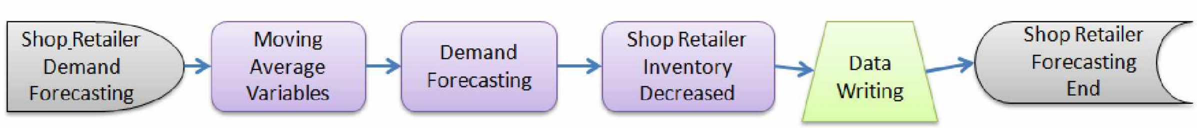

Fig. 3. Example of Forecasting Demand System of the Shop Retailer in the developed model.

$$Y_t^n = \min\{D_t^n, IS_t^n\} + SO_{t-1}^n \quad (2)$$

$$FS_t^n = \min\{IS_t^n - D_t^n, 0\} \quad (3)$$

$$SO_t^n = \max\{D_t^n - IS_t^n, 0\} \quad (4)$$

$$IS_t^n = FS_{t-1}^n + O_{t-1}^n \quad (5)$$

Moreover, the model contains four Forecasting Demand Systems, one for each one of the four main levels of the supply chain. It is based on storing the last five demands (*D,t,n-i*) received from the previous level of the supply chain and, based on them, the estimation of demand in the next period (*FD,t,n*). Thereby, the technique for the demand forecasting is a moving average of five periods. We chose this method becasuse we will simulate the system with random time series, which are statistical distributions. It is not necessary to use more complex forecasting methods, oriented to time series with periodicity and tendency. We can express the forecasting method in (6).

$$FD_t^n = \frac{D_{t-1}^n + D_{t-2}^n + D_{t-3}^n + D_{t-4}^n + D_{t-5}^n}{5} \quad (6)$$

From there, the order which will be made by each level (*O,t,n*) considers the forecasting (*FD,t,n*), taking into account available stock (*IS,t,n*), stockout generated in the previous period (*SO,t-1,n*) and the safety stock which has decided the level (*SS,n*). It is expressed in (7). Furthermore, these data are also stored in an external file for later analysis. As an example, a screenshot of the Forecasting Demand Systems of the Retailer at a time of the simulation is shown in Fig. 3.

$$O_t^n = \max\{FD_t^n - IS_t^n + SO_{t-1}^n + SS^n, 0\} \quad (7)$$

IV. Results

Once developed the model in ARENA 11.0, we have conducted various tests on it, mainly with the aim to evaluate the advantages and disadvantages offered by this alternative, compared with the multiagent methodology [4]. Draw conclusions on the causes of the Bullwhip Effect is not the aim of this paper.

Section 5 includes this comparison, emphasizing the application of supply chain simulation techniques to perform sensitivity analysis to assess the effect of changes in system parameters on the Bullwhip Effect in the Supply Chain.

As an example, we detail the calculations performed to determine the impact of the security stock in the generation of Bullwhip Effect along a specified supply chain. For this, we have conducted five different simulations. In the first case, all levels of the supply chain are working without a safety stock. In the rest, the safety stock is 5 (low), 10 (middle), 20 (high) to 40 (very high). In all cases, it was considered that the demand follows a normal distribution with mean 100 and standard deviation 10. Furthermore, we have carried out, in the five different cases, a simulation of 1500 days (approximately 214 weeks), considering a training period of 100 days (14 weeks), where the results are not considered in the calculation of final values.

TABLE I:
Results of the Tests Related to the Safety Stock (I)

Variance	*SS=0*	*SS=5*	*SS=10*	*SS=20*	*SS=40*
Consumer	116.83	116.83	116.83	116.83	116.83
Shop Retailer	170.42	170.19	170.20	170.91	175.15
Retailer	261.19	261.01	261.98	267.33	291.72
Wholesaler	418.24	418.61	422.19	438.98	511.06
Factory	694.65	696.47	705.60	745.81	914.00

TABLE II:
Results of the Tests Related to the Safety Stock (II)

Bullwhip Effect	*SS=0*	*SS=5*	*SS=10*	*SS=20*	*SS=40*
Shop Retailer	1.459	1.457	1.457	1.463	1.499
Retailer	1.533	1.534	1.539	1.564	1.666
Wholesaler	1.601	1.604	1.612	1.642	1.752
Factory	1.661	1.664	1.671	1.699	1.788
Supply Chain	***5.946***	***5.961***	***6.040***	***6.384***	***7.823***
Increase over SS=0	–	0.25%	1.56%	7.37%	31.57%

Table I shows the results of the five tests. It contains the variance of orders placed by each member of the supply chain throughout the simulation period. Note that the variance of the factory refers to the production rate, since it is the highest level of the chain.

Many authors quantify the Bullwhip Effect in supply chain as follows:

$$BW = \frac{\sigma_{df}^2}{\sigma_{dc}^2} \quad (8)$$

where σ_{dc}^2 is the variance in consumer demand for the product, and σ_{df}^2 represents the variance in the rate of the factory production.

Likewise, the Bullwhip Effect generated at each step can be defined as the ratio of the variance in orders sent to the next level of the supply chain (σ_{out}^2), and the variance in orders received from the previous level of the supply chain (σ_{in}^2). It is expressed in (9).

$$BW_i = \frac{\sigma_{out}^2}{\sigma_{in}^2} \quad (9)$$

This allows expressing the Bullwhip Effect along the entire supply chain as the product of the ratios that define the Bullwhip Effect at each level.

$$BW = \prod_{i=1}^{n} BW_i \quad (10)$$

Thereby, Table II contains the results of the test, but oriented Bullwhip Effect generation. It contains both the Bullwhip Effect generated at different levels, by (9), and the overall Bullwhip Effect generated in the supply chain in each case, by (10). Besides, it includes in the four cases in which it works with safety stock, the increase in the Bullwhip Effect related to the case with no safety stock.

Fig. 4. Relationship between safety stock and the Bullwhip Effect.

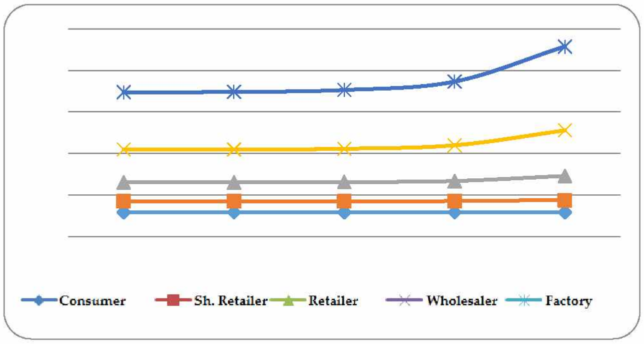

Fig. 5. Variance of the various levels in the different cases of safety stock.

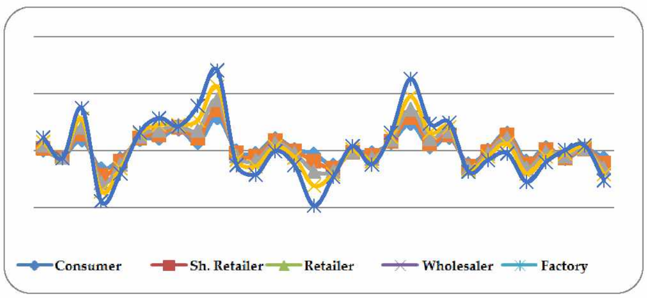

Fig. 6. Evolution in the demands from week 171 to week 200 in the simulation with 40 units of Safety Stock in each level.

Tables I and II show the relation in the studied time serie, between the safety stock and the Bullwhip Effect generated in the supply chain.

First, it is possible to note that in all cases the amplification of the variance of the demand for each level is increased as it moves away from the consumer. Moreover, the consideration of safety stock, in order to decrease the probability of stockout, increases the amplification of the variability of demands. That is, it is possible to conclude that in this case the Bullwhip Effect is greater when safety stock is increased. However, this increase is small, relatively speaking, while the safety stock used is not high.

Thereby, in this case, for safety stock levels which may be called "reasonable", its impact on the Bullwhip Effect is low. From there, it rises considerably, as it is possible to see in Fig. 4, which seems to outline an exponential relationship between the two variables.

Figure 5 shows the evolution of the variance of the demand of the various levels of the supply chain in the five different simulations throughout the simulation period (data obtained from Table I). Finally, Fig. 6 represents, as an example, variation of the demands in the different levels of the supply chain for thirty intermediate weeks (from 171 to 200) in the simulation related to 40 units of safety stock.

Finally, we want to recall that the purpose of this paper is not to assess the effect of stock safety in the Bullwhip Effect generation (it has only been done as an example for a particular time series and without the aim of drawing conclusions), but to evaluate the application of supply chain simulation techniques in the analysis of the Bullwhip Effect.

V. Conclusion: Comparative Analysis of Tools

This work complements the study of the Bullwhip Effect through multiagent methodology conducted by the same authors recently [4]. Having developed and implemented both tools based on a similar model, and after analyzing them with sufficient detail, we can conclude that:

– The approach to the problem through a multiagent system is a suitable alternative for the development of intelligent software, which is able to decide, based on a set of solutions available, the optimum for the system, according to selected criteria (related to improve the supply chain management). Through coordination between the various agents which simulate each level, this option allows to split a highly complex problem into a set of smaller problems. It is also possible to introduce advanced forecasting methods, offering a high performance in reducing Bullwhip Effect. Thus, the multiagent methodology improves supply chain management through collaboration between the different levels of it.

– The multiagent system can also analyze the causes of the Bullwhip Effect, especially the main one, related to errors in demand forecasts. However, sensitivity analysis, based on the study of the impact of a particular quantitative parameter on the Bullwhip Effect, simulation is a more appropriate tool. It allows this study with a high ease and efficiency. Through the supply chain simulation, it is affordable to simulate a time period large enough in different conditions, which it allows to decide which is the best alternative. The risk assumed with this alternative is minimal compared to the evaluation of various alternatives in the real supply chain. From there, it is possible to achieve a better understanding of the phenomenon, which may help to mitigate their appearance in order to reduce their harmful impact on the supply chain.

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