Mitigating the bullwhip effect in the electric power industry: a simulation model and a case study

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Abstract: This paper analyzes the main disturbances that can arise between the actors of a global supply chain and that can be comprised in the bullwhip effect: the amplification, oscillation, and phase lag of the demand from downstream to upstream of the supply chain. The paper is divided in two parts: the former one approaches the bullwhip effect through a literature review. The latter one deals with a real-life global supply chain in the electric power industry, by considering Elektrobudowa SA and its two main challenges in the Chinese market, where a new branch of activities is established, by opening a new manufacturing firm, which is expected to lead to restructuring their procurement and distribution process between China and Poland. Some simulation runs with iThink demonstrate that the EOQ-OP replenishment rule can cause stock-out at the distribution center so a Distribution Requirements Planning method appears to be more effective to plan the orders in advance.

Keywords: supply chain, management, bullwhip, simulation

1. Introduction

In literature there is a number of definitions for Supply Chain (SC e.g., Longoni and Koberg, 2019). However, the one that mostly fits the scope of this paper is related to the total flow of a distribution channel from the supplier to the ultimate user (Lane and Sterman 2018). The notion of distribution channel includes suppliers, manufacturers, distributors, and customers, connected by a common process and a set of supporting links in transport, communications, and other facilitators, to connect them to each other.

In the case of global corporations, some problems about the coordination among different actors emerge (Xuab et al. 2015, Leopold 2015, Cigolini et al. 2020, Pero et al. 2020). The marketing and sales department of a firm producing in Asia cannot easily match the specific needs of individual customers and market segments in North America, and the decision to outsource to Asia to supply Western European markets unleashes a chain of events and potential disturbances that shape some decisions in many areas.

An important role is played by the external environment, e.g. changes in public transport policy such as investments on highways or railways affect the transportation cost and the related Lead Time (LT). The transportation networks can be very different depending on the countries and regions: in Europe motor carriage is used heavily, whilst North America significantly uses rail and air transport (Cannas et al. 2020). Moreover, in Europe, the importance of solving the transportation problems at a regional rather than a national level has increased remarkably (Rossi et al. 2020). In addition, JiT-based approaches coupled with small-scale production of customized high-value products require flexible and fast transportation systems with reduced shipment sizes and increased frequency on a pan-European basis, which has brought deregulation in the transport industry, by removing customs clearance and cancelling trade barriers.

Recently there has been a pronounced change in relationship between shippers and logistics providers. Collaboration has become long-term in nature and logistic services now often include value-adding services such as final assembly, packaging, quality check and order tracking. Third-party logistic providers (3PLs) dominate the European transport market, with the strategic scope of increasing market coverage, improve the level of service or increase flexibility (De Almeida et al. 2015).

To this purpose, Industrial Dynamics relates to the study of the information-feedback characteristics of industrial activity, and it treats the interactions between the flows of information, money, orders, materials, personnel and capital equipment in a company or a SC or even an industry (Braz et al. 2018). According to Lane and Sterman (2018), an information-feedback system exists whenever the environment leads to a decision that results in action which affects the environment and thereby influences future decisions.

Once a mathematical model of the system is constructed, experiments are conducted to answer specific questions about the modeled system. This is the well-known simulation approach that leads to test is the name applied to this process of conducting experiments on a model instead of attempting the experiments with the real system (see e.g., Pozzi et al. 2019). In this way different management policies and market assumptions can be tested.

A very important industrial system is represented by a SC made up from manufacturing and distribution stages, where Industrial Dynamics is helpful to investigate the Bullwhip Effect. Indeed, the factory production rate fluctuates more widely than does the actual consumer purchase rate. So, a distribution system of cascaded inventories and ordering procedures amplifies small disturbances that occur at the retail level. In this way, the firm's marketing policies can directly influence the fluctuations that occur among the echelons of the SC. There is a feedback loop that relates the marketing departments with manufacturing areas of the SC.

As a matter of fact, the planned production level is the basis for making advertising decision. Consumers gradually respond to the advertisements by a change in purchasing policies and it affects the retail purchasing rate that is propagated through the distribution channel and changes the demand at the factory stage. The feedback loop is completed when the new production schedules begin to affect the decisions of new advertisements.

The paper is arranged as follows. In section 2 the concept of bullwhip is introduced, for a better understanding of the simulation models explained in section 3. Then, section 4 presents the case study of a real-life company, while section 5 shows some results. Finally section 6 draws the conclusions.

2. Background

Since the seminal study by Forrester, the bullwhip effect has been considered as an unavoidable outcome of order-to-delivery system, as the interacting flows of information, money and materials across the SC would lead to delays and oscillations in the flows of goods through the channel. Besides, behavioral causes have to be added, since decision makers make systematic mistakes in assessing the dynamic environments, leading to multiple feedback loops, time delays and nonlinearities and ultimately to the perception that bullwhip is part of their life: what you see is not what your customers face (Wang and Disney 2016, Naim et al 2017).

There are four main causes of bullwhip effect (Ciancimino et al. 2012). (i) Demand signal processing, as the bullwhip effect is related to the use of statistical forecasting methods by multiple stages in SCs. (ii) Order batching, as to optimize the whole SC retailers should issue balanced orders with small batch sizes and long order intervals. (iii) Price fluctuations, as a common complaint from the manufacturing side, and a common reason for severe demand distortions are unforeseen trade promotions at the retail stage. (iv) Shortage gaming, as proportional and linear allocation rules are shown to produce oscillations. In addition, when customers do not feel at ease with the ability of their suppliers to swiftly and reliably replenish their products, they hedge by firstly placing orders higher than the expected demand and then – once they have received what they need – they tend to cancel the balance of future orders.

To minimize the bullwhip, is essential to understand what drives customer demand planning and inventory consumption, as they trigger the replenishment orders in several places of the SC. Whilst even all the bells and whistles of modern SC management approaches cannot instantly stop the bullwhip, the harmful impact can be limited by leveraging on two main lines of action. The former one focuses on operational causes, such as production lags and order processing delays, procedures for demand forecasting, order batching (to take advantage of scale economies or quantity discounts), rational responses to product shortages, and price fluctuations caused by promotions. The latter line of actions emphasizes behavioral causes of SC instability. Due to the bounded rationality of decision makers, mainly the failure to account for feedback effects, accumulations, and time delays.

Both lines of actions above involve the management of inventory levels along the SCs. Indeed, stocks represents the way each single layer of the SC manages its resources, attempting to balance production (or inflow rate) with orders (or outflow rate). Typically, managers set the inflow rate to compensate for losses and usage, and to counterbalance any disturbance that pushes the stock away from its targeted value (see figure 1).

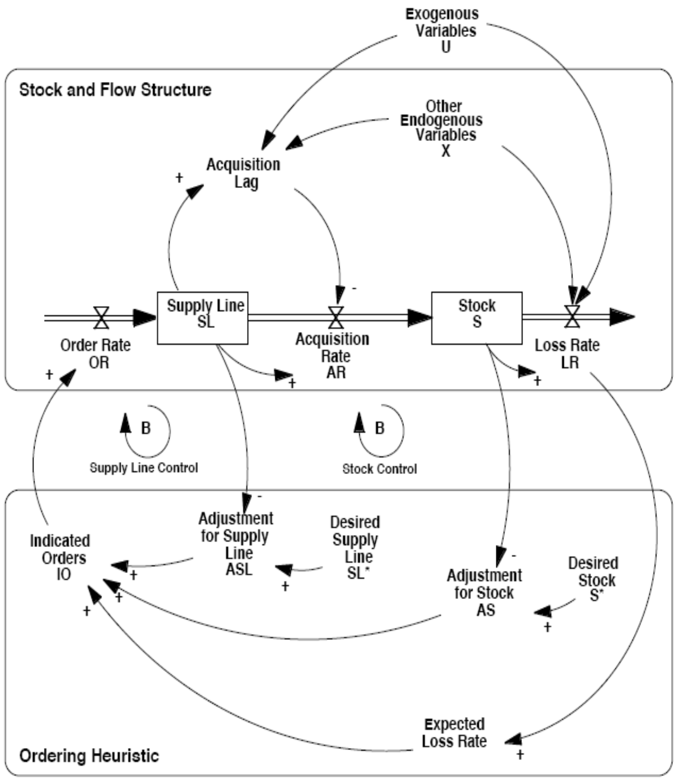

Figure 1: The generic stock management structure

The stock level (S) is the accumulation of the acquisition rate (AR) minus the loss rate (LR): $S=\int(AR-LR)dt$. Losses include any outflow from the stock and may arise from usage (for example raw materials) or decay (as in the depreciation of plant and equipment). The loss rate depends – maybe in a non-linear way – on the stock itself and on other endogenous variables X (like prices, marketing campaigns, competitors' responses) and exogenous variables U (like weather or accidents). Hence: $LR=f(S,X,U)$. Then, usually there is a time delay between ordering and delivery and so there is a supply line of unfilled orders corresponding to the stock of orders placed but not received yet. The supply line (SL) corresponds to the difference between the Order Rate (OR) and the acquisition rate: SL=∫(OR–AR)dt.

On the other hand, the acquisition of new units involves time delays (to fill orders, manufacture subassemblies or build capital plant). Hence the acquisition rate depends on the supply line and the average acquisition lag (λ): AR=L(SL,λ), where the lag functional L(·) denotes a material delay. The acquisition lag depends on the ability of the process to delivery, which depends on other endogenous and exogenous variables: λ=f(SL,X,U). Moreover, λ can also be influenced by managers, for example through overtime or expediting by paying premium freight.

When the acquisition rate is constrained by the capacity of suppliers the actual delivery time increases, causing deliveries to be delayed and products to be rationed, thus creating nonlinearities that will result in oscillation and instability (see e.g. Rossi et al. 2017). In most real-life cases, the complexity of feedbacks precludes an optimal strategy and managers resort to locally rational heuristic, according to the tradition of bounded rationality.

In this paper, the hypothesized decision rule is based on information locally available to the decision maker and does not presume that the managers have a global understanding of the system structure. Managers are assumed to issue orders to replace expected losses from the stock, to reduce the discrepancy between the desired and actual stock level and to maintain an adequate supply line of unfilled orders.

First notice that OR must be non-negative: OR=max(0,IO), where IO is the indicated order rate, based on anchoring and adjustment heuristic. Anchoring and adjustment is a common strategy where an unknown quantity is estimated by first recalling a known reference point (the anchor – here the expected loss rate) and then adjusting for the effects of other factors whose effects are obscure or expected to be negligible, thus requiring the decision maker to estimate these effects through mental simulation. Adjustments are then made to bring the stock and supply line in line with their desired levels: IO=L^e+AS+ASL, where AS (the Adjustment for Stocks), corrects discrepancies between the desired and actual stock, and ASL (Adjustment for the Supply Line), corrects discrepancies between the desired and actual supply line.

The magnitude – or amplitude – of the Bullwhip effect in a two-echelon SC can be estimated through equation (1):

$$\frac{Var(q)}{Var(D)} > 1 + \left(\frac{2LT}{p} + \frac{2LT^2}{p}\right) + (1-\rho) \quad (1)$$

Where: *Var (q)* is the variance of the orders placed by the retailer, *Var (D)* is the demand variance, *p* is the previous numbers of periods, *ρ* is the correlation parameter. If the number of previous periods *p* decreases, there are less periods to formulate accurate demand forecasts. So, when *p* is small, the increase of variability is significant. As a consequence, to mitigate the Bullwhip effect, it's better to formulate demand forecasting with the greater available number of previous periods. If *LT*s double, two times demand data is required to maintain the same variability. Hence, with longer *LT*s retailers must use more demand data to mitigate the bullwhip effect. *LT*s have to be shortened as much as possible, for example by introducing some operational collaboration the actors of the SC, like VMI (Vendor Management Inventory), JIT (Just in Time) or CPFR (Collaborative Planning Forecasting and Replenishment. Finally, the larger *ρ*, the smaller the increase in variability. When *ρ* >0 it means the demands are positively correlated.

3. The new model

The main objective of the experiment lies in testing the bullwhip effect on a simulated SC by eliminating the information delays through a smart implementation of EDI (Electronic Data Interchange). It has been used as SC simulator Simcas, which is based on the beer game. The flows between two consecutive tiers of the SC are delayed by 2 time-buckets, while the overall order LT placed by factory is one bucket and the inventory holding cost is 5 monetary units (mu) per unit. Finally, stockout cost is 10 mu per unit.

The objective function lies in minimizing the total costs of inventory. Final customer demand is stepped, with a shift (perceived only by the retailer) from 4 to 8 units per bucket. Each stage of the SC is hosted on a different computer, managed by human players who know only local information to determine their inventory policy. The simulations of the SC without and with EDI are conducted in a row, by randomly allocating the players to the different stages of the SC, and by keeping the members of the same team apart to prevent from them communicating with others. All the groups play the first round without EDI under information delays. Then the players are randomly re-assigned to other stages of the different SC to prevent the learning effect in the second run, taken with EDI and without information delays. In this way, 15 replications without EDI and 13 with EDI were run.

The structure of the SC gives birth to increasing values of the orders placed, of the costs, and of their respective standard deviation, since system's instability is related to management difficulty. Since in Simcas the overall factory LT is one week, there should be a fall in the stocks and in the mean and cumulative costs relative to the preceding stage of the chain. According to table 2, after removing the outliers, there are 15 trials without EDI and 13 with EDI left. The full implementation of EDI at all the stages of the SC has a positive and statistically significant impact, both for the chain as a whole and for each stage. Therefore, EDI provides a reduction of the Bullwhip, hence it reduces both costs and SC instability.

In addition, the use of EDI also allows companies to replenish their material requirements more frequently, in smaller batches: Procter and Gamble (P&G) has estimated that their order processing cost ranges between US$35 and US$75 (Hofmann 2017). These costs are one of the main reasons why companies often accumulate demand in batches before issuing orders, thus generating the Bullwhip.

	Without EDI				With EDI			
Run	R	W	D	F	R	W	D	F
1	7.68	8.93	11.24	11.78	7.61	7.49	7.41	7.41
2	7.98	20.93	26.63	26.83	7.39	7.27	7.29	7.27
3	8.20	37.44	51.44	55.10	7.63	7.78	7.93	8.15
4	22.29	32.10	50.90	51.10	7.56	7.41	7.02	6.78
5	7.17	17.37	19.02	16.98	8.00	8.05	10.34	9.95
6	11.02	33.54	54.85	58.34	7.71	13.20	13.20	13.68
7	7.85	16.71	60.76	60.61	7.02	6.68	9.63	9.63
8	7.71	12.59	24.12	31.02	7.15	6.83	7.10	7.07
9	7.46	6.98	7.90	7.98	7.50	7.30	7.00	6.80
10	7.71	6.59	6.10	7.54	9.50	8.40	9.60	9.80
11	8.30	10.10	20.90	20.30	8.00	8.20	7.20	7.30
12	7.70	8.10	8.60	8.90	7.60	7.70	7.60	7.70
13	8.10	9.40	33.00	13.90	7.60	7.60	7.90	7.90
14	8.40	9.90	10.30	11.00				
15	11.20	11.40	17.20	19.60				
μ	9.30	16.10	26.90	26.70	7.70	8.00	8.40	8.40
σ	3.80	10.30	18.90	19.70	0.60	1.60	1.80	1.90

R = Retailer, W = Wholesaler, D = Distributor, F = Factory, μ = average value, σ = standard deviation

Table 2: Orders placed without and with EDI

The ordering policies at the different stages of the SC are often based on the average of demand shifted forward for each bucket, to ensure a sufficient inventory to cover the expected demand variance during the LT. Consequently, the longer the LT, the greater the amplification and fluctuations in actual orders placed, thus intensifying the Bullwhip, and information delays are one of the major components of total LT. Hence EDI reduces both the size and the variability of orders placed.

4. Elektrobudowa SA

Elektrobudowa is a Polish firm that provides equipment and services mainly for the power engineering business. The equipment manufactured by Elektrobudowa for electricity distribution and transmission is operated in nearly all Polish power stations and it is widespread worldwide. The company provides turnkey projects to power industry, chemical industry, mining and public utility construction sector. Elektrobudowa manufactures three main product families: (i) low voltage switchgears, (ii) medium voltage switchgears and (iii) transformers.

The Supplying LT is a very important parameter. Mainly for the low voltages the LT is 3-4 weeks, while for medium voltages is 6-8 weeks. On the other hand, transformers' LT accounts for half a year, as they are expensive products. In summer, which is a peak season, the LT of the first two families increases by a week, whilst in winter period the lower orders variability makes it easier to supply the components.

The products of the firm are made up from many components and sub-assemblies, and ABB is one of the most important suppliers is. So, the manufacturing policy follows an ATO (Assembly to Order) approach: all the components are assembled only once a firm customer order has been received. However, the majority of products are not commodities, which prevents from using a standard forecasting process and three offices (in Katowice, Wroclaw and Konin) do market research: standard components unshipped in warehouse can be used also in the future, whilst customized components cannot.

Since Elektrobudowa cannot leverage on an accurate overall forecasting system, the firm is very reactive when there is an order from a customer and they recently have started to introduce Just In Time and Material Requirements Planning to seed up the logistic process that involves three departments, one for each product family (low and medium voltage switchgears and transformers) that are three different profit centers not at all coordinated one to another.

The lack of logistic coordination might represent a significant drawback given the plans to sell the products in China. It represents a challenge mainly because China is a cheap market where the price is one of the most important competitive weapons and ultimately it is an order winner, mainly because the components that are going to be traded in the Chinese market, are: push buttons, control lamps, insulators, insulated low voltage wires and mini-CBs, that are part of low voltage switchgears product family.

In the end, the main challenge of Elektrobudowa lies in shaping its SC according to a global footprint, from a twofold viewpoint. First, a new branch of activities has to be established in China, by opening a new manufacturing firm with new products. The second challenge is in restructuring their procurement and distribution process between China and Poland.

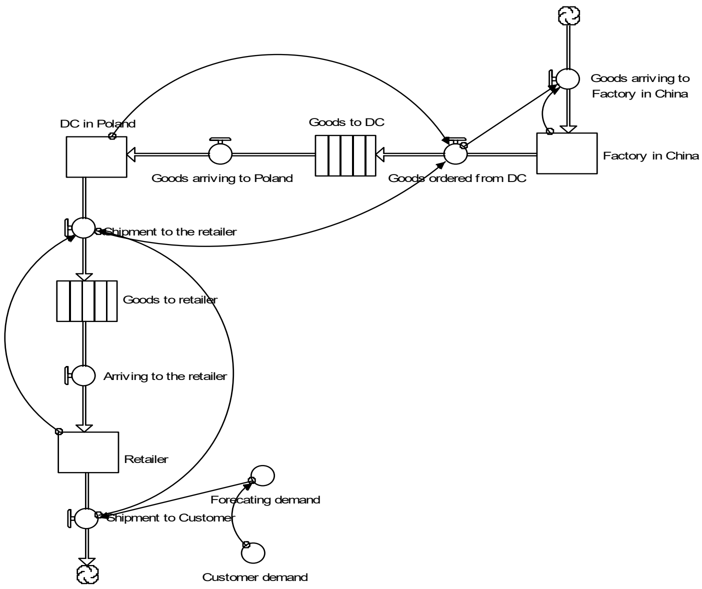

Figure 3: The global SC model developed via iThink

The global SC process is described as follows. Goods arrive to the factory in China with a replenishment policy based on rule: the Economic Order Quantity and re-Order Point (EOQ-OP) model. When the level of the stock in China's factory cross below the OP, an order is issued from the supplier of China's storage in a batch quantity equal to the EOQ, considering that there is a delay (i.e. a LT), between the time the order is planned and the one the goods arrive. Several final products are ordered by the DC in Poland to China's manufacturing facility via EOQ-OP and every product in transit from China to Poland take a transit time to arrive to destination. Then, the products are sent to the retailers, based on shipment requirements, which in turn depend on the level of the customer demand. Figure 3 shows the global SC model developed via iThink.

Beside the global SC configuration, the purchasing process between Elektrobudowa and a Chinese firm has been deeply redesigned, as in this case some disturbances can arise from the actors of the SC for both operational and behavioral causes. Since the focus is on the logistic process, the manufacturing process of the final products in China is not analyzed and the products in the Chinese warehouse are supposed to arrive following some replenishment rule of the Chinese warehouse.

In this case, the SC is as follows: finished products arrive to the Chinese warehouse according to a replenishment the finished goods are ordered by the DC in Poland to the Warehouse in China, where some vendors have a variable productivity over time, depending on motivation, efficiency, time required to travel etc. The DC issues the orders according to its OP, which however is ultimately linked to the productivity of Elektrobudowa's agents in China.

In the Polish manufacturing site, a manufacturer takes the role of decision maker and implements the stock orders from the DC according to the replenishment rule based on OP. The outflow from manufacturer stock is the producing process that depends directly on the wholesaler demand. In the end, the three stocks of the SC follow a replenishment rule that depends on the OP and figure 4 shows the iThink-based model.

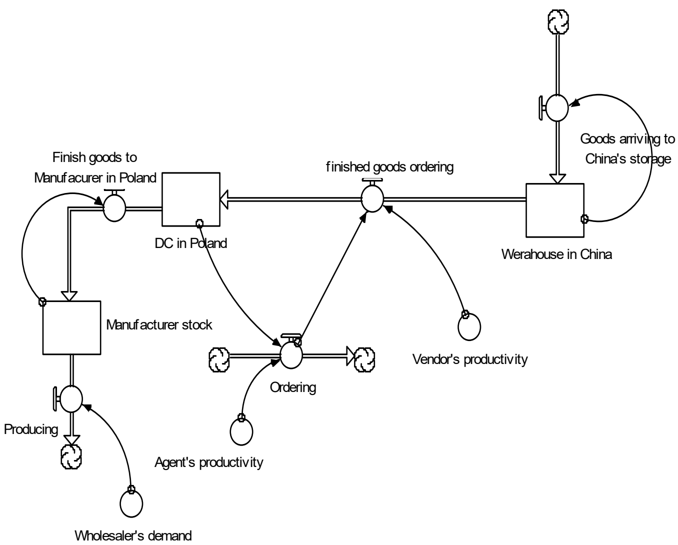

Figure 4: The purchasing process between Elektrobudowa and a Chinese firm

5. Results

This section describes the different experiments carried out via iThink simulation software, to analyze the global SC of Elektrobudowa (Case 1) and the purchasing process between Elektrobudowa and a Chinese firm (Case2).

5.1 Global SC with the new product lines in China (Case 1)

Three demand patterns are given: (i) steady demand, (ii) random demand and (iii) growing demand. The case of steady demand is the easiest one because the customer demand is always constant. The shipment to customer flow fluctuates from 0 to 100, which represents the steady state value, but with regular progress.

Under random demand, the demand is not steady, but it fluctuates between a minimum (20) and maximum (80) value. According to Figure 5, shipment to customer does not properly chase the customer demand and the Bullwhip emerges: the pink line (the upstream process) fluctuates with more amplification, than the blue line (the downstream process), with some indication of three-month lag.

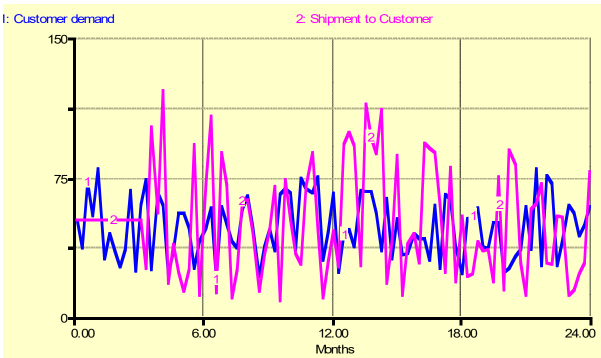

Figure 5: Shipment to customer and customer demand under random demand

Figure 6 shows the three stock levels of the model: the downstream actor is the retailer, the one in the middle is the DC in Poland, and the upstream one is the factory in China. These values are reasonable because the DC in Poland has to serve some Europe markets, so its inventory level has to be the highest of the three. On the other hand, the retailer has the lowest stock level as it as to serve only the final customer.

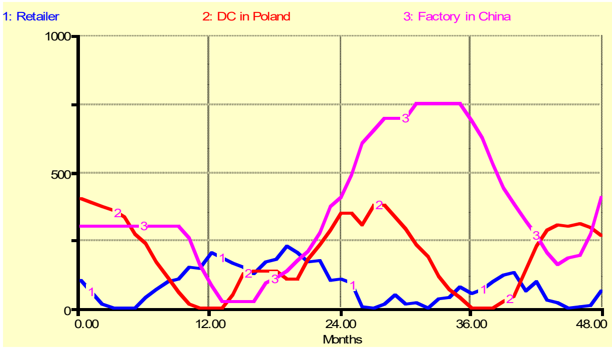

Figure 6: Retailer, DC in Poland, factory in China under random demand

By extending the timeline to 48 months, it can be clearly shown the way the inventory level oscillates as time goes by. Here again the Bullwhip emerges, as from the retailer downstream up to the Factory in China there is an amplification and phase lag of the demand variability, which leads the warehouse of the Factory in China to suffer more variability than the retailer. Finally, the shape of figure 6 cannot be generalized as it originates from a a random customer demand.

As soon as the level of the warehouse in China falls below the OP, a Normally distributed EOQ is issued with mean μ=100 units and standard deviation σ=30 and a delay LT=7 buckets) of 7 periods. With reference to the DC in Poland, the values of the parameters (OP, EOQ, LT) decrease since from upstream to downstream of the SC the variability of the orders decreases.

5.2 The Purchasing process between Elektrobudowa and a Chinese firm (Case 2)

Even under steady demand (see figure 7), the producing flow oscillates with great variability, which means that the system suffers from a remarkable instability, caused by the "random walk" of the Agent and Vendor's productivity. Indeed, Vendor's productivity is affected by various causes like motivation, and it can randomly change over time between a minimum and a maximum value. In addition, agents work directly for Elektrobudowa in China and they transfer the orders to be fulfilled are characterized by a randomly variable productivity.

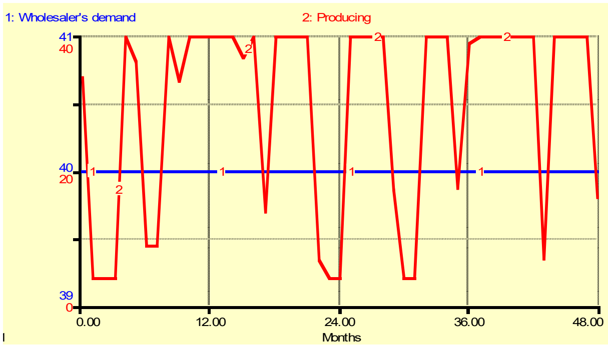

Figure 7: Wholesaler and producing under steady demand

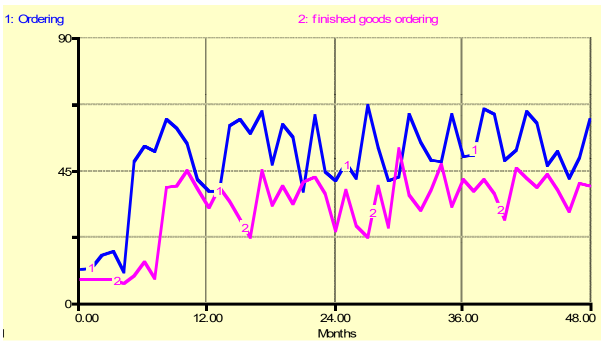

Figure 8: Ordering and finished goods ordering under steady demand

The relationship between Ordering flow and Finished goods on ordering, is interesting and reported in figure 8. The finished goods ordering is delayed by 3 buckets with respect to the Orders. In addition, not all the orders – due to the agent's productivity – can be processed, but only a certain amount depending also on Vendor's productivity. Besides, the replenishment rule is similar to the one of the Chinese warehouses, with a relevant difference, as when an order is placed, the amount supplied directly depends of the agent's productivity. So, in case of a low agent productivity is low – maybe depending on a low motivation level – just a small number of planned orders is sent to the Chinese warehouse.

In the case of random demand, the relationship between wholesaler's demand and producing flow is shown in Figure 9, where the producing flow – as expected – fluctuates much more than under steady demand (see figure 7).

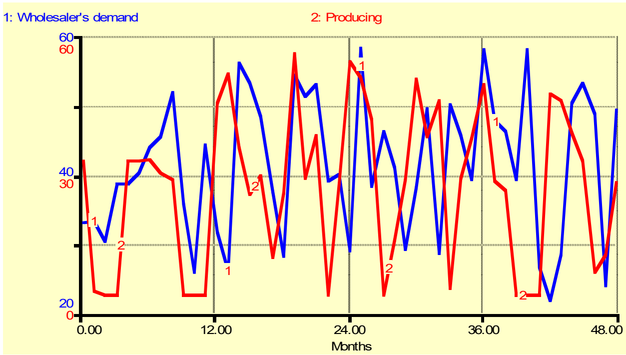

Figure 9: Wholesaler demand and producing under random demand

On the other hand, the ordering flow and finished goods ordering flow in the case of random demand, oscillate in the same way as under steady demand. It seems that the variability of the orders is not influenced by the demand shape, which is not counterintuitive as agent and vendor's productivity randomly oscillate in both cases.

Finally, under growing demand, according to the Bullwhip effect theory, the warehouse in China stock fluctuates with more variability than the DC in Poland (see Figure 10).

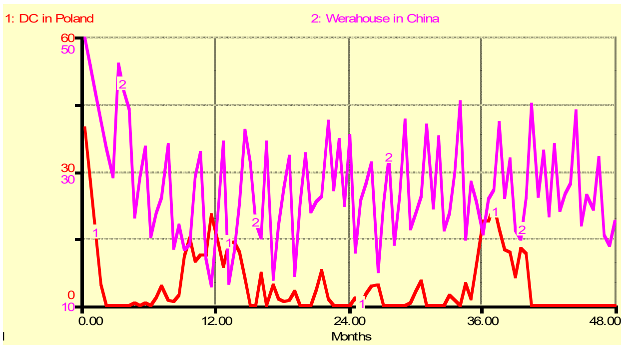

Figure 10: DC in Poland and Warehouse in China under growing demand

6. Conclusions

The case provided by Elektrobudowa is useful to understand very clearly that disturbances between the actors of a real SC – bundled under the name of Bullwhip effect – can cause variability in the whole SC, in such a way that – for example – the DC in Poland (the downstream actor) fluctuates more than the warehouse in China (the upstream actor)

Some consequences of this variability amplification, only to quote the most important ones, can range from schedule variability, capacity overloading, LTs lengthening, working and safety stock increasing, overall costs increasing, customer service levels decreasing, sales and profits decreasing.

Indeed, given that there is no way to completely eliminate the Bullwhip effect, some recommendations to mitigate it might lie in: (i) minimizing the cycle time in receiving projected and actual demand information, (ii) monitoring actual demand as close as possible to a real-time basis, (iii) understanding product demand patterns at each stage of the SC, (iv) increasing the frequency and quality of collaboration through shared demand information, (v) minimizing information queues that create information flow delays, (vi) eliminating inventory replenishment methods that release demand lumps into the SC, (vii) eliminating incentives for customers that directly cause demand accumulation and order staging prior to a replenishment request, such as volume transportation discounts, (viii) minimizing incentives promotions that cause customers to delay orders and thereby interrupt smooth ordering patterns, (ix) offering products at consistently good prices to minimize buying surges brought on by temporary promotional discounts, (x) identifying the causes of customer order reductions or cancellations, (xi) providing VMI-like services by collaboratively planning inventory needs with the customer to projected end-user demand then, monitor actual demand to fine tune the actual VMI levels.

Finally, in the simulations with iThink, the actors of the SC have been supposed to follow the EOQ-OP replenishment rule that however can cause stock-out at the DC, because it generates orders at the latest and OP is calculated with the assumption of a smoothed demand pattern. Hence, the Distribution Requirements Planning method (DRP) appears to be more effective to plan the orders in advance, with reference to the forecasted demand, thus avoiding stock-outs.

However, the connection between ETO industries – like the one where Elektrobudowa operates – and the bullwhip effect is still understudied. Therefore, the purpose of this paper also consisted in filling this gap, by studying the operational implications and proposing some mitigating actions. Then, some possible developments should refer to a deeper study of the bullwhip effect via big data and to extending the focus to other industries, like for example luxury and fashion).

References

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

Cannas, V., Cicculo, F., Pero, M., Cigolini, R. (2020) Sustainable innovation in the dairy supply chain: enabling factors for intermodal transportation, *International Journal of Production Research*, Published online.

Ciancimino E., Cannella S., Bruccoleri M., Framinan J.M. (2012) On the bullwhip avoidance phase: the synchronized supply chain, *European Journal of Operations Research*, 221, 1, 49-63.

Cigolini, R., Gosling, J., Iyer, A., Senicheva O. (2020). Supply Chain Management in Construction and Engineer-to-order Industries. *Production Planning and Control*, Published online.

De Almeida M., Marins F., Salgado A., Santos F., Da Silva S. (2015) Mitigation of the bullwhip effect considering trust and collaboration in supply chain management: a literature review, *International Journal of Advanced Manufacturing Technology*, 77, 495-513.

Hofmann E. (2017) Big data and supply chain decisions: the impact of volume, variety and velocity properties on the bullwhip effect, *International Journal of Production Research*, 55, 17, 5108-5126.

Lane D., Sterman J. (2018) A model simulator: The lives of Jay W Forrester, *Journal of Simulation*, 12, 2, 90-97.

Leopold A. (2015) Energy related system dynamic models: a literature review, *Central European Journal of Operations Research*, 24, 231-261.

Longoni A., Koberg E. (2019) A systematic review of sustainable supply chain management in global supply chains, *Journal of Cleaner Production*, 207, 1084-1098.

Naim M., Spiegler V., Wikner J., Towill D. (2017) Identifying the causes of the bullwhip effect by exploiting control block diagram manipulation with analogical reasoning, *European Journal of Operational Research*, 263, 1, 240-246.

Pero, M., Rossi, M., Xu, J., Cigolini, R. (2020) Designing supplier networks in global product development, *International Journal of Product Lifecycle Management*, forthcoming

Pozzi, R., Pero, M., Cigolini, R., Zaglio, F., Rossi, T. (2019) Using simulation to reshape the maintenance systems of caster segments, *International Journal of Industrial and Systems Engineering*, 33, 1, 75-96

Rossi, T., Pozzi, R., Pero, M., Cigolini, R. (2017) Improving production planning through finite-capacity MRP, *International Journal of Production Research*, 55, 2, 377-391

Rossi, T., Pozzi, R., Pirovano, G., Cigolini, R., Pero, M. (2020) A new logistics model for increasing economic sustainability of perishable food supply chains through intermodal transportation, *International Journal of Logistics Research and Applications*, published online.

Wang X., Disney S. (2016) "The bullwhip effect: Progress, trends and directions", *European Journal of Operational Research*, 250, 3, 691-701.

Xuab J., Kangba J., Shaoa L., Zhaoa T. (2015) System dynamic modelling of industrial growth and landscape ecology in China, *Journal of Environmental Management*, 161, 92-105.