A System Dynamics Model For The Simulation Of A Non Multi Echelon Supply Chain: Analysis and Optimization Utilizing The Berkeley Madonna Software

C. Caballini, R. Revetria

Abstract — In today's global market, managing the entire supply chain becomes a key factor for a successful business. World-class organizations realize that non-integrated manufacturing and distribution processes together with poor relationships with suppliers and customers are a huge limit for their success.

One of the most important aspect affecting the performance of a supply chain is the management of inventories. Inventory management in the supply chain system is quite a complex issue because demand at the upstream stage is dependent on orders from the downstream stage, and the final downstream stage receives orders from the market in uncertain conditions. Uncertainty is one of the major obstacle which limits the creation of an effective supply chain inventory model, able to optimize times and costs.

Being the management of a complex inventory model too difficult to analyze with traditional analytical mathematical methods, computer simulation is widely used to study this kind of problems.

This paper has the goal of modeling a single echelon supply chain and optimizing its inventories levels so to reduce the bullwhip effect and consequently minimize the supply chain costs. The supply chain here proposed consists of five stages – customer, retailer, wholesaler, distributor and factory – and its modeling is carried out through a system dynamics approach, utilizing the Berkeley Madonna software.

Keywords— bullwhip effect, inventory optimization, single echelon supply chain, system dynamics.

I. Introduction

Cconsidering and managing supply chains as a connection of tightly integrated stages that have a common final goal to pursue is nowadays mandatory for the good success of all the companies involved in the supply chain. As a matter of fact it has been frequently demonstrated that the lack of coordination and integration between the actors involved in the same supply chain, has brought to disruptive effects, such as loss in profits or unexpected costs. Among the critical success factor for the success of a supply chain, it can be identified the management of the inventories.

The objective of this paper is to model, simulate and optimize the inventory levels of a non–echelon supply chain consisting of five levels - customer, retailer, wholesaler, distributor and factory, developed by Robert Macey and George Oster at the University of California.

Because the management of a complex inventory model is too difficult to analyze with traditional analytical mathematical methods, it has decided to utilize computer simulation, and in particular the system dynamics methodology.

System dynamics is a well-known method for analyzing supply chain systems because it can prognosticate and model in an effective way the behavior of a complex system and improve its performances. System- Dynamics is a computer-aided approach for analyzing and solving complex problems with a focus on policy analysis and design. Initially called 'Industrial Dynamics' (Forrester 1961), the field developed from the work of Jay W. Forrester at the Massachusetts Institute of Technology. System Dynamics has its origins in control engineering and management; the approach uses a perspective based on information feedback and delays to understand the dynamic behavior of complex physical, biological, and social systems. Forrester (1961) defines Industrial Dynamics as "... the study of the information feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decision and actions) interact to influence the success ox the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or a national economy…". The elements of system dynamics diagrams are feedback, accumulation of flows into stocks and time delays.

The paper is organized as follows. Section 1 contains an introduction to the reference context and to the system dynamics approach, together with the objectives of the paper. The utilized research methodology and the system dynamics model developed utilizing the Berkeley Madonna software are showed in section 2; moreover some assumptions and simplifications are highlighted. In section 3 the obtained results are presented; in particular the "bullwhip effect" is showed and its main causes are explained. Section 4 presents an optimization of the different supply chain inventory levels as a way to reduce the bullwhip effect and, consequently, the total costs. Finally, in section 5, conclusions and recommendations are presented.

Claudia Caballini is with CIELI – Italian Centre of Excellence in Integrated Logistics of the University of Genoa, Via Opera Pia 15, 16145, Genoa, ITALY (email: claudia.caballini@cieli.unige.it).

Roberto Revetria is with DIPTEM – Department of Production Engineering, Thermoenergetics and Mathematical Models of the University of Genoa, Via Opera Pia 15, 16145, Genoa, ITALY (phone: +39 010 3532883; fax: +39 010 317750; email: roberto.revetria@unige.it).

II. MODEL DESCRIPTION

Due to the high complexity of the real world, supply chains are often characterized by more than one echelon. Besides each echelon may consist of more than one facility, which may include more than one upstream supplier or downstream customer. For example, a distribution centre may replenish different products from different suppliers and delivery these products to different retailers.

However, for a matter of model simplicity, the system dynamics model developed in this research represents a single echelon supply chain consisting of five stages: customer, retailer, wholesaler, distributor and factor, with their corresponding inventories.

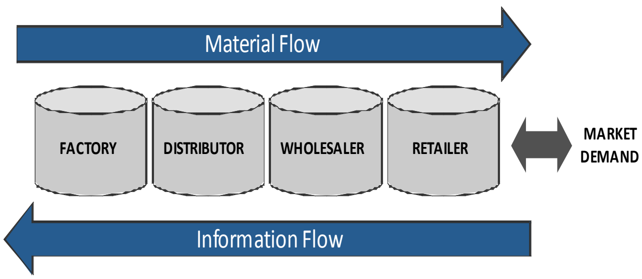


Fig.1 Model framework and flows

As figure 1 shows, orders are placed from customers towards manufacturing, while goods flow in the opposite direction. Downstream, each actor of the chain is interfaced with one single customer, whose orders has to be satisfied by him. Upstream each stage is linked with one single supplier to whom orders are placed.

The supply chain here proposed is considered as a “pull system”. This means that, typically, when a customer places an order to the retailer, the latter, as long as he has sufficient inventory on hand (on the contrary, a backlog is created), fulfills it. After the order fulfillment the retailer checks its inventory and if it is lower than its reorder point, he places an order to the upstream supplier, which is represented by the wholesaler, in order to avoid possible future stock outs. The preceding upstream supplier receives the order from the retailer, fulfills it, and then delivers it to the retailer. So the supplier checks its inventory to see whether or not to place an order to his supplier. The process will be continuing until the supplier is the final supplier of the supply chain. It can be said that the demand pull backwards the production process.

The research approach which has been followed to analyze this system behavior pattern and to find the optimum inventory level for each sector of the supply chain is shown in figure 2. First a conceptualization and specification of the problem has been faced. So, after the choice of a suitable system dynamics software (namely the Berkeley Madonna system), a model for the single echelon supply chain has been developed. After a phase of testing of the model to proof its validity, an optimization of all the inventory levels of the different supply chain phases have been carried out. Finally results have been evaluated and the related conclusions have been derived.

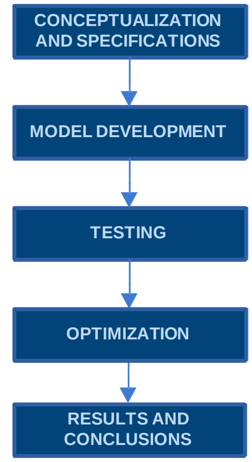


Fig.2 Research methodology

2.1 Assumptions and simplifications

Few assumptions and simplifications have been made on the model.

First it has been assumed that the system is not multi echelon, namely there are only one factory, one distributor, one wholesaler and one retailer.

Besides, the factory is characterized by a maximum capacity constraint and the transportation time has been set to 2 days, with no variability.

Moreover the capacity of trucks – expressed in number of pallets – is not specified, meaning that it is not taken into account in the proposed model. This means that all the ordered quantities that are on stock are shipped to the next module, regardless to the capacity of the truck and the number of pallets that it can house.

2.2 Model development

Figure 3 provides a part of the model developed with the Berkeley Madonna software.

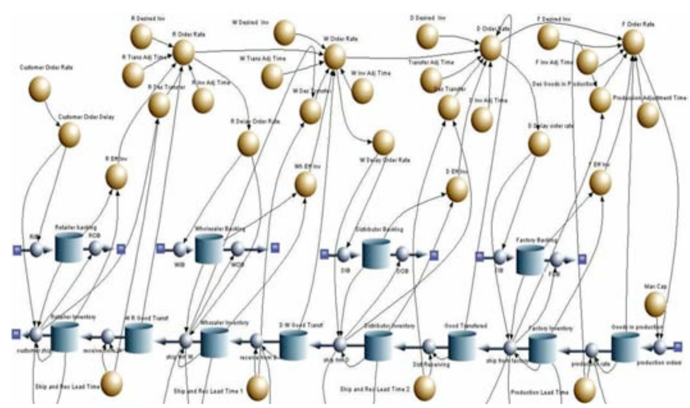


Fig.3 A part of the system dynamics model

Each level of the supply chain corresponds to a particular sub module.

The retailer module is designed to perform all the functions typical of a retailer. It is the only module that receives orders from outside customers. The main processes concerning the retailer module include order processing, shipment consolidation and inventory replenishment. More in detail, the retailer receives the customer orders and if its inventory is enough, it fills them otherwise they are backordered to await completion until the inventory becomes available. After the fulfillment, orders are consolidated for their delivering and finally they are delivered to the customers.

The distributor and wholesaler modules perform activities similar to the retailer one with the only exception that they refer to different suppliers and customers.

Finally the factory module is designed to accomplish the typical factory functions. Being the focus of this study on a production-distribution system, the module has been designed at a high level, which means that material procurement have not been here considered. So the factory module, whose main goal is to receive and fulfill orders coming from the distributor level, has been designed in a make-to-order fashion and with limited capacity.

Finally, a customer module has been designed to accomplish the role of a customer that places an order directly to the retailer and does not have any connection to the other modules of the chain.

In general, when a stock out occurs two alternative policies can be considered: lost sale or backorder. The lost sale policy means that when there is an out of stock, the relative demand is lost, while the backorder policy means that when an out of stock occurs, the corresponding demand is backordered and filled as soon as an adequate sized replenishment arrives. In this model it has been chosen to adopt the backlog policy. In other words if the retailer, for instance, has sufficient products on stock, the customer receives the desired quantity. If not, the orders are accumulated in the backlog of the retailer, and the customer receives the desired products only after that they have been shipped from the wholesaler to the retailer.

The inventories included in the model represent both traditional inventories and in transit inventories (that means products transported by trucks) and more precisely: the retail store inventory, the goods being transferred from the wholesaler to the retailer, the wholesaler inventory, the goods being transferred from the distributor to the wholesaler, the distributor inventory, the goods being transferred from the manufacturer to the distributor, the factory inventory and the goods in production.

Hereafter the whole process regarding the proposed non echelon supply chain is described more in detail.

The retail store places orders to the wholesaler according to the desired levels of its pipeline inventories, the actual levels of these inventories, the amount of sales and its backlog. The wholesaler places orders to the distributor according to its inventory, the retailer order rate and its backlog, and the distributor centre makes order to the factory using analogous variables. The parameters that influence the order decision are the “Inventory Adjustment Time” and the “Transfer Adjustment Time” which represent the speed with which the discrepancies between the current inventories (for the first one) or the pipelines (for the second one) and their desired levels are corrected. The order is not realized by the next module immediately. In fact, there is an order processing delay represented by “Delayed Order Rate”, so goods are shipped from the corresponding inventory according to the Delayed Order Rate. They spend some time on the way, which has been modeled by the stock "Goods Transferred", and finally they reach the store inventory. The difference between the order rate and the shipments gives the Backlog.

The manufacturer places orders according to the desired levels of its pipeline inventories, the actual levels of these inventories, and the orders placed by the distributor. The parameters that influence the order decision are the “Manufacturing Inventory Adjustment Time” which represents the speed with which the discrepancy between the current inventory and its desired levels is corrected and the “Production Adjustment Time”, corresponding to the time needed to adjust the production to the desired level. The “Manufacturing Order Rate” is limited by the “Maximum Capacity”. Goods spend time in production, represented by the stock "Goods in Production" and when they come out of production they enter the “Factory Inventory”.

Moreover the “Customer Order Rate” is the volume of demand that enters the retailer store.

Research on production and inventory literature indicates that the costs relevant in an inventory system are represented by the procurement costs, the costs associated with the existence of inventories and with stock outs (lost sales). The costs of the retail store consists of transportation and inventory costs. The cost of lost sales is embedded in the profit calculation.

In the following all the model equations at the basis of the described model will be showed.

The customer order rate is a function of time that can be changed over time in order to observe the inventories’ variation according to different order demand patterns (figure 4).

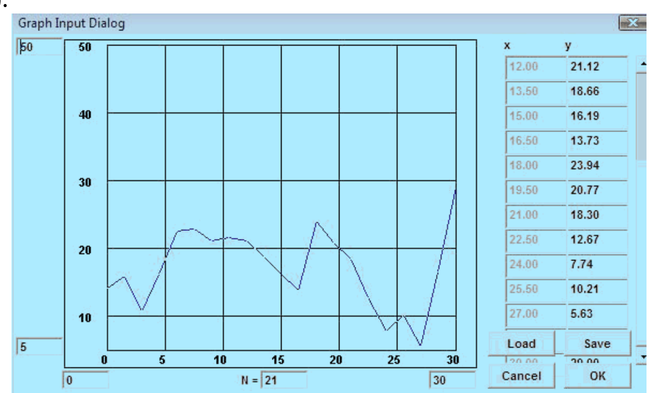


Fig.4 Customer order function (Berkeley Madonna Software interface)

The customer ship reduces the store inventory level and triggers the store ordering decision.

The part of the pipeline involving the retailer has mainly two inventories: the “Retailer Inventory” and the “Warehouse Goods Transferred” from the wholesaler inventory to the retail store. The decision of ordering, taken by the retailer, takes into account the desired levels of the two types of inventories, their actual levels, their adjustment times and the amount of sales (customer ships).

The retailer order rate for the retailer (R) is calculated according to equation (1):

$$ROrderRate = \left(\frac{RDesInv - REffInv}{RInvAdjTime}\right) + \\ + \left(\frac{RDesTransfers - WRGoodTranf}{RTransAdjTime}\right) + customership \quad (1)$$

The order rate for the wholesaler (W), is calculated as shown in equation (2). The order rates for the distributor and the factory are analogous.

$$WOrderRate = \left(\frac{WDesInv - WEffInv}{WInvAdjTime}\right) + \\ + \left(\frac{WDesTransfers - DWGoodTranf}{WTransAdjTime}\right) + ROrderRate \quad (2)$$

The desired inventory, expressed as “Des Inv”, is the level of inventory that the store tries to keep on hand, because it is considered to be the optimal one.

As already specified, the inventory adjustment time, expressed as “Inv Adj Time”, is the speed with which the discrepancy between the inventory and its desired level is corrected. Analogously, the transfer adjustment time, expressed as “Transfer Adj Time,” is the speed with which the discrepancies between the desired level of goods in transit (“Des Transfers”) and the level of goods actually transferred (“Goods Transferred”) are corrected. These two speeds are an input to the model.

More specifically, the desired level of in transit goods represents the level of goods that must be kept in transit in order to assure the steady flow of goods in the pipeline. It depends on the sales (“Shipped Goods”) and on the amount of time that passes from the shipment of the inventory goods until their exposure on the retail store shelves or, in other words, it is the time the items take on the way from an upstream inventory to a downstream inventory (“Ship and Rec Lead Time”). It is calculated by equation (3).

$$DesTransfers = ShippedGoods \\ *ShipandRecLeadTime \quad (3)$$

Shipments, expressed as “Ship from D” in the case of the distributor, are the number of items that are shipped correspondingly from the distributor to the retailer inventory. It is the minimum between the inventory of the distributor D and the sum of the its backlog “Delay Order Rate” of the wholesaler. It is calculated as shown by (4).

$$ShipfromD = Min(DInv, \\ (DBacklog + WDelayOrderRate)) \quad (4)$$

Of course, the shipments from the other stages of the supply chain are calculated analogously.

Focusing on the goods in transit, the level of “Goods Transferred” is increased by the goods shipped from the upstream level and it is decreased by goods received from the downstream stage, which is the rate at which the items arrive at the inventory.

The goods that the store receives, expressed as “Store Receiving”, is calculated by equation (5).

$$StoreReceiving = \frac{GoodsTransferred}{ShipandRecLeadTime} \quad (5)$$

The backlog of a particular stage is the part of the order that can not be met from the inventory of that stage and it is backordered. Equation (6) expresses the backlog for the wholesaler.

$$WBacklog = DelayOrderRate - ShipfromW \quad (6)$$

The effective inventory, expressed as “Eff Inv”, is the inventory level obtained subtracting the backlog of that level from its current inventory. Equation (7) provides the effective inventory for the wholesaler, as example. The other stages are similar.

$$WEffInv = WInv - WBacklog \quad (7)$$

The desired level of goods in production, expressed as “Des Goods in Prod”, is the level of goods that must be kept in production to assure the steady flow of goods in the pipeline. It depends on the production rate (“Prod Lead Time”) which takes into account the amount of time that goods spend in going through all the production steps, and on the amount of shipments from the factory (“ShipfromF”). It is calculated as in (8).

$$DesGoodsinProd = \frac{ShipfromF}{ProdLeadTime} \quad (8)$$

The production order, given by “Production Orders”, is the actual amount of production that is started every period; it is limited by the maximum capacity of the factory (“Max Capacity”). It is calculated by equation (9).

$$ProductionOrders = \\ min(FOrderRate, MaxCapacity) \quad (9)$$

The level of goods in production is increased by “Production Orders” and decreased by the “Production Rate”, which expresses the rate at which items come out of production. The production lead time, expressed as “Prod Lead Time”, is the amount of time that items spend in the production process. The rate of production, expressed as “Production Rate”, is calculated by equation (10).

$$ProductionRate = \frac{GoodsinProd}{ProdLeadTime} \quad (10)$$

The factory inventory, expressed as “F Inv”, is increased by the “Production Rate” (input flow) and decreased by the “Ship from F” (output flow), as shown in figure 5.

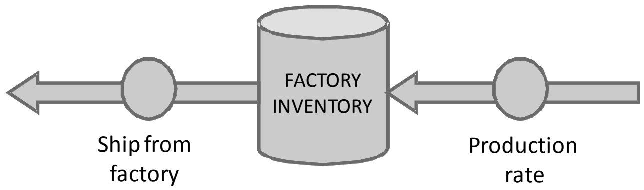


Fig.5 Basic dynamics of the factory inventory

More in general, as partially shown in figure 3, all inventories, backlogs and revenues are represented with stocks, which means that they are state variables, whose levels are increased by specific inflows and are decreased by outflows.

Let us now focus on the profits of the various supply chain stages, given through the computation of costs and revenues. The costs to be sustained by each actor can be split in transportation costs and inventory costs. These two cost terms, expressed in the model as “Inv Costs” and “Transp costs”, are calculated by equation (11) and (12).

$$InvCosts = F/D/W/RInvperunit* F/D/W/RInv \tag{11}$$

$$TranspCosts = ShipfromR/W/D/F* R/W/D/Fcostperunit \tag{12}$$

The sum of inventory and transportation costs gives the daily costs, expressed as “Daily Rev Costs”, which add up to make the cumulative R/W/D/F Costs (equation (13)).

Daily revenues are instead calculated by multiplying the sales and the price, as shown in equation (14), and they are added up to create the cumulative revenues. Finally, profit is calculated by the difference between revenues and costs - equation (15).

$$DailyCosts = InvCosts + TranspCosts \tag{13}$$

$$DailyRevenue = Sales * Price \tag{14}$$

$$Profit = Revenues - Costs \tag{15}$$

Moreover it must be underlined that the output model variables are represented by the Retailer Inventory, the Wholesaler Inventory, the Distributor Inventory, the Factory Inventory, the Customer Order Rate, the Retailer Profit, the Wholesaler Profit, the Distributor Profit and the Factory Profit.

III. Testing and Results

After having developed the model, the verification phase has been approached. Only after this step, results could be properly analyzed.

Verification is the process of determining if a model implementation accurately represents the developer’s conceptual description and specifications.

When a first simulation run is made, the values of the different variables are not stabilized yet. The values of the internal variables and the output parameters are not representative and are subject to great changes. However the model here presented is an example of a non-ending system; in fact it is characterized by a beginning situation that can run forever. This means that there is no possibility to point out a point in time where the system has reached a steady state. So it has been decided to set the simulation period to 30 days (the time unit of the model is one day).

The verification of distributed models is more difficult than the one of non-distributed models (ignoring the differences in the model logic and size). This happens because when something goes not as expected, the source of the problem is hard to find. It is possible that a problem in one module is caused by an error in another module. In this way it is not possible to isolate problems easily and in many cases multiple (long lasting) runs are necessary to find a problem and to solve it.

The following graphs show the result obtained by the model simulations. The graph in figure 6 shows the relationships between the customer order rate and the retailer inventory for a time period of 30 days. As easy to observe, peaks and valleys of the retailer curve (in blue color) are much more amplified in respect to the customer one (in red).

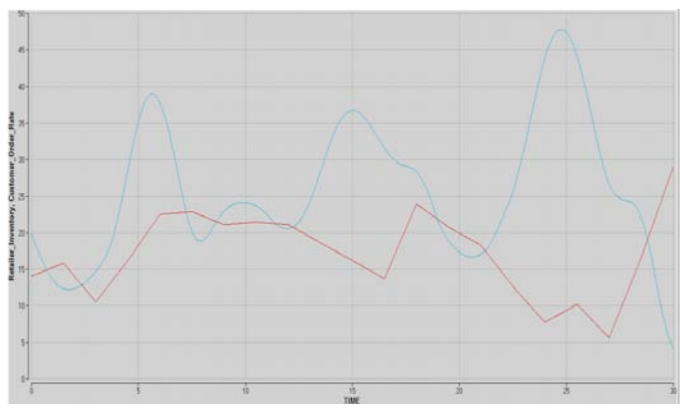


Fig.6 Customer order rate (red line) and retailer inventory (blue line)

Figure 7 represents the factory inventory trend over the simulation period. It can be seen that in some points the inventory rapidly increases and after those it rapidly decreases. This is due to the unpredicted behavior of the customer, which is placed far away for it especially in terms of information flows.

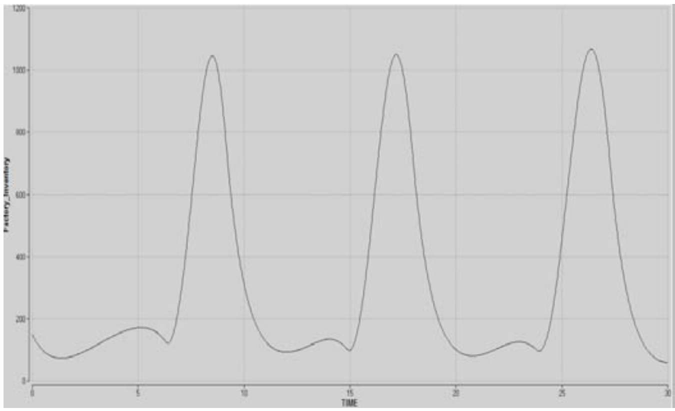


Fig.7 Factory inventory

Figure 8 represents the distributor inventory distribution. It is evident that peak values are decreasing in respect to the factory inventory distribution.

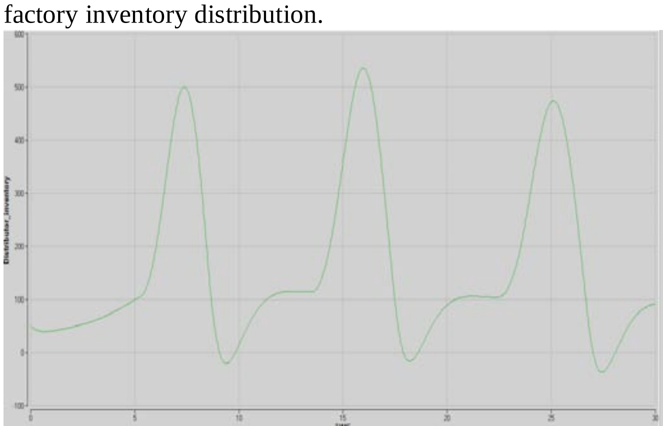


Fig.8 Distributor inventory

Finally, figure 9 shows the wholesaler inventory distribution. In contrast to the previous graphs, amplitudes are smaller. The reason for that is to be found in the closer relationship of the wholesaler with the final customer.

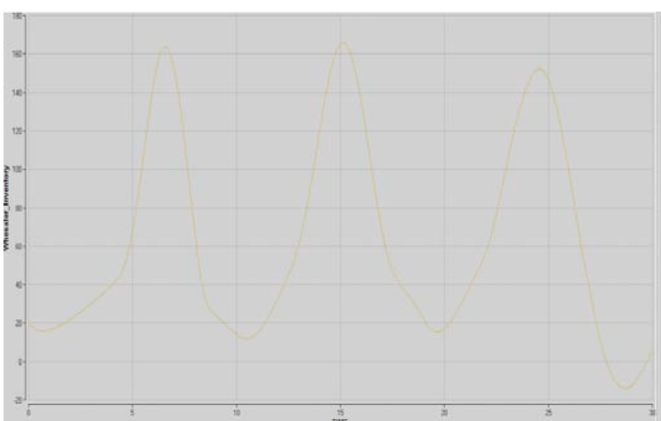


Fig.9 Wholesaler inventory

Figure 10 is instead the representation of the combined distributions of customer order rate, retailer inventory, wholesaler inventory, distributor inventory and factory inventory.

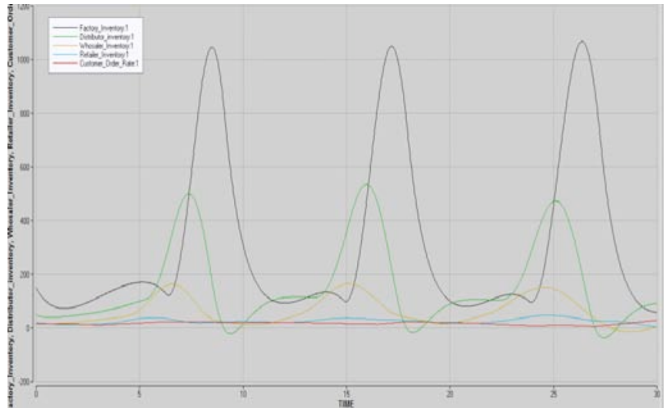


Fig.10 Customer order (red line), retailer (blue line) – wholesaler (orange line) – distributor (green line) – factory (black line) inventory

Curves in figure 11 represent instead the profit of each stage of the supply chain, for a period of 30 days (retailer profit in green line, distributor profit in orange, wholesaler profit in blue and factory profit in pink).

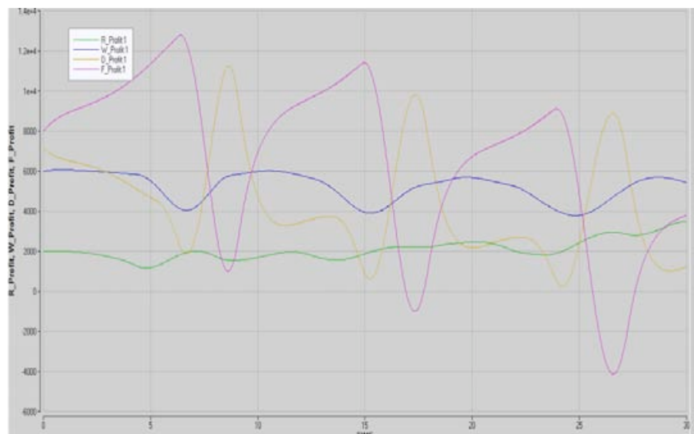


Fig.11 Retailer, Wholesaler, Distributor and Factory profits

Variations of the values of the profit in figure 11 are due to the fact that it is calculated for each day. Obviously, when the inventory level is high the profit decreases, caused by the higher inventory costs for keeping items on stock. On the opposite, when the inventory level is lower, inventory costs are lower too and the profit is higher. The retailer is characterized by almost steady profit because it has direct connection to the customer and so it is better informed about the quantity to keep on stock. Moreover, the retailer has the smallest inventory capacity and so the lowest inventory costs. This is also due to the fact that the inventory cost per unit has been set to 1 for all the modules in the considered supply chain. This means that, if the inventory unit is varied according to the quantity on stock of the different actors (according to the economy of scale), a more balanced distribution among the different curves can be reached.

In conclusion, when the customer order demand increases the inventory level of the retailer reduces and this reflects into a bigger order that the retailer places to the wholesaler. As a matter of fact, the retailer wants to increase the level of its inventory in order to fulfill an eventual next up going customer demand and at the same time minimize the risk of going out of stock. However, if unexpectedly the demand decreases, the retailer finds more items on stock than needed.

Because the system actually is a chain, the same dependency occurs with the other participants in the chain. In particular the factory, being in the last position of the information chain, in the case of a bigger market demand, sees its inventory rapidly increasing, with a consequent unnecessary big amount of items.

In supply chain management literature this is known as the “Bullwhip Effect”. More precisely the bullwhip effect is a tendency according to which small changes in end-consumer demand are amplified as moving further up the supply chain. This cause distortion to the whole system and potential loss in profits if not well managed.

Research into the bullwhip effect has identified five major factors that cause the effect. These factors interact with each other in different combinations in different supply chains but the net effect is that they generate the wild demand swings that make an efficient supply chain very hard to be run. More specifically they are represented by: demand forecasting, order batching, product rationing, product pricing and performance incentives.

Demand forecasting based on orders received by the downstream stage instead of on end user demand data will inherently become more and more inaccurate as it moves up the supply chain. Companies that are removed from contact with the end user can lose touch with actual market demand if they view their role as simply filling the orders placed with them by their immediate customers.

Order batching occurs because companies place orders periodically for amounts of product that will minimize their order processing and transportation costs. Companies tend to order in lot sizes determined by the EOQ (economic order quantity). Because of order batching, these orders vary from the level of actual demand and this variance is magnified as it moves up the supply chain. The way to address demand distortion caused by order batching is to find ways to reduce the cost of order processing and transportation.

Product rationing is the response that manufacturers take when they are faced with more demand than they can meet. One common rationing approach is for a manufacturer to allocate the available supply of product based on the number of orders received.

As far as regards product pricing, it causes product prices to fluctuate, resulting in distortions of product demand. If special sales are offered and product prices are lowered, this will induce customers to buy more product or to buy product sooner than they otherwise would (forward buying).Then prices return to normal levels and demand falls off. Instead of a smooth flow of products through the supply chain, price fluctuations can create waves of demand and surges of product flow that are hard to handle efficiently.

Finally, performance incentives are often different for different companies and individuals in a supply chain. Each company can see its job as managing its position in isolation from the rest of the supply chain. Within companies, individuals can also see their job in isolation from the rest of the company. It is common for companies to structure incentives that reward a company’s sales force on sales made each month or each quarter. Therefore as the end of a month or a quarter approaches, the sales force offers discounts and takes other measures to move product in order to meet quotas. This results in product for which there is no real demand being pushed into the supply chain.

The bullwhip effect is not harmful by itself, but because of its consequences:

• Excessive inventory investments: since the bullwhip effect makes the demand more unpredictable, all companies need to safeguard themselves against the variations to avoid stockouts;

• Poor customer service levels: despite the excessive inventory levels mentioned in the first consequence, demand unpredictability may cause stockouts anyway;

• Lost revenues: in addition to the poor customer service levels of the second consequence, stockouts may also cause lost revenues;

• Reduced productivity: since revenues are lost, operations are less cost efficient;

• More difficult decision-making: decisions-makers react to demand fluctuations and adapt (production and inventory) capacities to meet peak demands;

• Sub-optimal transportation: transportation planning is made more difficult by demand uncertainties induced by the bullwhip effect;

• Sub-optimal production: as transportation, greater demand unpredictability causes missed production schedules.

IV. Inventories Optimization

One of the way to reduce the bullwhip effect is to optimize the level of inventory for each stage of the supply chain. In order to do that, the optimizer provided by Berkeley Madonna software has been utilized. The goal is to find, for each stage of the supply chain, the optimum level of inventory able to minimize the total costs.

The graphs below represent the results obtained by the optimization of the different supply chain inventories.

Figure 12 puts into comparison the factory inventory before and after the optimization. As it can be seen the optimized inventory shows a smoothed oscillation along the time with lower values of products on stock. In other words, after optimizing the inventory decreases significantly with a direct reflection on the correspondent inventory costs. We have obtained the optimum inventory level at each moment of time, that allow the minimum total costs guaranteeing the satisfaction of the distributor demand as well.

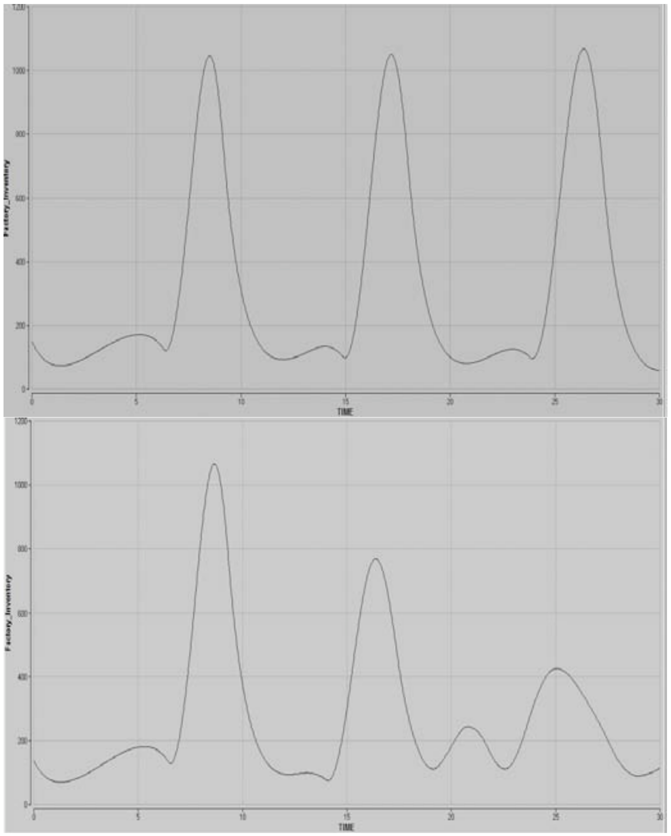
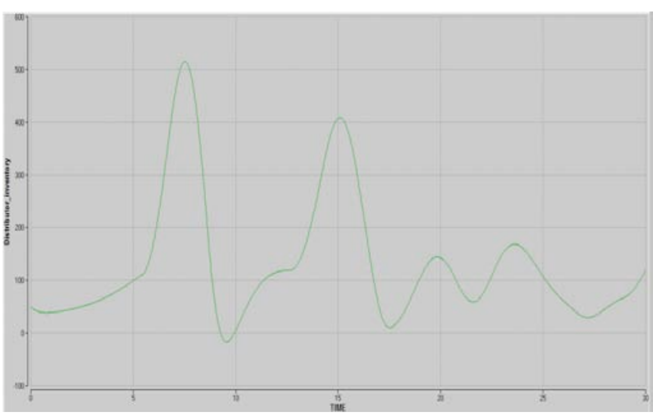


Fig.12 Factory inventory before (upper graph) and after (lower graph) the optimization

Going downstream the supply chain, the same concept can be applied to the distributor inventory (figure 13). The procedure for optimizing the distributor inventory level in the Berkeley Madonna system is the same for each stage. As a result of the optimization the inventory level of the distributor is again reduced in each period of time.



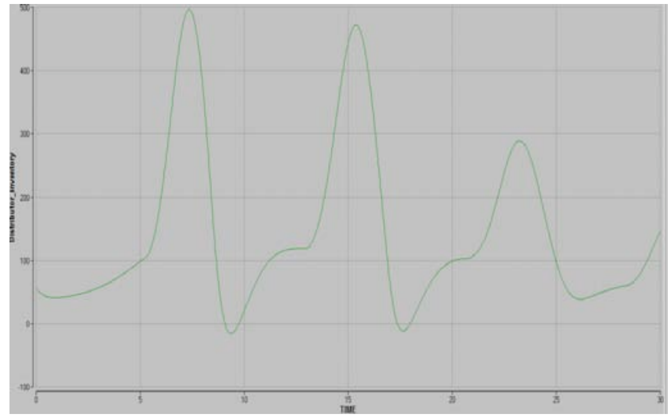


Fig.13 Distributor inventory before (upper graph) and after (lower graph) the optimization

Figure 14 highlights the results obtained before and after the optimization of the wholesaler inventory. In this case the inventory slightly increases in order to better satisfy the retailer needs.

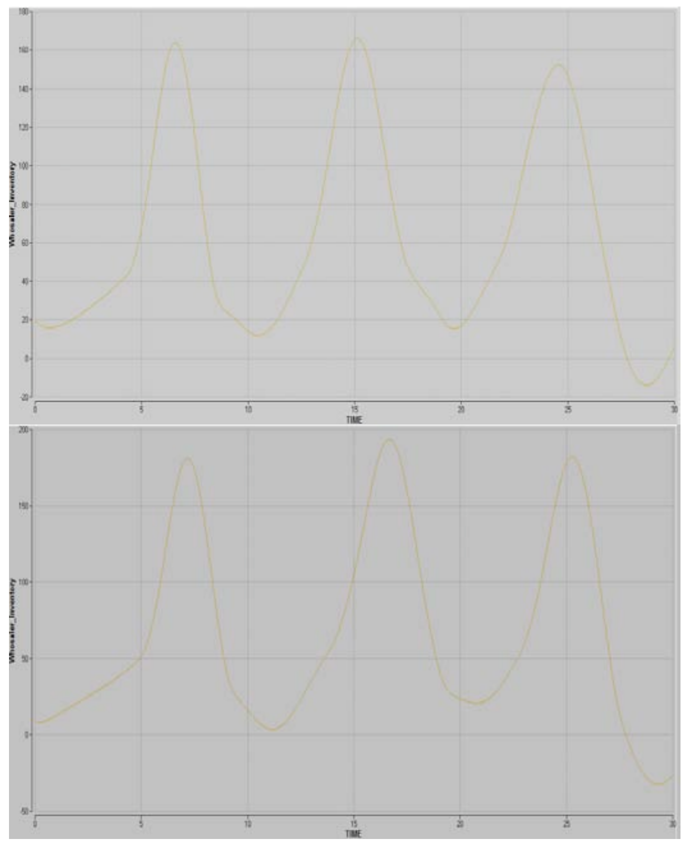


Fig.14 Wholesaler inventory before (upper graph) and after (lower graph) the optimization

Finally, graphs in figure 15 present the results related to the optimization of the retailer inventory. The deviation from the initial values before is optimization is negligible, meaning that the level of inventory before optimization was already optimized, so allowing the minimum inventory costs.

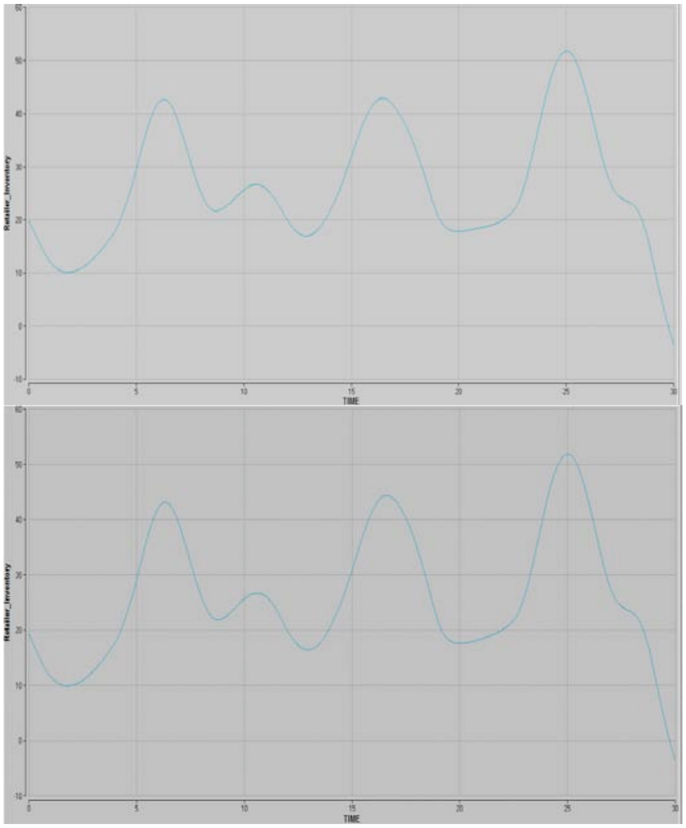


Fig.15 Retailer inventory before (upper graph) and after (lower graph) the optimization

In conclusion it can be stated that in comparison with the non optimized inventories, the optimized scenario has proved to be able to significantly reduce the total associated costs.

V. Conclusions

In this study, a System Dynamics simulation model has been built for a non multi echelon supply chain including the retailing, wholesaling, distributing and production processes, with the main goal of searching for inventory policies that yield reduced costs and/or increased revenues. Experiments have been done to test the effect of increased delays on the behavior of the system.

Two different kinds of delays have been considered: information processing delays and material delays. As delays are increased, the behavior of the system is disturbed, meaning that increased delays require closer control of the inventories.

Long and complex supply chain processes can cause unexpected results because of the dynamic interactions of the different stages involved in the supply chain. One of the big tasks of Supply Chain Management (SCM) is to control these dynamic interactions which can have very negative influences upon supply chains. Information distortion within the supply chain is a major internal cause of the bullwhip effect and the boom and bust effects.

A way to reduce the bullwhip effect is, as shown in the last part of this paper, to find the optimal levels for each stage inventory, able to minimizing the total costs.

Another way to reduce the bullwhip effect is through better information, either in the form of improved communication along the supply chain or (presumably) better forecasts. Because managers realize that the end-user demand is more predictable than the demand experienced by factories, they attempt to ignore signals being sent through the supply chain, focusing instead on the end-user demand. This approach ignores day-to-day fluctuations in favor of the running level.

Another solution is to reduce or eliminate delays along the supply chain. In both real and simulated supply chains, cutting order-to-delivery time by half can cut supply chain fluctuations by 80%. This can both bring savings from the reduced inventory carry costs and cut operating costs because less capacity is needed to handle extreme demand fluctuations.

References:

[1] Hugos M., *Essentials of Supply Chain Management*, 2003.

[2] Craig W. Kirkwood, *System Dynamics Methods, A Quick Introduction*, 1998.

[3] Venkateswaran J. and Charru Hasti, *Stability of Production-Inventory Control Systems Considering Inventory Shortages*, Proceedings of 10th Annual International Conference of the Society of Operations Management, IIM Ahmedabad, India, December 21-23, 2006.

[4] Chopra, Sunil, Meindl, Supply Chain Management: *Strategy, Planning, and Operations*, Upper Saddle River, NJ: Prentice-Hall, Inc., 2001.

[5] Fredendall, Lawrence D., Ed Hill, *Basics of Supply Chain Management*, Boca Raton, FL: St. Lucie Press.,2001.

[6] Forrester J.W., *Industrial Dynamics*, Cambridge Productivity Press, 1961.

[7] Mollona E., *Analisi Dinamica dei sistemi aziendali*, Egea, 2000.

[8] Sterman J., Business Dynamics: *System thinking and modelling for a complex world*, McGraw-Hill, 2000.

[9] Grange F., *Challenges in modeling demand for inventory optimization of slow-moving items*, Proceedings of Winter Simulation Conference, 1998.

[10] Bemhard J. Angerhofer, *System dynamics modelling in supply chain management*: research review, Proceedings of the 32nd conference on Winter simulation, Orlando, Florida, 2000.

[11] H. L. Lee, V. Padmanabhan, S. Whang, *The Bullwhip effect in supply chain*, Sloan Management Review, Spring, 1997.

[12] A. Gunasekaran, C. Patel, E.Tirtiroglu, *Performance measures and metrics in a supply chain environment*, International journal of operations and production management, vol. 21, 2001.

[13] Richmond B., *An introduction to system thinking*, Ithink software, 2004.

[14] Giuliano Caloiero G., Fernanda Strozzi F., Zaldívar Comenges J. *A supply chain as a series of filters or amplifiers of the bullwhip effect*, International Journal of Production Economics, Volume 114, Issue 2, Pages 631-645, August 2008.

[15] Towill, D. R., *Dynamic analysis of an inventory and order based production control system*, International Journal of Production Research, 20, 671–687., 1982.

[16] Sterman, J. D., *Instructions for Running the Beer Distribution Game*: MIT System Dynamics Group, 1984.

[17] Denis R. Towill, Li Zhou, Stephen M. Disney, *Reducing the bullwhip effect: Looking through the appropriate lens*, International Journal of Production Economics, Volume 108, Issues 1-2, Pages 444-453, July 2007.

[18] Ouyang Y., *The effect of information sharing on supply chain stability and the bullwhip effect*, European Journal of Operational Research, Volume 182, Issue 3, Pages 1107-1121, 2007.

[19] Revetria R., Oliva F., Taskov S. (2008) *Application of Artificial Neural Networks for Business Process Meta-Modeling for Leading ERP Implementation*, Accepted for Pubblication in WSEAS Transactions of Systems, ISSN: 1109-2777;

[20] Shahzad B., Afzal Safvi S. (2008) *Effective risk mitigation: a user prospective*, NAUN International Journal of Mathematics And Computers In Simulation, ISSN: 1998-0159, Issue 1, Volume 2, 2008, pp. 70-80;

[21] Ozyildirim C., Ozdincer B. (2008) *Risk Specifications in Risk Efficiency Analysis*, NAUN International Journal of Mathematics And Computers In Simulation, ISSN: 1998-0159, Issue 1, Volume 2, 2008, pp 36-41;

C. Caballini was born in Cremona (Italy) in 1980. In 2004 she obtained her degree in Management Engineering (5 years) at the Faculty of Engineering of Genoa University (Italy) with full marks.
From February to April 2003 she took part at the international program IEPAL - Intensive Educational Program in Advanced Logistic, promoted by DIP - Production Engineering Department of Genoa University, in collaboration with the Stevens Institute of Technology, Boston College and University of Florida - Centre of Simulation, during which she reinforced her competences in integrated logistics also utilizing Arena software.
From 2004 to 2006 she had a working experience in Costa Cruise Company and then she worked in a consulting project for the processes reengineering of an American company.
Since January 2007 she is working at CIELI – Italian Centre of Excellence in Integrated Logistics - of Genoa University as a PhD student, where she also actively collaborate with DIPTEM - Department of Production Engineering, Thermoenergetics and Mathematical Models of the University of Genoa.

Roberto Revetria, He earned his degree in mechanical engineering at the University of Genoa and he completed his master thesis in Genoa Mass Transportation Company developing an automatic system integrating ANN (Artificial Neural Networks) and simulation with the ERP (Enterprise Resource Planning) for supporting purchasing activities. He had consulting experience in modeling applied to environmental management for the new Bosch plant facility TDI Common Rail Technology in construction near Bari. During his service in the Navy as officer, he was involved in the development of WSS&S (Weapon System Simulation & Service) Project. He completed is PhD in Mechanical Engineering in 2001 defending his Doctoral thesis on "Advances in Industrial Plant Management" by applying Artificial iontelligence and Distributed Simulation to several Industrial Cases. Since 1998 is active in Distributed Simulation by moving US DoD HLA (High Level Architecture) Paradigm from Military to Industrial application. In 2000 he succesfully led a research group first demonstrating practical application of HLA in not dedicated network involving a 8 International University Group. He is currently involved, as reseacher, in the DIP of Genoa University, working on advanced modeling projects for Simulation/ERP integration and DSS/maintenance planning applied to industrial case studies (Contracting & Engineering and Retail companies). He is active in developing projects involving simulation with special attention to Distributed Discrete Event and Agent Based Continuous Simulation (SwarmSimulation Agents). He is teaching Modelling & Simulation, VV&A, Distributed Simulation (HLA), Projecty management in Master Courses Worldwide and he is teaching Industrial Plants Design in University of Genoa Masters' Courses. He is member of SCS, IASTED, ACM, ANIMP, AICE, MIMOS and Liophant Simulation Club. He is Associated Professor in Mechanical Engineering and Logistics.