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Bullwhip effect reduction in supply chain management: one size fits all?

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Abstract: In this paper, we try to investigate whether specific solutions suggested by selected authors in the relevant literature, aiming at controlling the so-called bullwhip effect and consequently reducing inventory and stock-outs, and increasing stock turnover in supply chain managements, are of general applicability. In order to do that, a numerical simulation model was developed and suggestions by Forrester, Kirkwood and Sterman were modelled and tested.

Keywords: bullwhip effect; numerical simulation; supply chain management.

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1 Introduction

One of the most important opportunity areas within the field of supply chain management is to find ways to mitigate (and possibly eliminate) the so-called bullwhip effect. According to Anderson et al. (1996), although cyclicality is a well known and accepted fact in market-driven economies, less understood is the phenomenon of amplification as one looks upstream in industrial supply chains. Still according to the authors, 'the bullwhip effect describes the amplification of demand variances that occurs along a supply chain from manufacturer to retailer, as a result of coordination failures and non-stationary demands.' (p.3) While it is less likely that one can substantially reduce the amplification via reducing demand cyclicality (the fact that demands are normally non-stationary), it is increasingly accepted by academics and practitioners alike that higher levels of coordination along the supply chain can play an important role in it.

In this paper, we try to investigate whether specific solutions suggested by some selected authors in the relevant literature (e.g. Forrester, 1973; Kirkwood, 1998; Sterman, 2000), aiming at controlling the so-called bullwhip effect and consequently reducing inventory and stock-outs, and increasing stock turnover, are of general applicability. This study derived from a wider research, the objective of which was to analyse the broad situation of a group of distributors for Johnson & Johnson consumer products in Brazil. In the original study, the strategic, economical, financial and dynamic aspects were analysed, as well as the impact of the findings of this research on the imminent implementation of a VMI process (by the manufacturer) in the analysed supply chain.

2 Scope

The study was carried out based on a three level marketing system of the Indirect (wholesale) Channel (Bowersox and Closs, 2001), with the distributor operating with the *exclusive distribution system* (Lambin, 2000). In order to completely characterise this channel it is also necessary to add that it is inserted in a *monopolistic competition* market (Pindyke and Rubinfeld, 2001). Some supply chain coordination proposals found in the literature were simulated, analysed and compared.

3 The Forrester effect

Before Forrester's studies in the 1950s (1973), there was little awareness of the effect of delays, amplification and organisational structure on the dynamic behaviour of the production – distribution type of system. His work showed that the interactions between the components of this type of system could be more important than the components themselves.

In his honour, the name Forrester Effect is sometimes given to the dynamic behaviour inherent to the supply chains, which is characterised by the increasing amplification of the demand variance perceived by each node upstream of the supply chain, when a disturbance is introduced in a downstream node, e.g., a sudden increase in sales to consumers.

When he performed sensitivity analyses[1] in the system of equations proposed to model the supply chain in his study, Forrester (1973) concluded that the system is not sensitive to changes *in most* of the equation parameters. However, the system is very sensitive to a few equation parameters, which are called *leverage points* of the system, such as *delivery delays*[2] and *production adjustment delays*. Other leverage points found were the *information flows* that control labour and inventory changes.

One of Forrester's (1973) conclusions is that the elimination of nodes (levels) from the supply chain significantly helps to reduce the characteristic fluctuations of demand in that type of system.

More than 40 years have passed since his pioneer contribution, but the elimination of nodes from the chains was not a widely adopted solution, since it sees to the chain's dynamic optimisation but does not meet some strategic and economical requirements of real life. In some instances, *disintermediation* does not allow each link to focus on its core business nor does it minimise the *transaction costs*, when the objective of the manufacturer is to reach a large number of independent points of sale, which is often the case in a continental-sized country such as Brazil.

Pressures to implementing agile manufacturing practices (Corrêa, 2003) and the reduction of the *transaction costs* allowed by the easier and cheaper access to communication and information technology resources, made it possible for companies to begin to organise their interfaces, originating the perspective that Karlson (2003) called 'a shift from *enterprises* to *extraprises*'. It is within that perspective that the coordination efforts between companies emerge and EDI (electronic data interchange), ECR (efficient consumer response), VMI and other initiatives are but some examples.

4 Vendor-Managed Inventory (VMI) and its practical results

> "To address these issues, many firms have moved to integrate the supply chain from customer to raw materials supplier. These policies go by such names as EDI (electronic data interchange), ECR (efficient consumer response), and VMI (vendor-managed inventory)." (Sterman, 2000)

According to Sterman (2000), all those policies are part of the general trend towards lean-manufacturing and just-in-time movements and each one of them intends to solve a different problem of supply chains.

EDI reduces time delays and order costs, allowing customers to purchase smaller lots and more frequently, smoothing the order flow received by the supplier.[3] ECR (Sterman, 2000) involves additional changes in the processing of orders, distribution and shipment policies in order to reduce delivery time.

Those policies can include outsourcing storage, continuous replenishment, use of mixed loads to rationalise freight and other techniques. Point of sale information can also be electronically shared with suppliers, trying to eliminate information distortions and delays. However, VMI goes further (Sterman, 2000): its philosophy is that the *vendor* manages the entire downstream supply chain and determines how much to ship to each level, eliminating the need of customers to place orders.

VMI is a planning and management system that is not directly linked to inventory ownership. This means that the nodes of the chain must operate within a collaborative and trustful frame of mind. With VMI, instead of the customer monitoring sales and inventory to trigger off replacement orders, the vendor takes on the responsibility for this activity.

This is based on the fact that a large part of the inventory management activity depends on demand forecasts. The forecast uncertainty for each point of sale is normally large. However, as the forecasts become more aggregated at higher levels of the chain they are less uncertain (because of the so called *risk pooling* effect).

The system increases the frequency of the orders and reduces the volume of every item in the orders. However, as one of the system's objectives is to reduce the inventory throughout the chain (increase the service level is normally another), the savings obtained in reduced inventory carrying cannot be overcome by the increase of logistics costs. Consequently, the system is especially applicable to chains with a great variety of items and a relative low unit price. Thus, a few units of each part number will constitute an order, which will have many different part numbers, decreasing some fixed and semi-fixed logistics costs such as freight.

That system is offered by systems solution providers with the declared purpose of:

- improving the vendor's knowledge about the demand in a lower (downstream) point in the supply chain
- allowing the inventory throughout the chain to be reduced, by means of the vendor's management
- allowing the vendor to reduce the impact of the bullwhip effect on production, resulting in a more economical manufacture
- allowing, through the set of aforementioned measures, to reduce the product cost, so the Vendors can pass on part of the cost reduction to the consumer, increasing the value generated by the chain, and increase the contribution margin of the distributor, fostering availability of the product in increasing numbers of points of sale.

In practice, however, the results of VMI are debatable and contradictory, as the following statements show:

> "By understanding and managing the costs, and controlling the risks through careful negotiations, one can make both consignment and VMI work not only for the customer, but for the supplier as well." (Williams, 2000)

> "Officially, the acronym VMI refers to vendor-managed inventory. Today, however, some 15 years after its introduction, the initials could also stand for *very mixed impact.* Although some businesses are going ahead and implementing the practice of VMI, others are retreating from the concept." (Cooke, 1998)

> "These industry initiatives – ECR, VMI, CRP[4], and QR[5] – failed to fully address the needs of companies producing and distributing goods because the initiatives were not developed specifically for particular industries. These approaches do not coordinate the demand supply-chain processes, which is the exact point where manufacturers and distributors must coordinate requirements and replenishment. Additionally, they do not provide for disparate trading partners that adopt other approaches or use conventional practices." (Simbari, 1996)

Author: Reference to Mathews and Ryan, 1995 is an uncited reference and does not appear in the reference list. Please cross-check and delete if not required or supply details.

> "Almost a year to the day since its inception, one of wholesaling's most progressive and promising efficient consumer response (ECR) initiatives has been shut down. Spartan Stores announced that effective Oct. 31 it was closing the door on what some called its continuous replenishment program (CRP), a program Spartan executives always described as their vendor-managed inventory (VMI) effort." (Mathews and Ryan, 1995)

> "Various published accounts have described VMI benefits that range from cheaper new product introductions to reduced returns at product end-of-life, but the literature often fails to explain just why these benefits have resulted from VMI. As with many new management theories, it is sometimes difficult to distinguish the achievable results from the hype, just as it is difficult to determine how these results might be replicated elsewhere." (Waller et al., 1999)

In trying to understand this apparently occasional success of VMI for supply chain management, we recurred to system dynamics and numerical simulation.

The primary objective of supply chain management can be understood as to offer a suitable value to the customer and an increased return on assets, by effectively managing the flow of materials, information and financial resources (Reis, 2003).

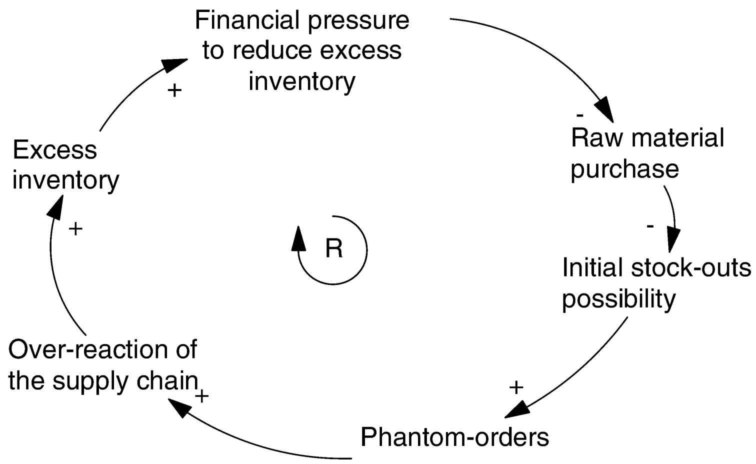
The return on assets for any node in the chain is given by the product between net margin and turnover (Stickney and Weil, 2000).

In the specific case of monopolistic competition markets, gross margin is often exogenously determined by market conditions. That will reduce the economic degrees of freedom of the nodes of the chain leaving basically the fixed costs and inventory turnover to be managed at each different level.

As the ratio between the flow of *sales* and the *inventory* determines turnover, there is a great pressure to reduce inventory.

The causal diagram by Sterman (2000) (Figure 1) shows us that, in the long term, the *direct effort* to reduce the inventory can actually worsen the problem. Therefore, reducing the inventory should not be seen as the main action point, but as a consequence of actions aimed at other points of larger leverage in the chain.

Figure 1 The direct pressure to reduce excess inventory is self-reinforcing



Source: Sterman, 2000, p.753.

Thus, from this simple analysis, a natural question follows: ‘Which point should be acted upon for the turnover to increase?’ An important clue can be learned from Forrester’s (1973) and Kirkwood’s (1998) assertions, that practical experience has shown that modifications to information links in a business process can have a deep impact on the process performance.

5 Why do some supply chains benefit from VMI and others do not seem to?

In order to carry out this investigation, we used Kirkwood's (1998) dynamic model for two nodes of the supply chain as a starting point and added a third node to represent the distributor, thus completely emulating the lower end of the intended three-node supply chain.

Dynamic numerical simulations of the supply chain were performed with help of the VenSim®[6] software, chosen for offering graphic output, having simple syntax formulation for equations and boundary conditions (that simulate the inventory and information flows among the partners of the supply chain), as well as being available at no charge, upon registration, for the academic version. To preserve integrity while carrying out simulations, the method and restrictions recommended by Kirkwood (1998) in his original model were adopted.

By applying a step-type stimulus to the system at the retail demand level function, we simulated the typical response of the supply chain system. The retail demand starts at a constant value and suddenly assumes a new, larger value, remaining constant at this new level. According to Kirkwood (1998), a step-type signal triggers the system in all its resonance frequencies, i.e., in all its natural vibration modes, therefore, being very useful to fully characterise the system's *behaviour over time* (BOT).

In the inventory and flow diagrams, the variables in small letters represent auxiliary variables and those in capital letters represent auxiliary constants. The variables starting with a capital letter represent inventory and, finally, the variables with the first three letters in capitals represent functions.

The BOT for the system is studied after submitting it to an increase of 20% in the initial retail demand, which is 100 units/week, remaining constant at this new level. The increase occurs in week 10. It is important to notice that, before the change made to the demand function (TESt input), the model reflected a system in steady state.

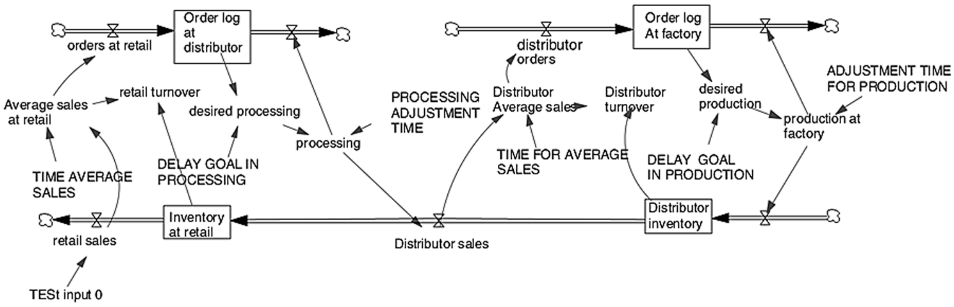
The following were the restrictions of modelling in our original study:

- The normal flows are the logistical, downstream, and that of production orders, upstream. For the purpose of this simulation, the return of products was not allowed. The products are sold and not consigned, thus there are fairly large restrictions to return products which are not sold. In practice, in the real supply chain which we used as a base case, only damaged or exchanged products based on the Brazilian Consumer Protection Law could go upstream.
- In addition to the distributor's sales, distributor's orders, distributor's inventory, order log at the plant and production at the plant, aspects which were studied by Kirkwood (1998) in his model, we also added the turnover calculation at each node, aspect directly related to the yield of the chain, as mentioned above.

- Normally, in an actual arrangement, the chain's nodes become more numerous as they approach the retail end.[7] The large number of points of sale was modelled as a single node, but with aggregated demand in our simplified model. Thus, the random (or non-systematic) demand fluctuations at the consumption end are reduced by a number of points of sale greater than a few dozen. However, the system remains entirely sensitive to market macroscopic (or systematic) fluctuations such as, for example, that caused by an advertisement campaign. In other words, the covariances become much more important than the consumption variances for individual points of sale, since they are much more numerous. This makes a simplified, aggregated-demand model plausible, as well as the assumption of roughly constant demand level at the beginning of our observation period.

An important observation in the proposed diagram of two links and three nodes (Figure 2; Model 16) is that the information flow does not need to be conservative as opposed to the material flow.

Figure 2 Model 16: inventory and information stock and flow diagram for two links and three nodes: retail, distributor and vendor



Note: Model numbers from 1–3 were reproductions of Kirkwood's original models, used for study and acquaintance with his methods. Models 4–15 were experimental models of extended chains – two links and three node models – which did not achieve suitable mathematical closure for the set of equations.

The system is fully modelled by 27 equations that represent the inventory and information flows, stocks and boundary conditions that are necessary to simulate the interactions of the extended chain. The set of equations was integrated over time with the aid of the VenSim® software, using the Euler (Kopchenova and Maron, 1975) numerical method. This method requires that the time step chosen for the numerical integration be less than 1/3 of the largest time constant present in the process, which was observed.

The dynamic response of the model, for the first two nodes, was compared with the response of Kirkwood's (1998) original model, in order to certify it before performing any other changes.

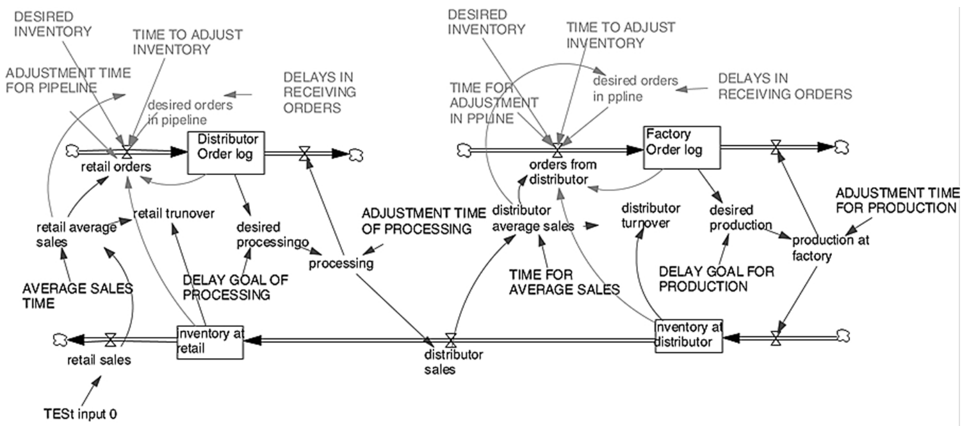
Then, we tested Kirkwood's, Forrester's (1973) and Sterman's (2000) proposals to stabilise supply chains, in our specific model. According to Kirkwood, a suitable way for attenuating fluctuations (volatility) is to increase delays in placing orders and also to consider orders already in the pipeline when placing a new order. Forrester's findings also give support to the idea that the increase of delays tends to stabilise the system. His proposals of leverage points are the delivery delays, production delays and direct insertion of the number of orders received in the decision processes on labour, a variable that we did not explicitly consider in our chain model. Still according to Forrester, actions should be focused on the information points that control the inventory and labour changes. He also suggests increasing the smoothing of average sales and inventories. Hence, in a broad sense, Kirkwood's proposal is in line with Forrester's and so both were handled as being only one in our simulation.

On the other hand, according to Sterman (2000), a sensitivity analysis of the supply chain shows that the greatest leverage of the system is attained by reducing delays in the chain response (production and delivery) to demand fluctuations. The causal relation would be as follows: as orders are met at a faster pace and the chain's response reduces the incidence of initial stock-outs, the phantom-orders[8] level drops and the customers demand less defensive inventory, stabilising the orders in the entire chain.

Therefore, if their recommendations were of a general nature, Kirkwood (1998) and Forrester's (1973) proposal of increasing delays when placing orders and to consider orders in the pipeline would follow a direction apparently opposite to Sterman's (2000).

Figure 3 displays all changes carried out to the information flow of our baseline supply chain model, to allow for simulations of Kirkwood's or Sterman's recommendations, one at a time. The number of equations in the set for the representation of this new model increased to 37.

Figure 3 Model 16 after modification for subsequent tests at the leverage points suggested by Kirkwood or Sterman



Some care must be exercised before making changes to time constants of a dynamic model that simulates a supply chain: Forrester (1973) found that the production – distribution systems are relatively insensitive to changes in the parameters and that sensitivity studies must be carried out changing the parameters by a factor of at least two.

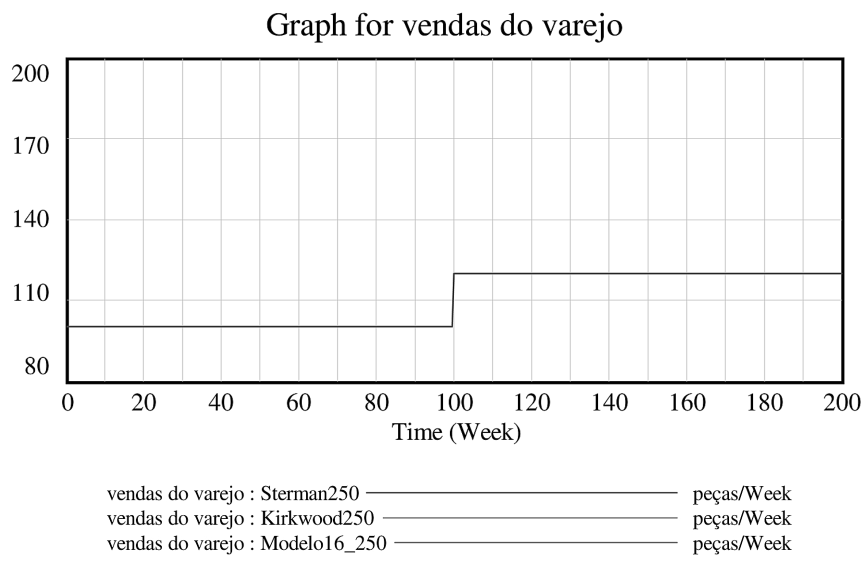
As a consequence, in order to check the system's dynamic response to the candidate hypothesis, all delay parameters were duplicated (Kirkwood's) or halved (Sterman's), as compared to the reference model (Model 16, modified), except the time interval for average sales, which remained 1 week for all tests. The general *stock and flow diagram* was not altered for the tests, only the time parameters.

Also, as a good practice in any system dynamics simulation and as explicitly recommended by Kirkwood (1998), it is important to make sure a system is running in a steady state before evaluating its dynamic response to a disturbance. If it is running in a transient regime and a new disturbance is applied, it is not possible to tell the response from new stimuli from previously existing transient fluctuations. In order to observe this restriction, we have run the modified model with time delays duplicated and halved, but without any changes made to the demand function. This allowed us to identify the *relaxation length of time* for each set of delay constants (for otherwise identical models).

In the case of the modifications suggested by Kirkwood (1998), it was determined that the length of relaxation of one of the variables studied was around 50 weeks (plant production). As a precaution, a relaxation time of 100 weeks was adopted for the model when the time delays were doubled.

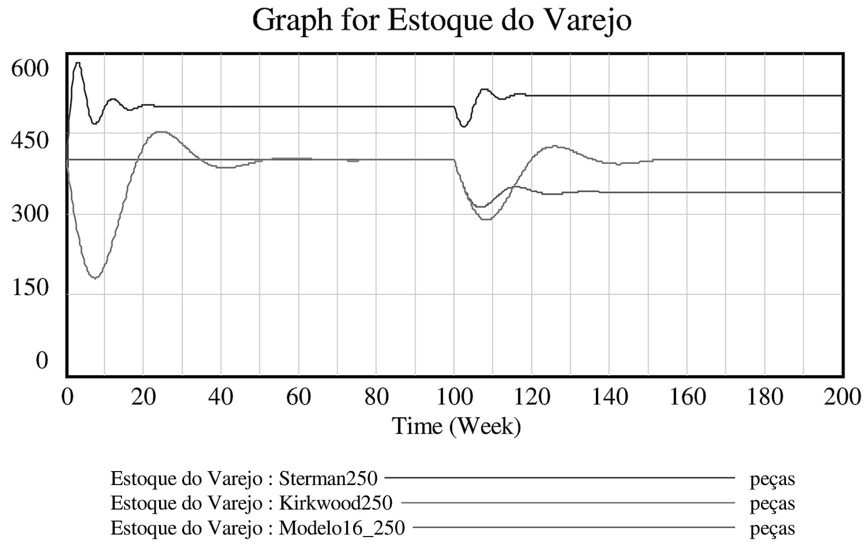
In the case of the modifications suggested by Sterman (2000), the length of relaxation found was 25 weeks. To allow the direct comparison of all the results in the same graphs, we adopted, for all the simulations, the sales step occurring in the 100th week and a total time horizon of 250 weeks for the simulation (only 200 shown). Therefore, only after 100 weeks of simulation time, we would apply the step signal for testing the new models' sensitivity to a 20% increase in demand. The results for both simulations are shown together in the graphs below (Figures 4–14), along with our reference model (16).

Figure 4 Retail sales



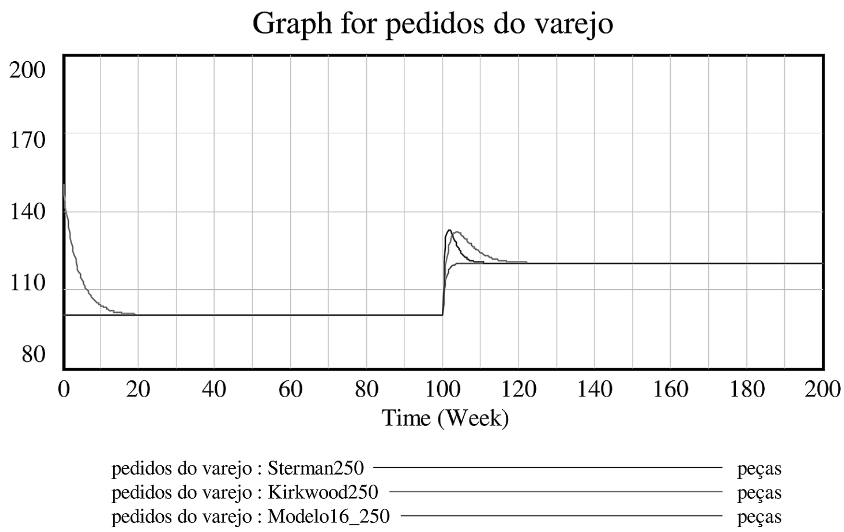
Notes: Vendas do varejo = retail sales. The sales pulse (20% increase) was induced in the 100th week. The variation of retail demand is considered an exogenous variable to the system and is determined by the STEP function that increases its value in 20 units in week 100. Therefore, the behaviour of the three models is the same regarding retail sales.

Figure 5 Retail inventory variation over time



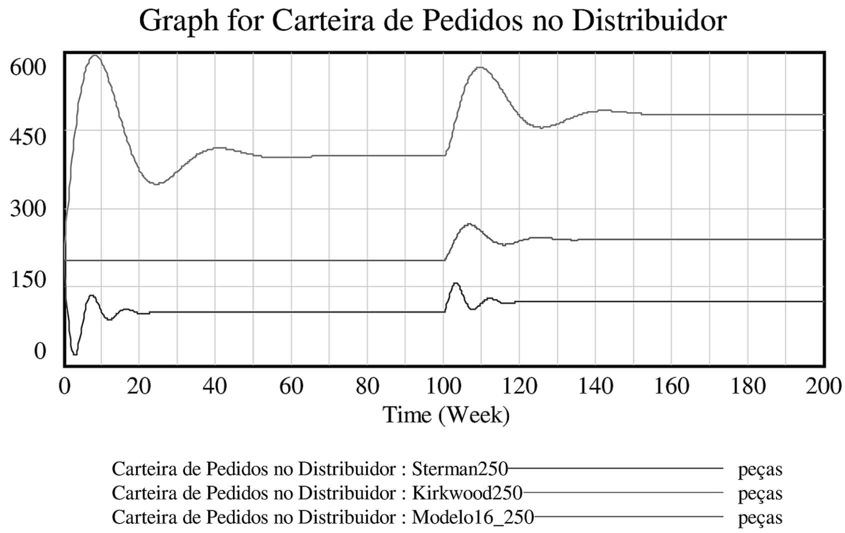
Notes: Estoque do varejo=inventory at retail. Notice that the oscillation of the model with modifications based on Sterman's findings ceases around the 20th week and that the oscillation of the model with modifications based on Kirkwood/Forrester's findings ceases around the 50th week. Also, we can clearly see that before the pulse initiated in the 100th week, all models are in a steady state. After the step change, the model based on Sterman's findings is the one that returns sooner to steady state (more stable). However, the retail inventory balance level is the highest. Model 16 (reference) shows a smooth decay of oscillations and stabilises at the lowest inventory level.

Figure 6 Retail orders



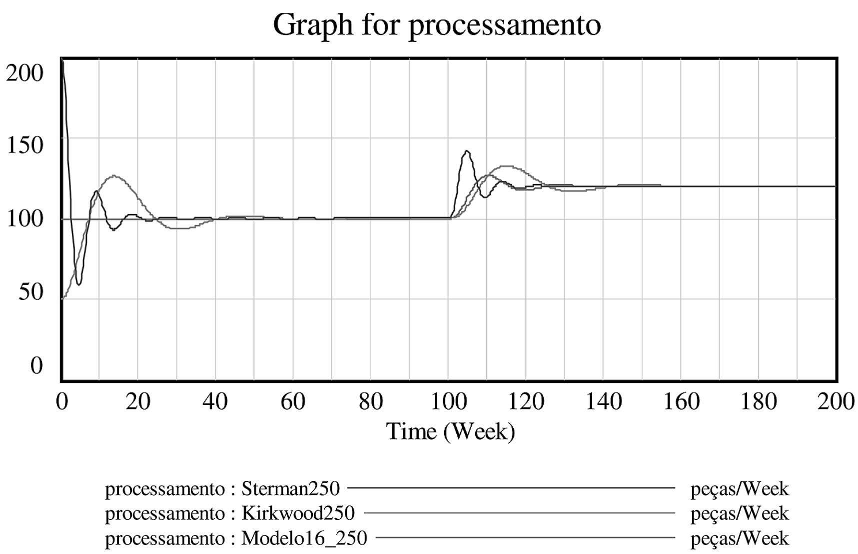
Notes: Pedidos do varejo=orders from retail. Model 16 (reference) shows straightforward behaviour, while the models modified with Sterman's and Kirkwood's findings show overshooting[9] behaviour.

Figure 7 Order log at distributor



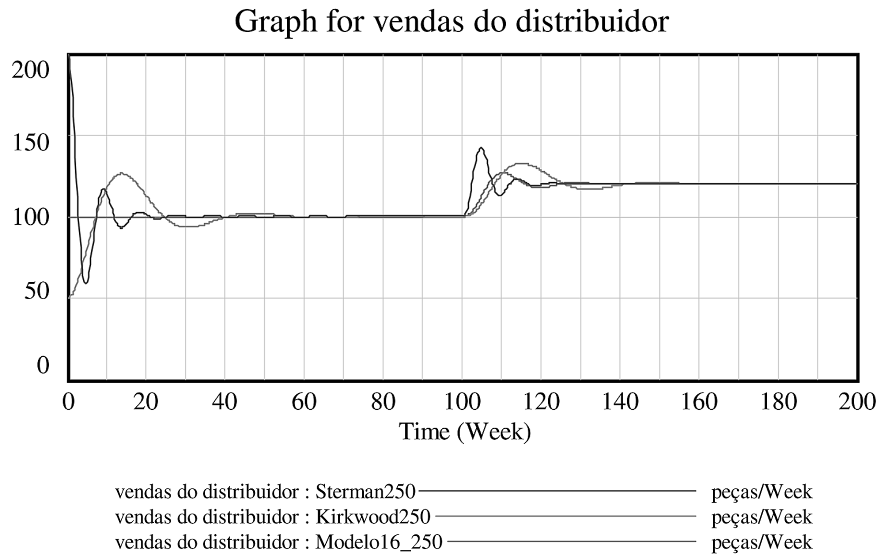
Notes: Carteira de pedidos no distribuidor=order log at distributor. The model modified to simulate Sterman's findings allows earlier stabilisation of the order log at the distributor.

Figure 8 Order processing



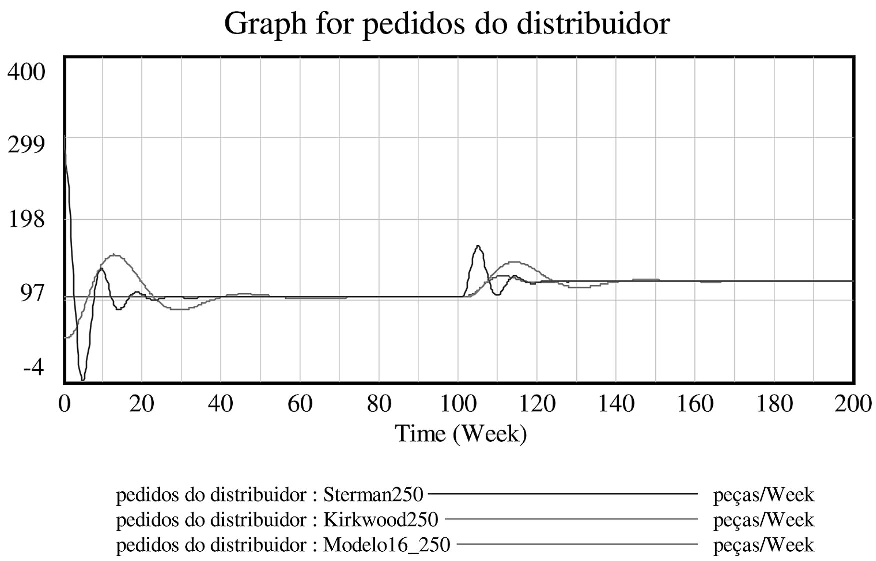
Notes: Processamento=fulfilment of orders at the distributor. The original model (16) shows the smallest oscillations regarding order processing.

Figure 9 Distributor sales



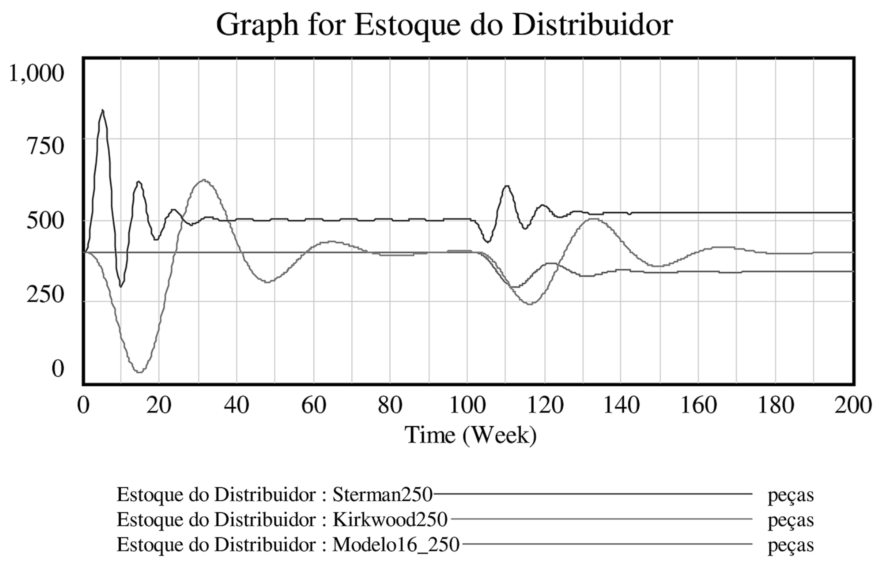
Notes: Vendas do distribuidor=distributor sales. The original model also shows the best stability.

Figure 10 Distributor's orders



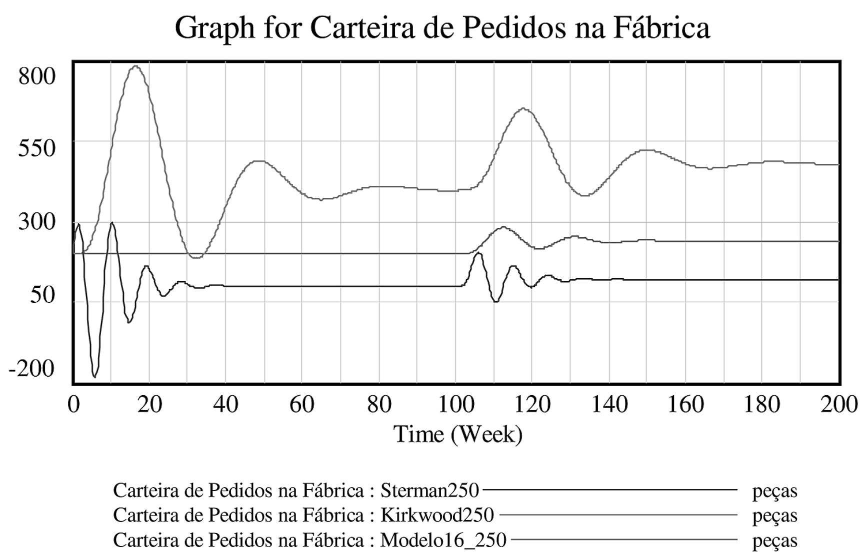
Notes: Pedidos do distribuidor=orders from distributor. The reference model also shows the smallest oscillation amplitude in the orders.

Figure 11 Distributor inventory



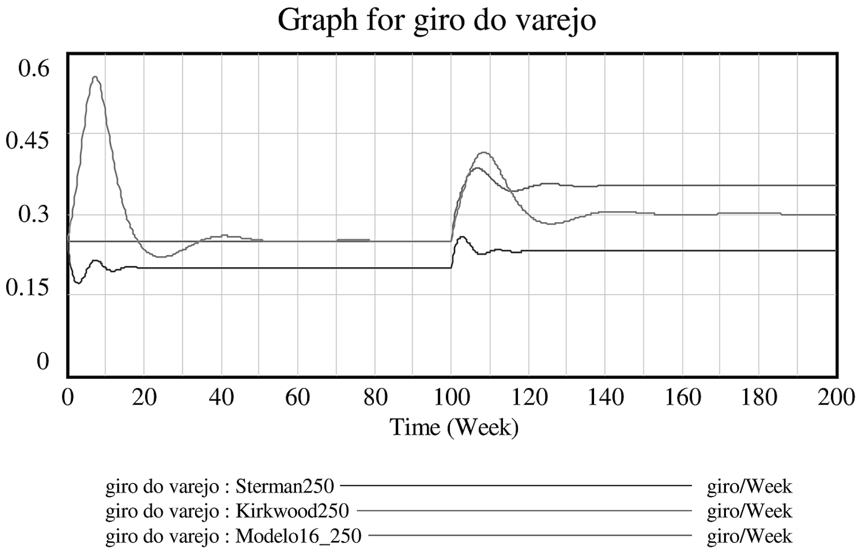
Notes: Estoque do distribuidor=inventory at distributor. The reference model (16) is the one that oscillates with lowest amplitude and allows for the inventory to reach the largest turnover.

Figure 12 Order log at factory



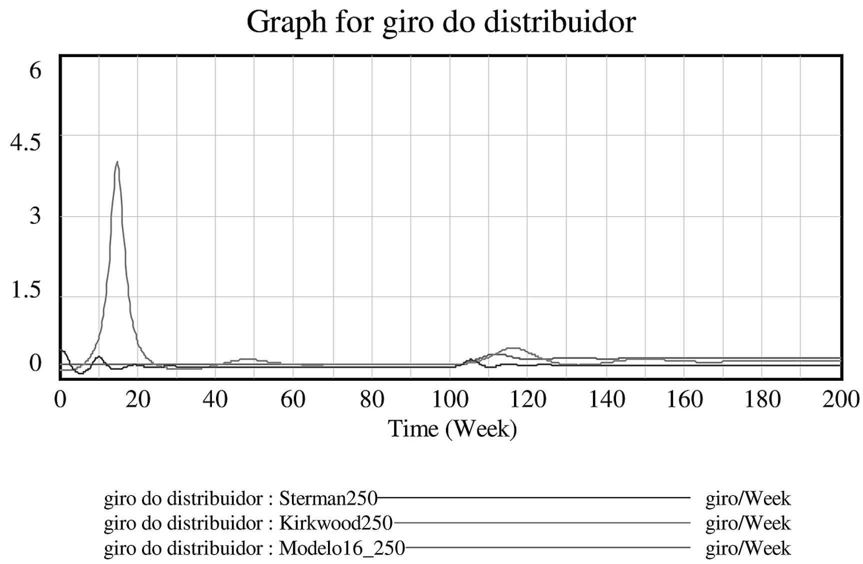
Notes: Carteira de pedidos na fábrica=order log at factory. The model based on Sterman's findings provides faster-paced manufacture and therefore, the order log at the plant is the smallest. However, the reference model (16) has smoother oscillations. Notice that the order log does not reach negative values for the target simulation period (after week 100).

Figure 13 Retail turnover



Notes: Giro do varejo=turnover at retail. The largest retail turnover is attained with the reference model. However, the model based on Sterman's findings is again more stable.

Figure 14 Turnover at distributor



Notes: Giro do distribuidor=turnover at distributor. The same analysis as that of retail turnover applies.

4 Conclusions

The findings of the different researchers seem not to be applicable in a general manner, but only to the specific models proposed and studied by them. These are different from the model proposed herein with the purpose of simulating a specific distribution chain, characterised previously.

This implies that each chain has its material and information flow particularities (as well as others), and that it also has different relevant leverage points. The generalisation of this conclusion suggests the requirement for deeper sensitivity studies, with larger variations of the delays studied. However, it is obvious that the distribution chain is a particular combination of activities and, as such can offer a company, or a network, a unique competitive position (Porter, 1999). The configuration of a supply chain implies the association of dozens of activities and, therefore, is difficult to reproduce or imitate.

This conclusion could help to explain Chase et al.'s (2001) statement: 'Many companies are attaining significant competitive advantages by establishing *and adjusting* their chains.' Chase et al. also consider that the main measurements of efficiency of the supply chain are the *inventory turnover* and the *number of weeks of supply in stock*. However, they point out the fact that many chains do not look for reducing costs, but maximising the value for the customer. Therefore, we can also come to the conclusion that the adjustment of each chain depends on the strategy set between the partners and that it is case-specific.

Thus, the application of practices known as Vendor Managed Inventory (VMI), without being particularised for a specific chain, has reasonable chances of worsening some of the performance metrics that one is trying to improve, resulting not in the legitimate 'Vendor-Managed Inventory' but in a 'Very Mixed Impact' (Cooke, 1998).

References

Anderson, Jr., E.G., Fine, C.H. and Parker, G.G. (1996) 'Upstream volatility in supply chain: the machine tool industry as a case study', *MIT Working Paper*, October.

Bowersox, D. and Closs, D. (2001) *Logística Empresarial: O Processo de Integração da Cadeia de Suprimentos*, São Paulo: Atlas.

Chase, R.B., Aquilano, N.J. and Jacobs, F.R. (2001) *Operations Management for Competitive Advantage*, 9th edn., New York: McGraw-Hill Irwin.

Cooke, J.A. (1998) 'VMI: Very Mixed Impact?', in: *Logistics Management and Distribution Report*, Radnor. Dec.

Corrêa, H.L. (2003) *Teoria Geral da Administração: Abordagem Histórica da Gestão de Produção e Operações*, São Paulo: Atlas, p.117.

Forrester, J.W. (1973) *Industrial Dynamics*, 8th edn., Cambridge, Massachusetts: M.I.T. Press.

Karlson, C. (2003) 'The development of industrial networks', *IJOPM*, Vol. 23, No. 1, pp.44–61.

Kirkwood, C.W. (1998) *System Dynamics Methods: A Quick Introduction*, Version 1–4/1/98.

Kopchenova, N.V. and Maron, I.A. (1975) *Computational Mathematics: Worked Examples and Problems with Elements of Theory*, Moscow: Mir.

Lambin, J.J. (2000) *Market-Driven Management: Strategic & Operational Marketing*, London: Macmillan Business.

Pindyke, R. and Rubinfeld, D. *Microeconomics*, 5th edn., Upper Saddle River: Prentice Hall.

Author: Reference: Cooke Please supply full publication details.

Author: Reference: Kirkwood Please supply full publication details.

Porter, M. (1999) *Competição: On Competition. Estratégias Competitivas Essenciais*, 8th edn., São Paulo: Campus.

Reis, M. de Andrade e Silva (2003) *Logística*, Escola de Administração de Empresas de São Paulo, Fundação Getúlio Vargas, Departamento de Administração da Produção, Logística e Operações Industriais, 01313-902, São Paulo, SP, Brasil.

Ryan, M. (1995) 'Spartan pulls the plug on VMI', *Progressive Grocer*, Vol. 74, No. 11, p.64.

Simbari, D.J. (1996) 'Competitive advantages', *Manufacturing Systems*, Vol. 14, No. 9, pp.92–96.

Sterman, J.D. (2000) *Business Dynamics: Systems Thinking and Modelling for a Complex World*, New York: Irwin-McGraw-Hill.

Stickney, C.P. and Weil, R.L. (2000) *Financial Accounting: An Introduction to Concepts, Methods and Uses*, 9th edn., Orlando, Dryden Press, p.238.

VenSim® [Computer Program] (2003) Ventana Systems, Inc. Available at htttp://www.vensim.com/, in academic version, accessed on 25/04/2003.

Waller, M., Johnson, M.E. and Davis, T. (1999) 'Vendor-managed inventory in the supply chain', *Journal of Business Logistics*, Vol. 20, No. 1, pp.193–203.

Williams, M.K. (2000) 'Making consignment- and vendor-managed inventory work for you', *Hospital Materiel Management Quarterly*, Rockville.

Author: References: Ryan and Simbari Please confirm whether these are books or publications.

Notes

[1] An analysis of sensitiveness is normally performed through changes, by a factor of two or more, in the governing parameters (Forrester, 1973).

[2] According to Forrester (1973, p.269), and confirmed by our original research, for specific cases, faster answers tend to make the system unstable.

[3] The dynamic analysis of the original research suggested that the smoothing results from the purchase of smaller quantities and not from removing delays. Removing delays is a necessary consequence when purchasing smaller lots.

[4] Continuous replenishment processes.

[5] Quick response.

[6] Trademark of Ventana Systems, Inc.

[7] Normally, a manufacturer has a small number of distributors and those serve a large number of retailers. At every level analysed, therefore, the number of elements increases. Frequently, a group made up of a manufacturer, his distributors and retailers is called a *Network*.

[8] Ghost-orders: a term used to explain the repetition of orders not fulfilled, a typical self-defence reaction from a customer who is losing sales due to supply interruption.

[9] *Overshooting*: this is said of a system when its response exceeds the intended target-value, before converging to it. This behaviour normally appears when an exponential growth is not suitably compensated by a damping function as it gets near the target-value.