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IDEAS FOR MODELING AND SIMULATION OF SUPPLY CHAINS WITH ARENA

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ABSTRACT

This paper presents a research project being developed at the Industrial and Systems Engineering Graduate Program at the Catholic University of Paraná (Brazil). The objective is to develop a system to aid professionals from management and logistics areas to evaluate the performance of supply chains through computer simulation. Among the several possibilities for analysis, simulation can allow one to perform detailed studies on the bullwhip effect in supply chains, caused by the demand variation from the point-of-sale to the suppliers. Two performance measures are of particular interest: average inventory level and service level, both for each stage at and for the whole supply chain. The structure considered in this project is the traditional supply chain composed by suppliers, manufactures, distributors (or wholesalers), retailers and customers. A first version of the proposed Arena simulation models is under development and is presented in this paper.

1 INTRODUCTION

Until some time ago, the marketplace forced companies to compete against each other – individually. Nowadays, this is changing – companies still compete with each other, but more in terms of supply chain against supply chain. This is a tendency that should remain for a while. For this reason, being able to manage the supply chain (SC) as a single, interconnected and interdependent structure can lead the participating companies to the success. With this view in mind, one can better identify low performance points (stages or strategies) incurring high costs to the final product. This will benefit all chain members and not just one or two – usually the big ones. In this sense, companies now tend to collaborate more, "working as a team" in several operational and logistics aspects, as for instance, dealing with demand, making it available from the point-of sale to all stages of the supply chain. One can see that such integration has a significant impact on the SC performance. Computer simulation can play an important hole in this scenario, since it can be used to evaluate the impact of the integration (or the lack of it) in the chain. The project described go towards these ideas.

The structure considered is the traditional supply chain mentioned by Ching (2001) composed by sources, suppliers, processors, distributors, retailers and consumers, since one knows that most corporations do in fact adopt this macro-vision (Figure 1). In this approach, there exist two types of flows, the information flow, in the upstream direction, that is, customers to suppliers, and the material (products or services), in the downstream direction – suppliers to customers (Slack, Chambers, and Johnston 2001).

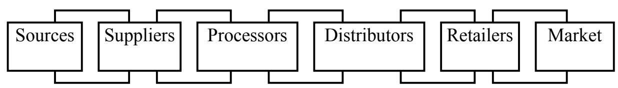

Figure 1: Traditional Logistics Chain (Ching 2001)

In general terms, this project regards the development of a computer environment in Arena (Rockwell Software Inc.) to aid the responsible for operations to better analyze and test new ways to improve supply chain performance (increase its profitability), under the idea of having all of its chain members collaborating. More specifically, a simulation environment to allow the study of new technologies to supply chain management, like, for instance, implementation of collaborative planning, forecasting and replenishment (CPFR) ideas. Secondly, the overall project will show that the bullwhip effect can be more easily study with high-level computer simulation – instead of spreadsheets, which can perform very limited analysis of dynamic and stochastic systems like supply chains.

This paper also describes the first version of the simulation models under development. In fact, usually the literature on SC simulation shows very little detail on how to simulate the intricacies inherent of supply chains. Authors mention results, but lack detailed explanations on how they have built the supply chain simulation structure (most of the time this is due to the simplifications made, like "*only one product*", "*one or two SC stages*", or "*no order,* *transportation and/or production lot sizes*". To make it trustworthy, a supply chain simulation model has to consider, at least:

- Four SC stages: Customers, Retailers (wholesalers or distributors), Manufactures and Suppliers;
- Different customer demand behaviors;
- Different product types;
- For each product type, different bill-of-materials (each product is manufactured from different raw materials
- and/or components;
- Minimum production lot sizes;
- Safety inventory levels;
- Several retailers and suppliers;
- Information and material (components or products) flows:
- Distribution (delivery) lead-times; and
- Minimum order and delivery quantities.

The models presented here are not finished, but already show that all the consideration made above can be easily implemented (in fact most of them are already done so). However, these ideas are a first step towards more realistic SC simulation studies.

This paper is organized as follows: Next section makes a quick review on computer simulation and supply chains. The third section proposes a structure for the modeling and simulation of supply chains. Section four shows initial results (Arena simulation models). Conclusions and next phases for the project are presented in the last section.

2 A BIRD´S EYE VIEW ON SIMULATION AND SUPPLY CHAINS

This section presents a brief review about the main topics considered in this study: Computer simulation and supply chains.

2.1 Computer Simulation in Manufacturing

Nowadays, simulation is synonymous to computer simulation, which is, informally, the activity of imitating (or mimicking) the behavior of a system (being designed or not), through the creating of a computer mathematical model. But there are several formal definitions for simulation. According to Hollocks (1992), for instance, simulation is an operations research technique that involves the creation of a computer program representing a portion of the real world, such that experiments in the simulation model can predict what will happen in the reality. To Pedgen *et al.* (1990), simulation is the process of designing a computer model of a real system and conduct experiments with this model to understand its behavior or to evaluate strategies to its operations. Basically, a simulation model gives support to the decision-making, allowing the reduction of risks and costs involved in a process (or project). Therefore, more and more simulation is being accepted and being part of daily activities of analysts as a technique (or tool) to check and propose solutions to problems commonly found at different industry sectors.

A simulation project normally involves a sequence of steps. According to Banks & Carsen (1984), Pedgen *et al.* (1990), and Law & Kelton (1991), these steps can be summarized as:

- Conceptual problem formulation and analysis;
- Data and information collection;
- Model building;
- Verification and validation;
- Experiment design;
- Experiment execution and results analysis;
- Refinement of experiment design;
- Final results analysis; and
- Process documentation.

Among these steps, data collection is probably the most time consuming and maybe the most important (remember: "*garbage in - garbage out*"). Validation is right next. One needs to make sure the model created corresponds to the real system in order to perform the experiments and propose changes.

The dynamics inherent of manufacturing systems are usually too complex to be dealt with from an analytical point-of-view, especially when manufacturing processes have characteristics like high variety and low quantity production, unexpected events, too many planning decisions, routing flexibility, etc. In such scenarios, simulation comes up as a powerful tool for performance analysis and optimization

In manufacturing, simulation has been used at several different applications. Objectives varies, but based on past works, simulation is usually related to:

- Inventory reduction – setting appropriate levels according to the production planning;
- Performance improvement;
- Making sure that new processes are tested and approved before their actual implementations;
- Reaching the optimal use of resources (machines, production lines, personnel, etc.);
- Obtaining better logistics results within the supply chain;
- Use of a model to foresee the future behavior, that is, the effects produced by changes in the system or by new operations methods (Pedgen *et al.*, 1990);
- Study of capacity usage, inventory levels, control logic, integration, sequencing/scheduling, bottlenecks, search for better layouts (Lobão & Porto, 1996).

Among the advantages of using simulation in systems modeling and performance evaluation, one can find, for instance:

- "What…if analysis" – where decision policies can be rapidly tested and compared (Corrêa, Gianesi, Caon 2001);
- Hypothesis about how or why certain phenomena happen can verified (Pedgen et al., 1990);
- A simulation study usually shows how a system really works, in opposition to how people think it works (Banks and Carsen 1984);
- The development of a simulation model helps the company to separate controllable from non-controllable parameters and study the influence of each parameter in the system performance;
- Analysis of long time periods in short execution times;
- Problems that are usually solved by intuitive rules can be solved (and tested) formally.

Beyond manufacturing (logistics and supply chains), simulation can be applied to many other fields, like hospitals, supermarkets, airports, banking, computer networks, etc. Next section defines the context of this project.

2.2 Supply Chains

A supply chain should be understood as a net encompassing all the organizations that comprise the material (component or product) supply, production, distribution and selling of goods to the final customer. According to Ballou (2001), a company usually is not able to completely control the product flow, from raw material sources to the point-of-sale. Managing these channels is the core of supply chain management, and its key activities are related to keeping high customer service levels, transportation efficiency, inventory management, information management and order processing. These logistics (management or planning) activities go beyond a single organization's limits.

A supply chain forms a complex net of physical (material/products and capital) flows and non-physical flows (information). Decision made in one stage of the chain will usually have an unpredictable impact on other stages of the chain. The relationships among the stages (and their functions) are non-linear and the results of an action may not be estimated precisely before hand. As mentioned by Kuo & Smiths (2003), the focus has shifted from individual companies competition to competition among business networks, and from an individual firm performance to the performance of the whole supply chain.

Managing a supply chain concerns activities that promote functional interactions, both within a single company and amongst distinct ones. Based on Ho, Au, and Newton (2002), one can see that such activities include the access to SC members planning systems, sharing of production plans, information exchange via EDI (electronic data interchange) or simply through the internet, knowing inventory levels, standardized procedures, packaging, demand forecasting, promotional events, etc. This behavior increases the complexity in managing and analyzing supply chains.

Methods for supply chain management should be able to simplify such complexities, probably by taking a systemic view of the functioning of the whole chain. The overall system performance will depend not on isolated actions but on collective ones, which will benefit everyone in the chain and not one or two.

Turbam, Rainer, and Potter (2003) state that a supply chain involves three basic parts: the upstream (suppliers and suppliers´ suppliers), internal part (include all of the organization processes that transform materials into products) and the downstream part (distribution and delivery of products to the final customers). A supply chain simulation model must consider all of these parts.

The literature, although quite vast on the SC subject, is limited on simulation of supply chains. Based on Banks *et al.* (2002), Payne (2002), Ramakrshnan, Lee, and Wysk (2002), Armbruster, Marthaler, and Ringhofer (2002), Linn, Chen, and Lozan (2002), Ritchie-Dunham *et al.* (2000), Chang & Makatsoris (2002), Jain *et al* (2001), Yee (2002), Bansal (2002), and Khator & Deshmukh (2002), one can note that works on SC simulation usually lack detailed description on what the SC models considered, stages, functions, interactions among the companies, production and logistics rules adopted (as, for instance, minimum truck load, production or safety stock levels, order processing times, bullwhip effect). Lots of simplifications are made and are briefly explained, like, single product, no *bill-of-material*, a product is made of only one component or raw material, very simple chains, demand is constant or well known, etc. The supply chain simulation models overcome these (and other) simplifications.

The SC structure presented in the following section is used to aid the development of the first version of the simulation models being created in ARENA (Section 5).

3 A SIMPLE STRUCTURE FOR SIMULATING SUPPLY CHAINS

As mentioned by Ching (2001), the traditional logistics chain is composed by six stages: suppliers´ suppliers (sources), suppliers, processors (manufacturers), distributors (or wholesalers), retailers and consumers. The simplified SC structure initially considered in this project has four stages: suppliers, manufacturer(s), retailers and consumers. There are two main objectives in the development of a simulation structure: to analyze the benefits of CPFR and to study the bullwhip effect on supply chains. It is known that companies using CPFR have reported a 67% reduction on lead times, 60% reduction of forecasting errors, 40% reduction on inventory levels, 22% increase in service levels and 47% increase on sales (Vieira & Cesar 2003). The proposed use of simulation will permit the company to estimate the impact of integration or the consequences of the use of new managerial strategies to the whole supply chain. Regarding the bullwhip effect, this is a well-known problem that clearly deserves more in-depth study.

The structure for modeling and performance evaluation for this type of supply chain through computer simulation is composed of hierarchical levels. The first level, the most general, is composed by the four elements and by their integration made by orders and material/products flows. At the second hierarchical level, one performs the intermediate modeling of each SC member. Detailed modeling of specific functions (intra-company) is designed at the third and fourth levels.

The first version for the proposed structure presents a single way to model suppliers, manufacturers, retailers and customers. Initially, a fourth level was implemented detailing even more of each supplier, retailer and manufacturer, however, it was later realized that this was redundant for the proposed model. The generic structure with three hierarchical levels has been developed for the CS considered, and is shown at Figure 2.

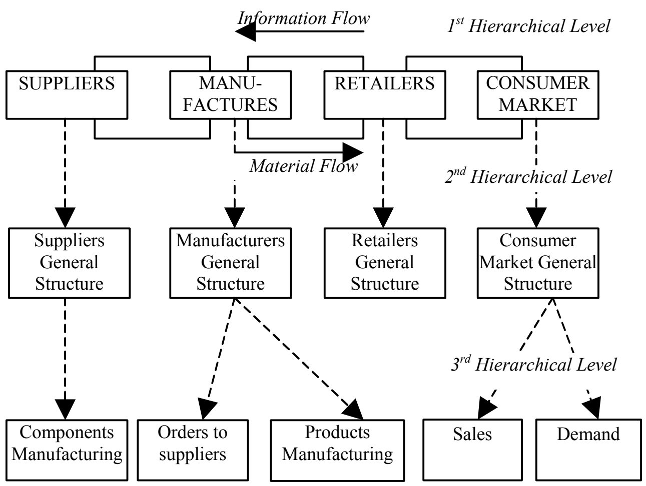

Figure 2: SC General Modeling Structure

The inventory control policy, at this time, is simply this: when an inventory level gets lower then a minimum specified (safety inventory level), an order for the material (component or product) purchase (or manufacturing) is placed. The optimum order size (quantity) and the safety inventory levels are given by the decision-maker. At a production facility, two types of orders exist: *purchase orders*, for the purchasing of components from suppliers, and *production orders*, for the manufacturing of products (different product types are considered, and each product is made of different combination of components).

Regarding the consumer market, each retailer has demand patterns. There are different demand behaviors, one for each product-to-retailer combination. The demand can follow a simple distribution or, more accurately, can follow a "schedule of arrivals", entered by the decision-maker. The schedule of arrivals permits the use of varying demand patterns, including, for instance, seasonality.

A supplier receives orders for a component from a manufacturer. If it has enough inventory, it immediately dispatches the ordered components to the manufacturer. A minimum order quantity must be respected (it is not worth, for instance, to assign a truck for a delivery of a small order size). If the supplier does not have the quantity needed in stock (warehouse), it will then manufacturer the component and then deliver it to the manufacturer. In this case, the supply chain service level and cycle time will be deteriorated.

The retailer-manufacturer relationship follows similar ideas. When a manufacturer receives an order from a retailer, the quantity is dispatched and the order is closed if it has sufficient inventory. On the contrary, the order remains open until the manufacturer produces the product and delivers it to the retailer. The manufacturer can wait for orders from different retailers in order them orders and be able to better setup production levels and minimize costs. (Demand forecasting can be included in the model, in this case, the manufacturer could plan production according to a master production schedule, for instance – it would use a *make-to-stock* philosophy instead of *make-to-order*). In many scenarios, the make-to-assembly, a combination of both strategies, would be the ideal policy. All of these operation strategies can easily be integrated in the proposed simulation structure. Some of them are in fact already implemented.

When the manufacturer does not have enough inventory to meet a retailer's order, it will soon have to open (or launch) a production order. In this case, the necessary components to make the product need to be in the manufacturer inventory. If this is not the case, the manufacture will dispatch appropriate orders to suppliers. As soon as the manufacturer receives all of the needed components from the suppliers, a signal is sent to initiate production. Products will then be sent to retailers or will just build inventory to satisfy minimum (safety) levels.

Therefore, the proposed simulation structure follows the principle of pull (or just-in-time) production, however, minimum inventory levels are used, as in most companies.

SC performance measures are mainly related to meeting demand (service levels), how quickly this is done (cycle times), and inventory levels, both for at a stage and at the whole supply chain.

The bullwhip effect can easily be studied with this structure. Basically, it regards the variation of production and inventory levels in the stages of the chain (low variations in demand at the upstream stage will incur in large inventory and production levels variations at the downstream stages).

For the modeling of the proposed structure in the simulation software ARENA, a set of global variables needs to be defined, as exemplified at Table 1. All these variables are bi-dimensional, with their respective sizes represented by the variables in between brackets. In this table and on the Arena models, some of the notations used were:

Table 1: Notations and Variables for the SC Simulation Structure

Notations:	*General Variables:*
SS : safetey stock	nc: number of components
IL : inventory level	np: number of products
dnm : demand not met	ns: number of suppliers
comp : component	nm: number of manufacturers
prod : product	nr: number of retailers
qty : quantity	
sup : supplier	
mft : manufacturer	
ret : retailer	

Specific Variables:		
To suppliers:	*To manufacturers:*	*To retailers:*
sup_IL_comp [ns, nc]	mft_IL_comp [nm, nc]	ret_IL_prod [nr, np]
sup_SS_comp [ns, nc]	mft_SS_comp [nm, nc]	ret_SS_prod [nr, np]
sup_dnm_comp [ns, nc]	mft_IL_prod [nm, np]	ret_dnm_prod [nr, np]
sup_prod_rate [ns, nc]	mft_SS_prod [nm, np]	ret_qty_needed_prod [nr, np]
sup_qty_needed_comp [ns, nc]	mft_qty_needed_comp [nm, nc]	
	mft_qty_needed_prod [nm, np]	
	mft_prod_rate [nm, np]	
	mft_dnm_prod [nm, np]	

4 AN EXPERIMENTAL EXAMPLE

To illustrate how these ideas can be implemented, this section shows the implementation of the supply chain presented previously. The figures, taken directly from the simulation program show how the hierarchical levels were implemented, through the use of *sub-models*, as well as the specific and managerial functions of suppliers, manufacturers, retailers, and the consumer market, mentioned previously.

In this example, the supply chain is composed of three suppliers, which supply eight different types of components to a single manufacturer. The manufacturer can produce three types of products: A, B, and C. The chain also has three retailers and a consumer market that generates demand for them. Supplier 1 manufacturers components 1 and 2; supplier 2 produces components 3, 4, and 5; and supplier 3 manufacturers components 6, 7, and 8. The adopted bill-of-material (BOM) shows that product type 1 is made from components 1, 3, and 6; product 2 is made of components 2, 4 and 7; and product 3 uses components 5 and 8. Note that the manufacturer will often order components from more than one supplier.

Figure 3 presents the model for the first hierarchical level. Note that the right-to-left arrows indicate order signals and left-to-right arrows, components or products delivery.

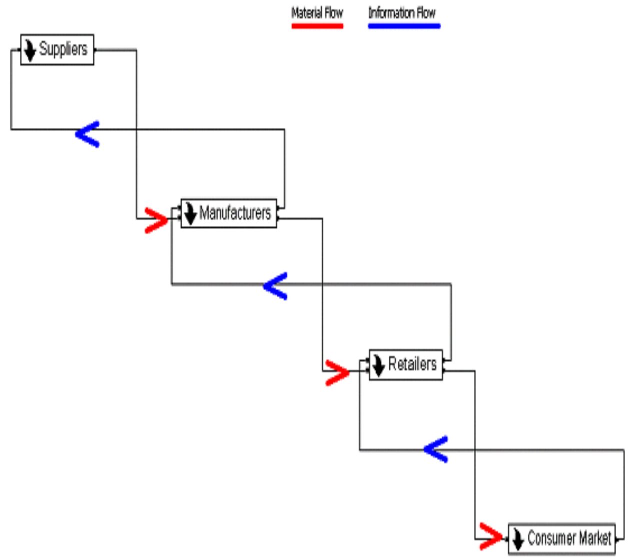

Figure 3: First Hierarchical Level of the SC Simulation Model

On the entry points are represented by little squares on the left side of the rectangles, while exit points are triangles on the right side of the sub-model rectangle. In the case of *Manufacturers* sub-model, two pairs of entry-exit points exist. The upper pair regards orders (from retailers and to suppliers), while the bottom pair of entry-exit points stands for entrance and delivery of products to retailers and from suppliers.

Figure 4 shows the generic suppliers simulation model (at the second hierarchical level of the SC structure). Displays (filled rectangles) are used to show performance measures, order types, etc.

Figure 5 shows the generic modeling of the manufacture at the second hierarchical level of the simulation model. Note, however, the presence of two "long" rectangles on the right side (although not quite readable, their

labels are "order component purchase" and "product manufacturing"). These are actually sub-models, representing the presence of a third hierarchical level. These are shown at Figures 6 and 7.

Different from the supplier simulation model, the manufacture model has two entry and two exit points. The upper entry-exit pair of points is for the information flow and the lower entry-exit points are for material (component or product) flows, as explained earlier.

The filled rectangles shown at Figure 6 represent the detailed modeling of orders of components for each specific product (according to its BOM). The upper rectangle, for instance, creates three orders for the three suppliers of components 1, 3, and 6, which are needed for manufacturing of product 1.

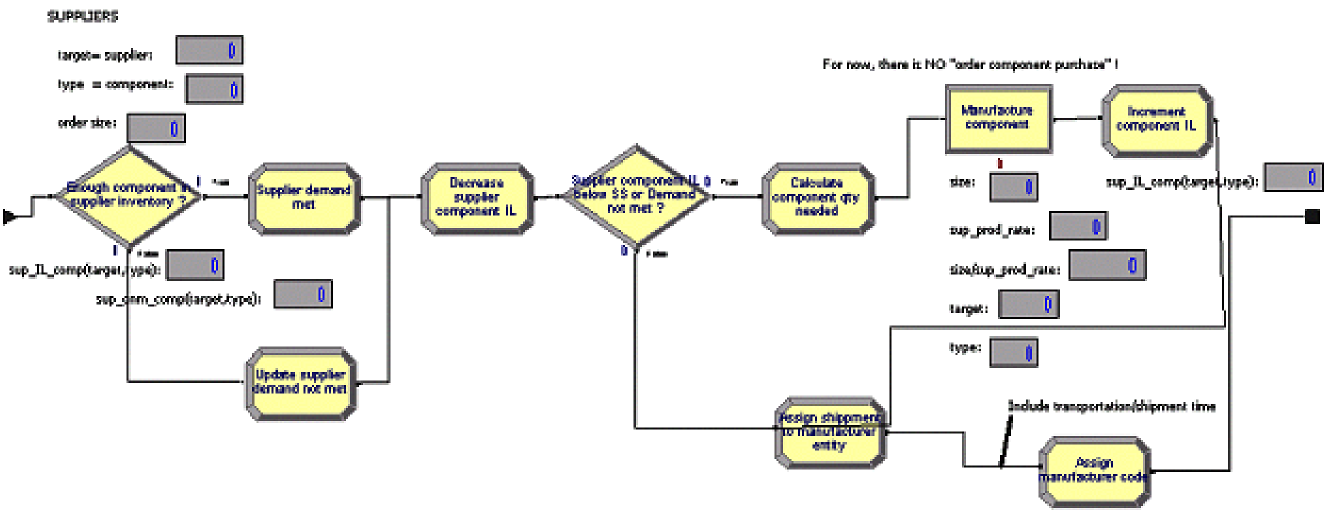

Figure 4: Suppliers Simulation Model

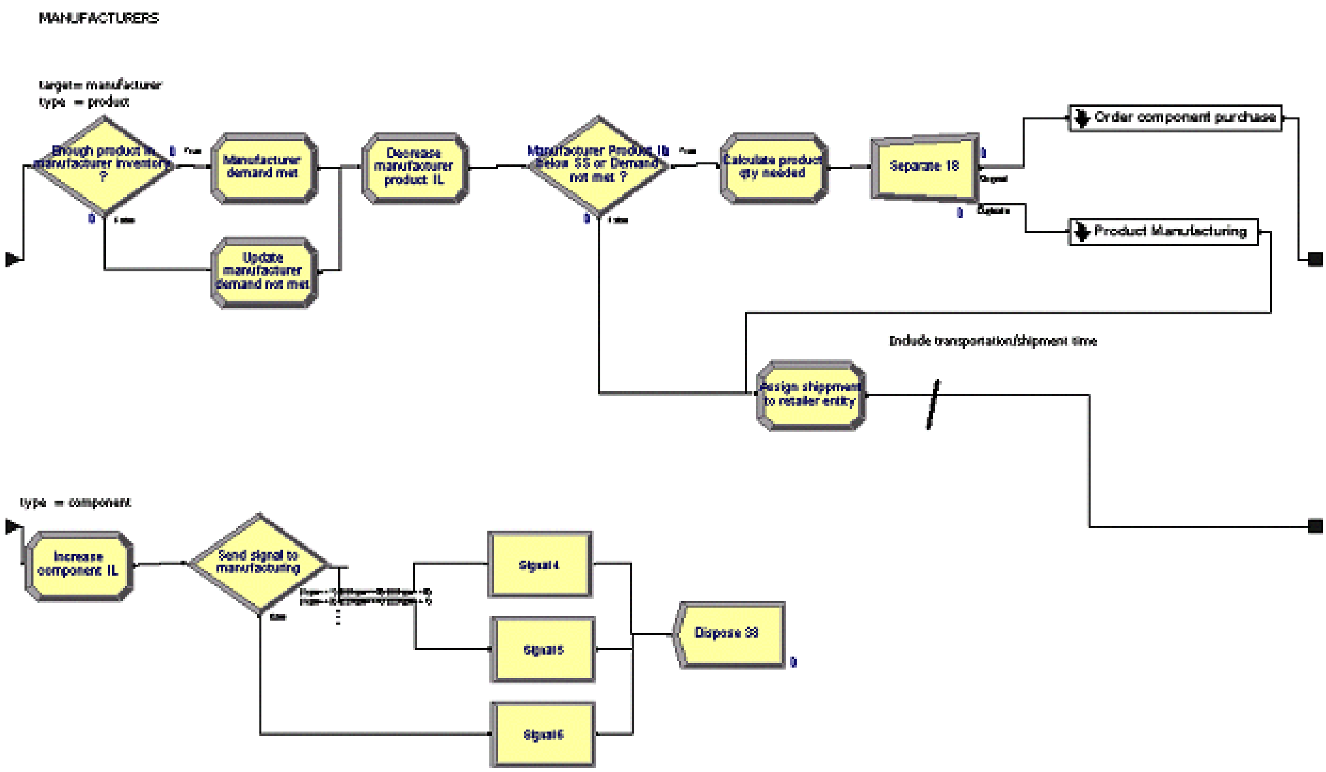

Figure 5: Manufacturer Simulation Model

Although not quite readable, the filled rectangles at the sub-model Product Manufacturing at Figure 7, checks to see if there are sufficient quantity of components in stock to initiate production. If not, the production order stays in a queue until a signal signaling “raw material (component) arrival” at the manufacturing facility. Based on this signal, the next queued production order is (re) sent to verification for sufficient raw material. If there is still not enough inventory, the production order is sent back to the queue. The sequencing rule at the queue should consider priorities, like, earliest due date, longest waiting time in queue and/or priority flags. These scheduling rules are easily implemented in Arena.

Figure 8 shows the retailers modeling. As most of the other models, it was developed sufficiently generic so that it can be adapted to an “unlimited” number of retailers.

Similar to the manufacturer simulation model, the retailers model also needs two pairs of entry-exit points, for both the information and product flows.

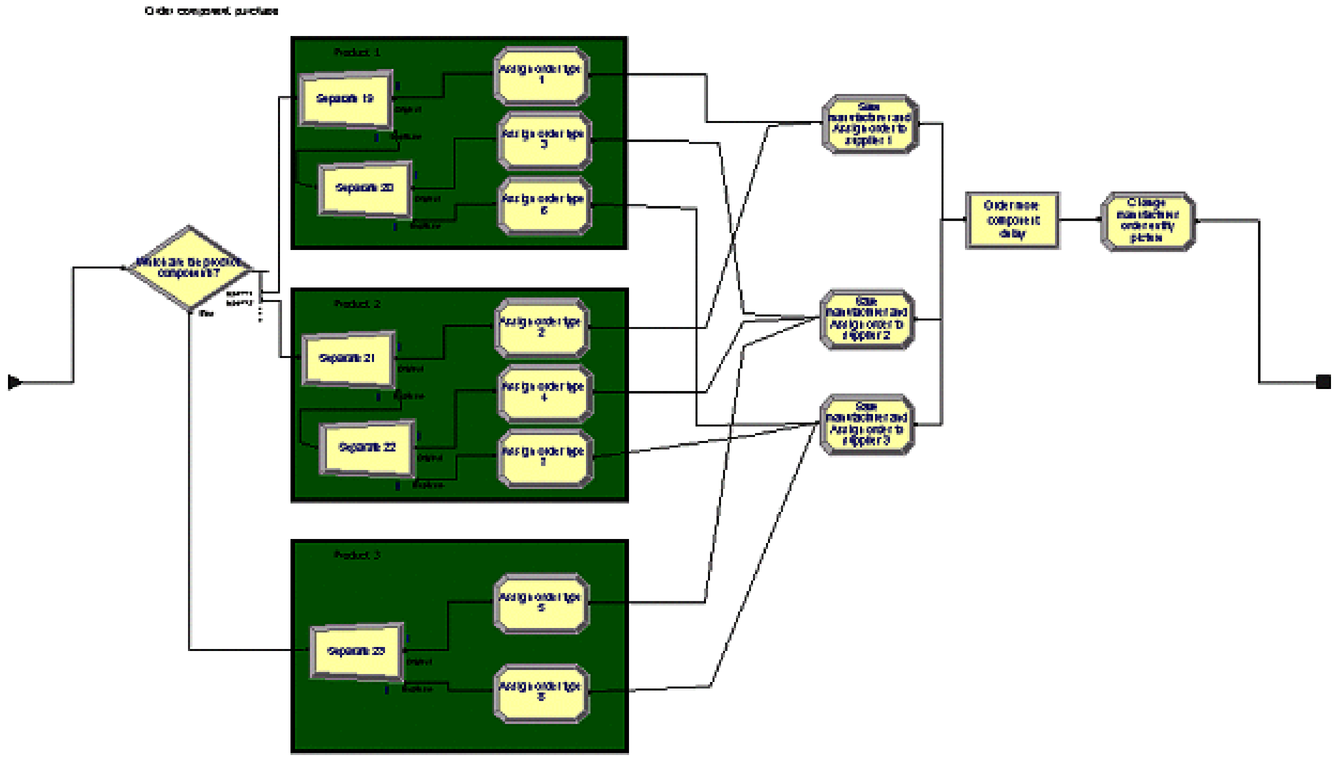

Figure 6: Sub-Model for the Component Ordering

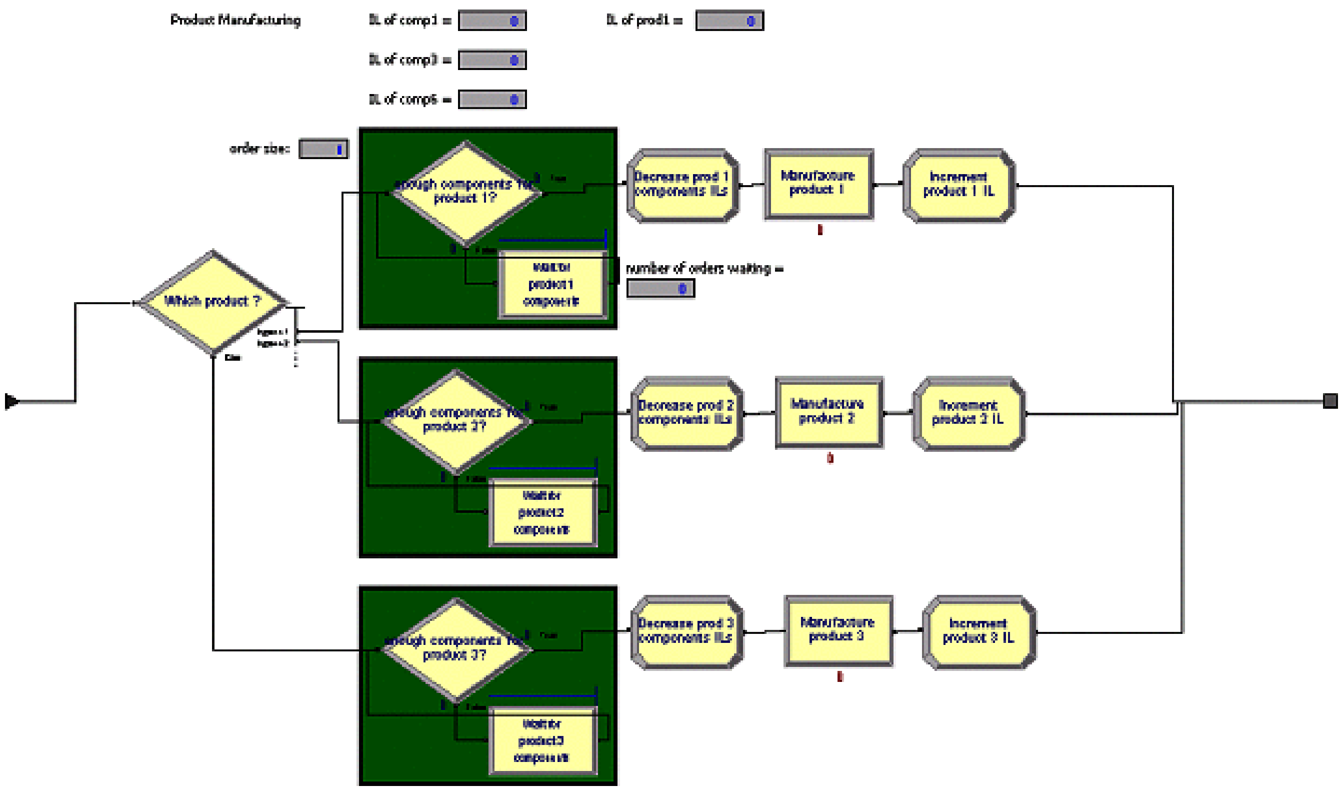

Figure 7: Sub-Model for the Product Manufacturing

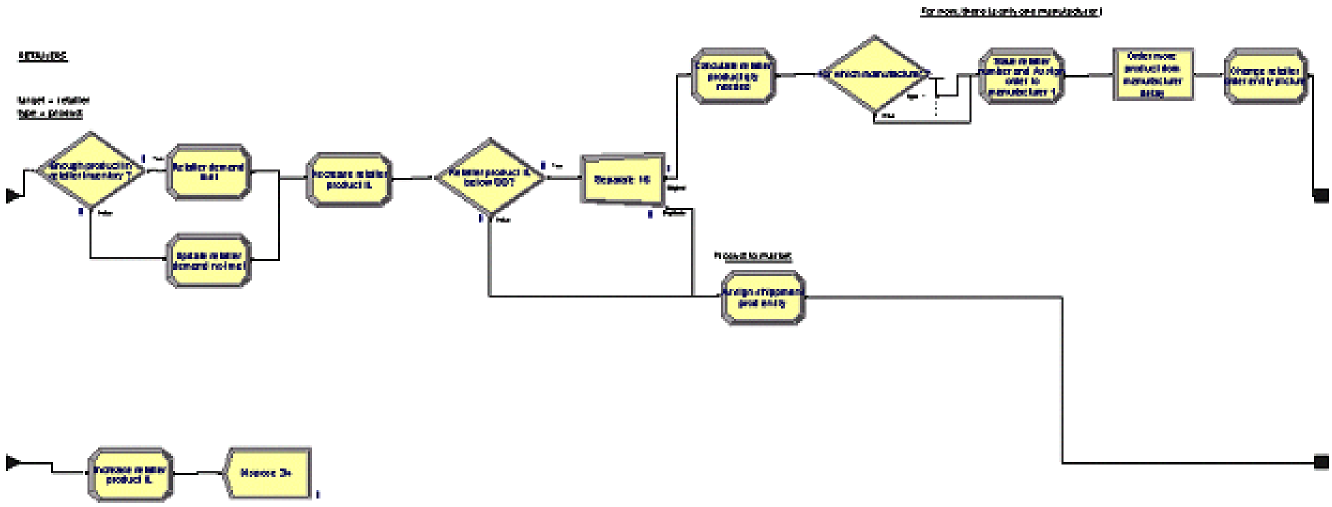

Figure 8: Retailers Simulation Model

The consumer market model is represented at Figures 9 and 10. It is composed basically by products coming in (retailers sales) and by consumer demand behavior, represented by consumer orders to retailers.

Figure 9: Consumer Market Simulation Model

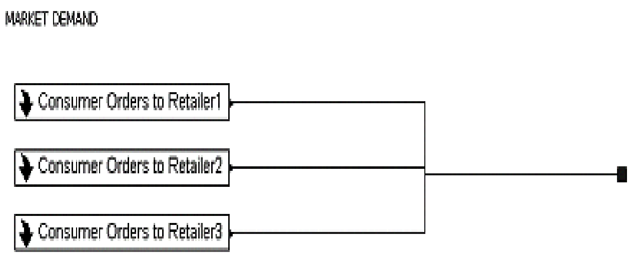

Figure 10: Market Demand Simulation Model

Figure 10 details the market demand behavior. Note the presence of three sub-models (*Consumer Orders to Retailer "i"*) indicating the third hierarchical level at this supply chain stage. Each "*Consumer Orders to Retailer i*" sub-model is implemented by a set of arrivals (and scheduled arrivals) representing the demand patterns. (If wanted, exact previous demands can be used as input data – ARENA can read data from text files.) As mentioned previously, seasonality can also be considered through the use of scheduled arrivals, or obtained directly from imported data files.

To run the model, one should specify the initial inventory levels, safety stock targets, minimum production quantity (standard lot sizes), production rates, minimum truck loads, communication/transaction times (time to place and record an order, for instance), transportation times, and, of course, the appropriate demand patterns for each product-to- retailer demand. Some of these data are needed for both suppliers and manufacturer. Transportation times, for instance, should be specified among all of the supply chain stages.

5 CONCLUSIONS AND PERSPECTIVES FOR THE PROJECT

This paper presented first ideas of a research project currently under development. It proposes to use computer simulation in modeling and evaluation of supply chain performance. Certainly, just the first ideas have been presented – however, they already confirm the project's viability. Such study will bring interesting contributions to both academia and industry professionals, since one can easily create high-level simulation models for his/her supply chain and test new managerial alternatives.

The models presented are currently being detailed and refined, and more precise performance measures are being included. All of this will contribute to the analysis of supply chains. In particular, these models will help to study the bullwhip effect on complex chains – in a much more in depth analysis, completely different from the oversimplified, but important, examples shown in the literature (e.g., Slack *et al.,* 2001). It is important to mention that although simulation and supply chains are well-studied subjects, both by industries and academia, simulation of supply chains has not been treated with much frequency, perhaps because of the complexity of such systems. Few works have actually tried to simulate a whole supply chain – the interaction among stages, distribution or logistics heuristics, overall inventory management and associated costs, bullwhip effect, and service levels, for instance.

This paper presented a new way to analyze all of this through simulation models, which break down the system's complexity on different hierarchical levels. Hierarchical levels facilitate the modeling and the supply chain analysis. Three levels compose the proposed SC model. The overall chain is done at the first level. At the second level, the overall suppliers, manufacturers (only one was considered in the experimental model), retailers and consumer market. At the third level, specific functions for some of these models were implemented, like the product ordering, manufacturing processes, and customer demand patterns.

As suggestions and goals from this point of the project, more detailed modeling of the several components and hierarchical levels are needed (perhaps more then three levels will exist). A clearer definition of performance measures needs to be defined, along with the parameters to be used to calculate these measures. Besides inventory, production and service levels, it is also suggested the inclusion of costs and due-dates. Certainly, a strategy that groups orders and deliveries must be included in the model. The ARENA software allows for the creation of templates. This project also comprises the development of a supply chain simulation template. This will greatly facilitate the development of other models by decision-makers, especially in industrial environments. Lastly, more complex supply chains should be considered, having, for instance, six stages (the fours stages proposed plus distributors, wholesalers, or supplier's suppliers, for instance.)

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