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A CONCEPTUAL MODEL FOR THE CREATION OF SUPPLY CHAIN SIMULATION MODELS

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ABSTRACT

This paper presents the development of conceptual models that can be used in the creation of certain types of supply chain simulation projects. The supply chain considered is composed of four elements: suppliers, manufacturer, retailers, and the consumer market. The presented ideas can be used in supply chain simulation projects, which objective can be, for instance, to study the bullwhip effect or new collaboration practices. ARENA simulation models using the conceptual models presented are currently under development.

1 INTRODUCTION

In the past two decades, there have been a lot of changes to production systems. The globalization of economy, inciting stronger competition, and technological innovation proposing new ways of manufacturing and communication have pushed companies to reconsider their production structure. Capitalism is molding itself along the course of time, suffering conjuncture transformations and defining new productive paradigms. Where before there was confrontation between capital and labor, today rises the participative administration given by the importance of all in the corporation and from all corporations involved in the production supply chain. Where before there was pressure because of high customs barriers, limiting competition and consequently administrating prices in terms of desired profit margins, today there is the need to reach the greatest number of markets, both in the search for suppliers as well as for new consumer markets. Currently, the fixed cost is diluted with the increase of production and sales, the physical frontiers between countries are ruptured in search of the consumer wherever he is, consequently forcing a greater competition among companies and generating a lower market price for products or services. Companies must hence adapt their cost structures or be prone to failure (Tubino 2000).

Giving continuity to the evolution of productive sectors and the increasing competitive level, one may say that today there is no existence of competition among companies, simply, but a competition among supply chains. This again leads to the conclusion that good supply chain management will define who will stay and who will leave the market (Martins & Laugeni, 2002).

A common problem to those who deal with supply chain management is the so-called Forester effect (or bullwhip effect). According to (Lee, Padmanabhan, & Whang, 1997), this effect occurs when there is a lack of coordination among the elements of the supply chain at the moment when there is a variation in the quantity demanded by the final client, with the reactions of suppliers tending to be amplified at each passage upstream through the chain. All of them react increasing or diminishing the orders differently from what is really necessary, seeking to protect themselves. For long chains, the results may be extremely negative, for distortions, in the client to supplier direction accumulate, amplifying in a non-linear way. This effect is caused by the lack of an adequate and coherent supply chain management as a whole. Each link in a traditional arrangement, looks only to the demand generated by its the immediate client and seeks to maximize the financial performance, even though for such, the performance of other links is strongly deteriorated, which will affect the performance of the chain to the eyes of the only link that injects money and sustains the network: the final customer.

According to Chopra & Meindl (2001), the lack of coordination felt mainly by the Forester effect is caused by two reasons: the different stages of the supply chain has conflicting objectives, and the information sent among the different stages suffers delays and distortions.

Collaborative management envisages the reduction of negative consequences of the bullwhip effect or the lack of coordination in supply chains. It can be said that the main objective of collaborative management is to obtain, by means of shared planning, a greater precision in sales forecasts and replenishment for all in the chain (not for one or two chain members). As a result, it is possible to decrease the inventory along the supply chain and obtain better service levels that in turn tend to result in sales increases and cost reductions (Skjoett-Larsen, Thernoe, & Andresen, 2003).

The implementation of collaborative management techniques should be adequately analyzed, since besides the high investments necessary, there should be a change of behavior of the companies and employees involved. A tool that may help managers in the administration and also in the analysis of new strategies is computer simulation. According to Colmanetti (2001), a simulation project enables, among other possibilities, that an analysis be made of a system that is still inexistent, obtaining important information for the objective of the study being performed. This is done by means of the construction of a logical mathematical model that satisfactorily represents the real system. Especially when referring to supply chains management, simulation can bring benefits when used to the pre-analysis of implementation of new management techniques.

One may say that the development of a basic model for supply chain simulation, which takes into account the main variables and characteristics involved in this type of system, would be interesting for those requiring methods for the analysis of supply chains. The objective of this paper is then to show the development of a conceptual model that may be used in projects of discrete simulation of supply chains. This model considers four stage supply chains, and takes into account variables and characteristics such as random demand, production and delivery lead times, material restrictions and material requirements, safety stocks, optimum production levels and inter-relations between different corporations.

This work is organized in the following manner: besides this Introductory Section, Section 2 presents a rapid overview on simulation of supply chains. Section 3 describes the conceptual model developed, and the last section presents some final thoughts about the project presented.

2 A BRIEF REVIEW OF SC SIMULATION

Specialists in manufacture technology recognize the importance of simulation. Modeling and simulation of systems have been identified as the two great discoveries that will accelerate the resolution of great challenges to be found by manufacture industries in 2020 (Bansal, 2002). A simulation study enables among other possibilities, to perform the analysis of a system which is not yet existent, obtaining important information for the objective of the study performed. This is done by the preparation of a logical mathematical model that represents the real system in a satisfactory form. Colmanetti (2001)

According to Retzlaff-Roberts & Nichols (1997), simulation offers an effective analytical tool for organizations that need to measure the performance of a cycle time in the environment of supply chains. Due to the complexity of many supply chains, one may say that a simulation model is one of the few tools that can capture the dynamic nature of a system in a realistic manner. For Pedgen, Shannon, & Sadowski (1995), simulation is the process of projecting a computer model of a real system and conducting experiments with this model with the purpose of understanding its behavior and/or evaluating strategies for its operation.

In this way, simulation models of supply chains may be used to study several processes that may comprise factories, distribution centers, and transport systems, among others (Miller & Pegden 2000).

In these models, individual plans are modeled as being units of restricted production capacities, or, these are simplified, for the purpose is to check how these perform in the supply chains as a whole.

Supply chain simulation can be understood as a process of creating a supply chain model and testing it until finding an acceptable configuration, as being a dynamic process (Chwif & Barreto,2002).

Supply chain simulation is used in decision taking in the case of implementing a new supply chain, or for performing modifications to existing chains. These changes may be classified in two categories: Structural and Operational. Structural decisions affect the supply chain in long terms; however, operational decisions affect the supply chain in short terms. Simulation may be used as a tool to assist decision taking in both cases (Pundoor, 2001).

The greatest difficulty for creation of a simulation model for the supply chain is the level of detailing of each part of the chain that will be modeled, and which, in turn depends on the objectives desired to be reached. The aspects that influence, direct or indirectly, the measures of performance should be included in the model. The process of selection of factors to be modeled and the level of detail of each one of them is defined as an abstraction process. The purpose of the abstraction process is to capture the essence of a real system and use it in the simulation model. It can be said that this step is the “art” in the science of simulation (Jain *et al.*, 2001).

Thus, it can be said that simulation seeks to model a system or process, giving support to decision taking that enables the reduction of risks and costs involved in a process, being a tool for optimization of a process. It is also important to model the interaction precisely among the various participants, the planning of both and performance of activities should be considered. The typical activities include the management of stock, production and delivery of final products. The performance of each participant of the supply chain has impact on the performance of all other participants. Hence the importance in coordinating the actions of the various participants of the supply chain.

More and more, simulation is being accepted and becoming part of the day-to-day of analysts, being looked upon as a technique to verify and provide solutions to problems encountered in the most diverse industrial segments.

Some advantages in using simulation in supply chains, according to Maria (1997), Pedgen, Shannon, & Sadowski (1995), Banks, *et al*., (2002), and Chang & Makatsoris (2001), are:

- Simulation assists the understanding of the entire process and characteristics of the supply chain by means of graphics and charts.
- Capacity to capture data for analysis: users may model unexpected events in certain areas and understand the impact of these to the supply chain.
- Can diminish drastically the risk inherent to changes in planning: users may test several alternatives before making the change to planning.
- Investigate the impact of changes due to a greater demand for components of the supply chain.
- Investigate the impact of some innovations within the supply chain, of eliminating an existing infrastructure or adding a new one within the supply chain; of strategic operational changes to the supply chain, such as process, location and use of new facilities, the fusion of two supply chains or the impact of the separation of some components of the supply chain, and of manufacturing products inside the company, and also of the impact of creating new suppliers or subcontracting some processes.
- Investigate relations between suppliers and other components of the supply chains to rationalize the number and size of order lots, using as a basis the total of costs, quality, flexibility and responsibilities.
- Investigate opportunities to diminish the varieties of product components and standardize them throughout the supply chains.

As all techniques, simulation also has disadvantages. Among them one can mention:

- A good simulation model may become expensive and take several months to develop, especially when the data is difficult to obtain;
- Simulation results are often difficult to interpret. Since models attempt to capture the variability of systems, it is common to find difficulties in determining when an observation found during an execution is due to any significant relation in the system or to random processes built in the model (Pedgen, Shannon, & Sadowski (1995).

3 THE PROPOSED CONCEPTUAL MODEL

The supply chain adopted in this study considers for stages: suppliers, manufacturers, retailers, and the consumer market. The structure for the conceptual model proposed for this type of chain 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 levels.

The first version for the proposed models 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 1. This is the structure proposed by Vieira (2004):

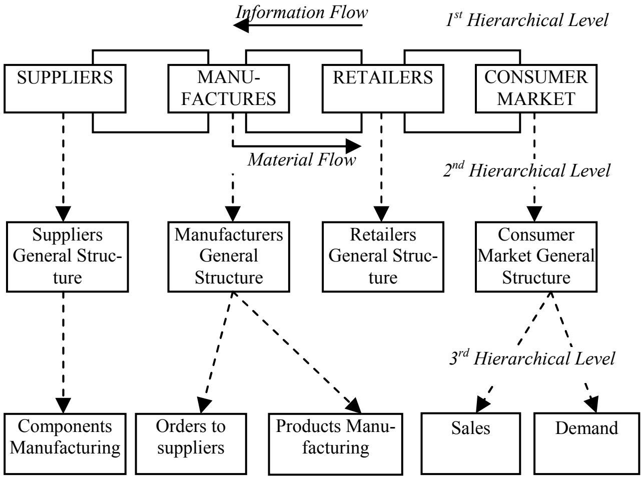

Figure 1: SC General Modeling Structure (Vieira, 2004)

The inventory control policy is simple. Following the illustration presented by Slack, Chambers, & Johnston (2001), a stage assumes that next period's demand will equal the current period's. For this, each SC element will try to maintain ending inventory equal to the current period's demand. Assuming that the period's (accumulated) demand for an SC element is of size "q", the element will place an order of size "2q" for its predecessor stage. This will allow the SC element to meet current period's demand (q) and also maintain *q* units as inventory to meet next period's demand, expected to be of size *q*. (Slack, Chambers, & Johnston (2001) use this concept to illustrate the bullwhip effect.)

The inventory control police could however be more sophisticated. 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. In a more precise model, 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).

The developed conceptual models considered some simplifications, as those proposed by Slack, Chambers, & Johnston (2001):

- It does not consider any lead time between the demand occurrence and the transmission to its supplier;
- It does not consider minimum purchase lot, that is, whatever the order size is, it is placed, independent of its cost;
- Minimum production lot size is not considered, that is, whatever the lot quantity is, it is manufactured, independent of cost;
- The conceptual model is not taking into consideration some internal operation functions such as forecasting, shop-floor scheduling/planning, capacity planning, etc.

3.1 Performance Measures

Several indicators can be used to measure the performance of supply chains. The proposed conceptual model can in particular consider and suggest the use of three of them:

Cycle time between retailer and manufacturer. This measures the time, in hours or days, between a retailer's order and the product's arrival, sent by the manufacturer. This indicator is particularly interesting to show that SC collaborative management can reduce the time to serve the consumer, since this is an indicator that increases due to the bullwhip effect – another phenomena that can be analyzed through computer simulation models.

Variation on the production or order levels at the supplier's site. This measures the variations in the production of ordering sizes at or to the supplier. One calculates the average production level and the standard deviation. This indicator can tell, for instance, how collaborative can reduce this variation at the supplier's site, since it is at the last upstream stage of the SC that the bullwhip effect has the strongest negative impacts.

Variation in the total average inventory in the supply chain. This measures the total inventory kept on the whole supply chain, that is, the sum of the averages of the following inventories: end products at the retailer's site, end products at the manufacturers', and components at the manufacturers' and at the suppliers'. It is the sum of the inventory averages in each time period and calculates its average variation period to period. This performance measure can be used to show how SC collaborative management can reduce the number of total inventory kept through the supply chain – and this is one of the main negative consequences of the Forrest effect. If the, for instance, collaborative management can reduce the total variation of inventory levels through the chain, it will automatically reduce the safety inventory levels that companies often need to consider;

3.2 Hierarchical Levels

As said before, 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.

Next sub-sections describe the conceptual models proposed for each hierarchical level. Each description is made mostly by means of the flowcharts.

3.3 The First Hierarchical Level

Four elements compose the first hierarchical level in the proposed SC simulation conceptual model: suppliers, manufacturers, retailers, and the consumer market. The integration is simplified by information and material (components or products) flows. Capital flow can, however, be included in future works. This is illustrated at Figure 2. The letter in circles are used to detail the models in the following descriptions.

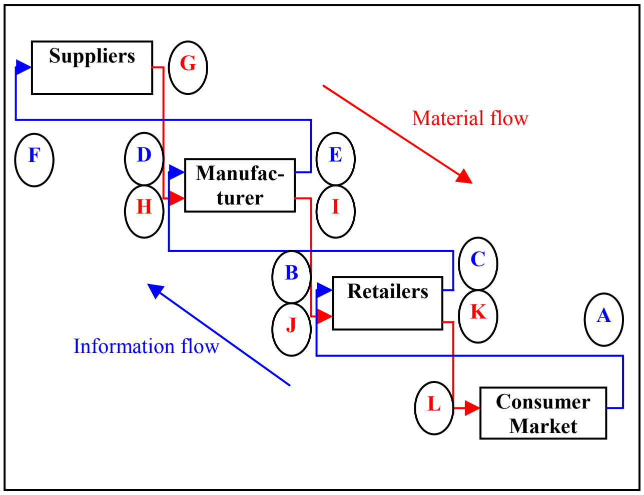

Figure 2: First level in the proposed conceptual model hierarchy

3.4 The Second Hierarchical Level

This level implements the suppliers, the manufacturer, retailers, and the consumer market conceptual models, as explained next.

3.4.1 The Suppliers' Conceptual Model

Figure 3 details the generic conceptual model for the suppliers. The text in the flowchart boxes explain the logic considered.

It is important to know how suppliers, manufacturers, and retailers prepare themselves, period by period. Basically, following the illustration given by Slack, Chambers, & Johnston (2001), each one of these members will assume that the demand for the next time period will be equal to the last demand occurred, therefore, they will always place and order to their SC predecessor member that has twice its since, to attend current order and also prepare themselves to the following period, again, assuming its coming demand will be equal to the last one.

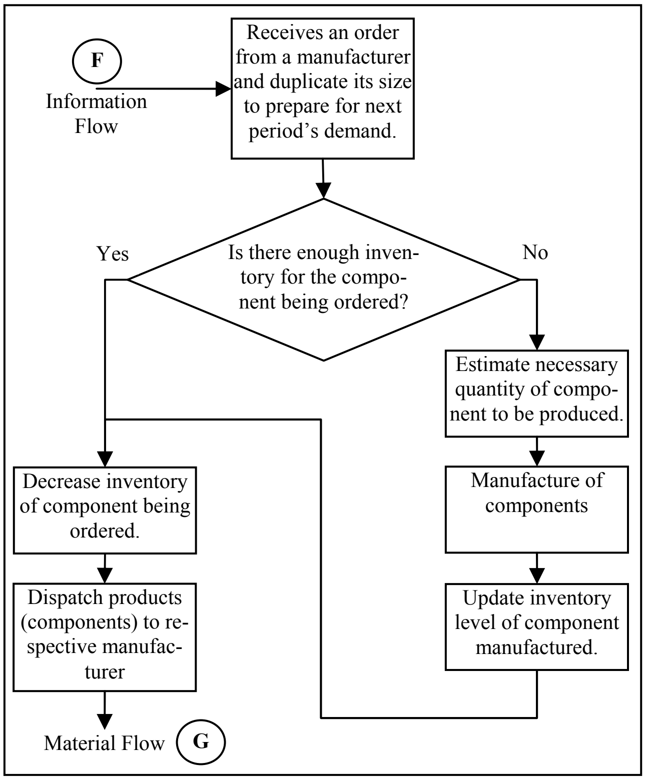

Figure 3: Suppliers' conceptual model.

In the first text box, an order (*o*) of size (*q*) for component (*c*) is made by a manufacturer (m) to a supplier (*s*). This value (*q*) is duplicated, that is, following Slack, Chambers, & Johnston (2001), the supplier will imagine that next period's demand will equal *q* and it anticipate its production. This will guarantee that the inventory at the end of the current period will be equal to the last order size (*q*).

In the next decision box, inventory should be checked to see if there is enough inventory of the component being ordered. This means, the inventory of c is at least *2q*. If so, the needed quantity is taken from the inventory and dispatched to the appropriate manufacturer. The remaining inventory will be saved for the next period. If there is not enough inventory of *c*, the system should calculate the necessary quantity of *c* to be produced, so that the current order and the expected demand for the next period can be met. Production takes place and, after it is done, the inventory of the component should be updated. The logic then goes back to fulfilling the order and dispatching it to the manufacturer.

3.4.2 The Manufacturer's Conceptual Model

Figure 4 details the generic conceptual model of the manufacturer.

The manufacturer receives orders from retailers for the products it makes. Upon the arrival of a retailer's order, the manufacturer duplicate its size, preparing for next period's demand. Again, this is used to guarantee that the inventory in the end of the current period will equal the last period's demand. Inventory should then be checked to verify is there is enough of product being ordered, for both current and next periods' demands (i.e., *2q*). If so, product inventory is decreased from the quantity being ordered and the remaining inventory is kept for the next period's demand. If there is not inventory to meet both current and next periods' demands, it should be checked if at least the current period's demand can be met. If so, the order can be met immediately. At the same time (and also if there is not enough inventory to meet current period's demand), it should then be calculated the quantity needed for the product. Since a product is made of components and following the company's product bill-of-material, the quantity for each component making the end product should be calculated. This will be used to verify if components should be ordered to suppliers and to trigger the manufacture of products, M and N flows, respectively (Figure 4). Figures 7 and 8 detail each one of these procedures.

Once components have been ordered to suppliers (if needed) and products were manufactured, the logic flow returns to the manufacturer conceptual model logic (letter K). Inventory should be decrease of the retailer's order quantity places and products should be dispatched to the retailer.

When components sent by suppliers get to the manufacturer (letter H), corresponding component inventory level is updated and a signal is sent to production stating that material is available for manufacturing, in case the sector has any production order waiting for the arrival of components.

3.4.3 The Retailers' Conceptual Model

Figure 5 shows the generic retailers' conceptual model. It is, in fact, similar to the manufacturer's conceptual model, except for the product manufacturing and components ordering procedures.

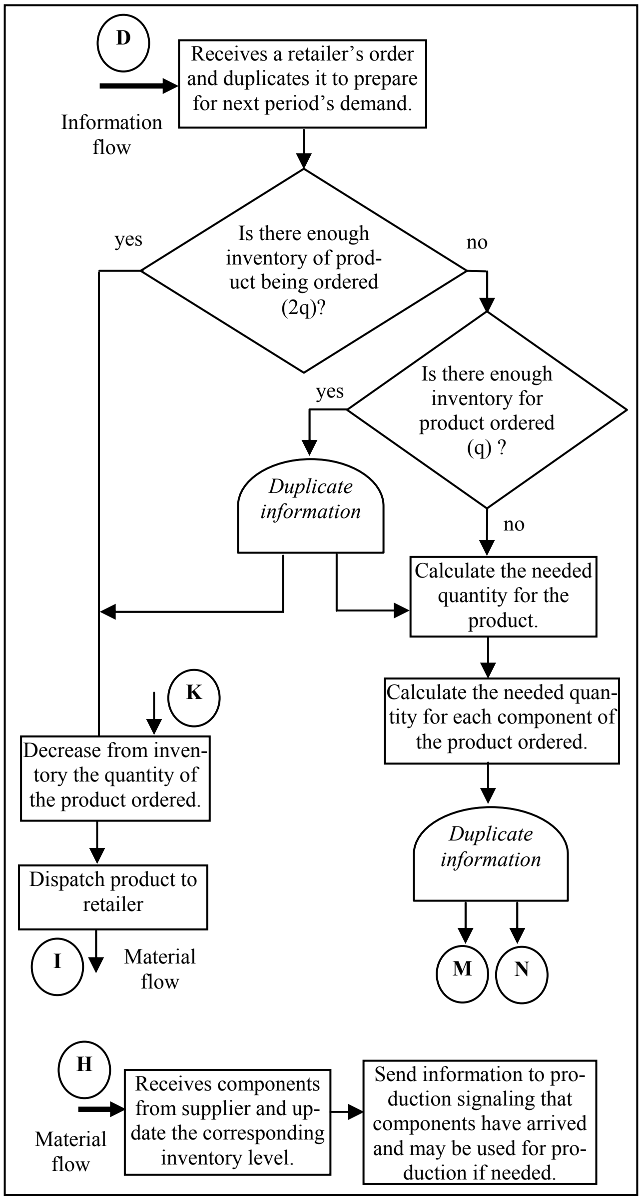

Figure 4: Manufacturer's conceptual model.

A retailer receives orders from the consumer market for a product it sells. Upon the arrival of an order, the retailer duplicate its size, preparing for next period's demand. Again, this is used to guarantee that the inventory in the end of the current period will equal the last period's demand. Inventory should then be checked to verify is there is enough of product being ordered, for both current and next periods' demands (i.e., *2q*). If so, product inventory is decreased from the quantity being ordered and the remaining inventory is kept for the next period's demand. If there is not inventory to meet both current and next periods' demands, it should be checked if at least the current period's demand can be met. If so, the order can be met immediately. In this case, information about the order placed is doubled. A copy is used to dispatch the order to the market, while the other copy is used to calculate the quantity needed for the product. The retailer will then place and order to the manufacturer.

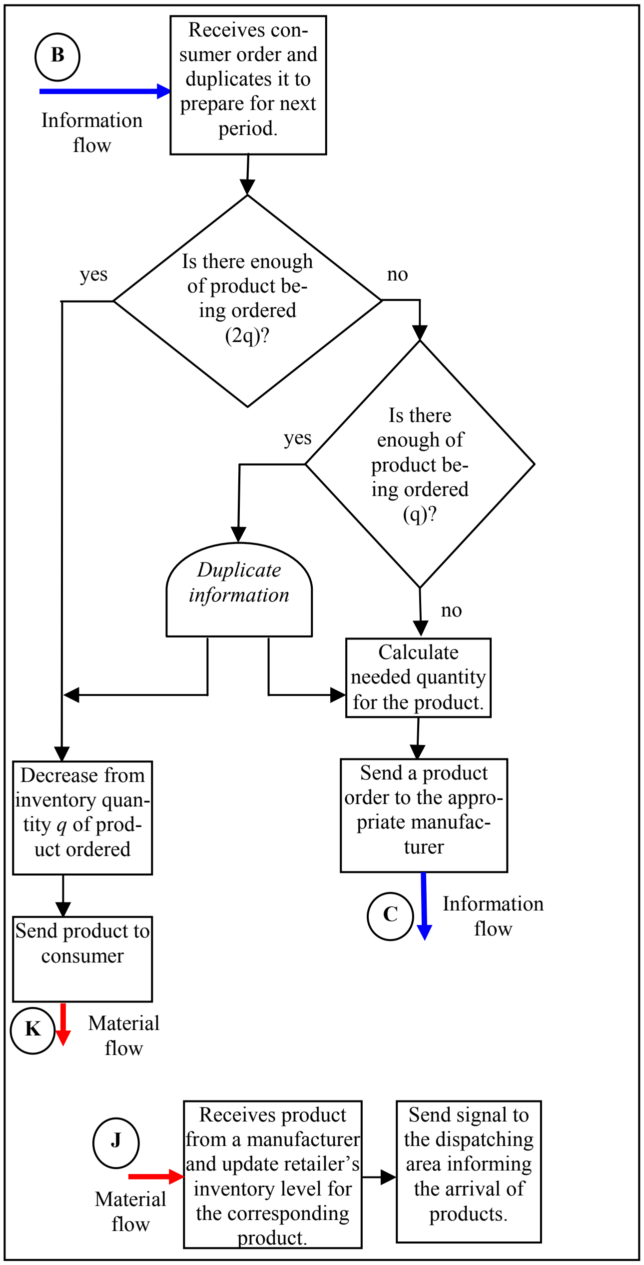

Figure 5: Retailers' conceptual model.

At Figure 5, the letter entry "J" point refers to the area where products are received from the manufacturer. As products get in the retailer's site, inventory for the corresponding product should be updated and a signal should be launched to the dispatching areas in case there are open consumer orders, that is, customers' order not yet delivered.

3.4.4 The Consumer Market Conceptual Model

Figure 6 details the generic consumer market conceptual model. Through this model, the market places orders to retailers. An order should include information regarding the product type, quantity, and the retailer to receive it. Other information will regard the demand pattern or behavior. This can be taken directly from a text file, following a demand forecast or historical data, or it can be represented by a distribution function.

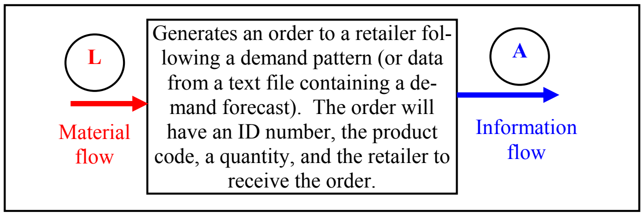

Figure 6: Consumer market conceptual model

3.5 The Third Hierarchical Level

The third level is used to detail some of the functions of the manufacturer, specifically, the ordering and fabrication procedures, as explained next.

3.5.1 Manufacturer's Components Ordering Procedure Conceptual Model

Figure 7 details the manufacturer's components ordering procedure conceptual model. In the first module, the inventory for all needed components to manufacturer the product ordered are checked. If there are enough inventory for all the components needed, an estimate of the ending inventory levels for each component is made. An order is issued to a supplier whenever component's inventory level is not enough for the manufacture to trigger a production or the estimated component's stock level falls bellow its safety level. In either case, the appropriate components quantity should be calculated and an order placed. There should be one order for each component for each supplier.

It is important to see that the actual components inventory levels will only be decrease when production is triggered, and this occurs at the manufacturer's product manufacturing area, as shown at the next section.

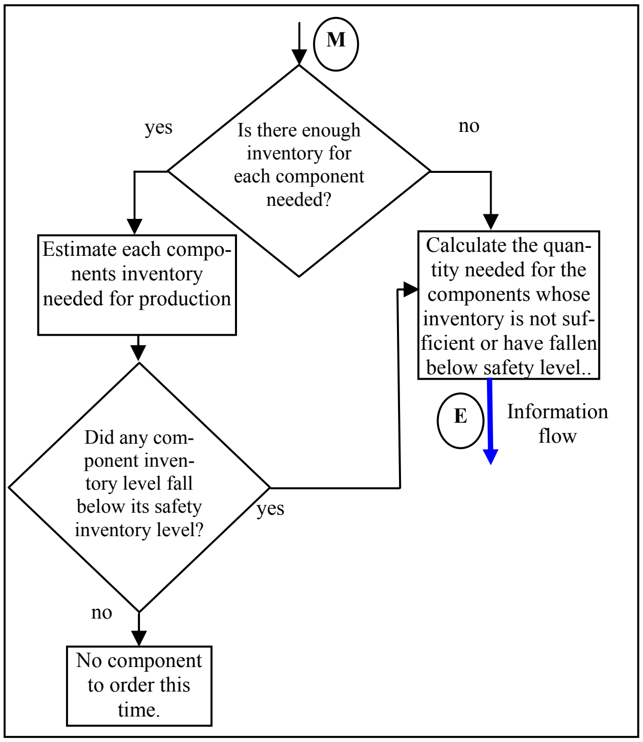

Figure 7: Manufacturer's components ordering procedure conceptual model

3.5.2 Manufacturer's Product Manufacturing Procedure Conceptual Model

Figure 8 depicts the manufacturer's product manufacturing procedure conceptual model. The first block checks for enough inventory of the appropriate inventory. If so, the needed quantity is removed from inventory. Production is then initiated. If inventory is not sufficient to start production, the production order waits for a signal informing that material has arrived at the manufacturer's site.

If there is enough components, manufacture of a product can initiate. When production is done, the end product's inventory level should be updated. The information flow goes back to the manufacture's second hierarchical (letter K).

Specific manufacturing details, like, material flows, layouts, rework, rejection, etc, can be specified at the manufacture product block. Another hierarchical level can then be used for this purpose.

4 SOME FINAL COMMENTS

Improvement of supply chains performance is still a wide area for research and undoubtedly computer simulation tools can be of great help to the modeling and analysis of such systems. This paper presented a conceptual model that can be used by anyone intending to develop supply chain simulation models, independent of the software program he/she uses.

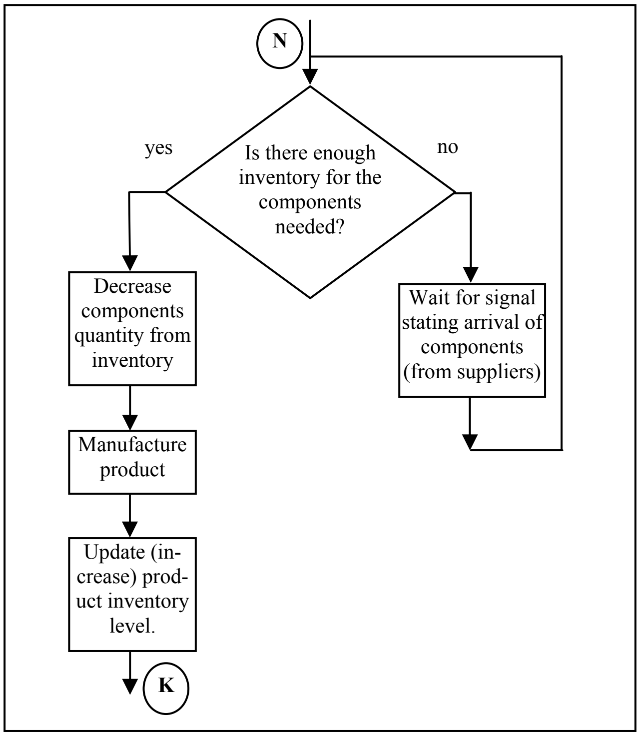

Figure 8: Manufacturer's product manufacturing procedure conceptual model

This work considered supply chains composed of four links (suppliers, manufacturers, retailers, and consumer market) but can easily be expended to more stages, since most of the concepts are common to SC corporations.

Some simplifications were made but several variables and characteristics were taken into consideration, which often are neglected by similar works in this area. Among the most interesting considerations made, the model allows the one to consider minimum inventory levels (safety stock levels), ordering process (with varying quantities), production and delivery lead times, several different types of products - and their respective structure (bill-of-materials), inventory replenishment policies, random demand patterns and demand forecast can be easily modeled, among others. Regarding simplifications, the model is not considering: (a) minimum purchase lot sizes, that is, whatever the order size is, it is placed, independent of its cost; (b) minimum production lot size, that is, whatever the lot quantity is, it is manufactured, independent of cost; and (c) the conceptual model is not taking into consideration some internal operation functions such as forecasting, shop-floor scheduling/planning, capacity planning, although some of them can be included in future projects.

Other suggestions for future works regards the use of simulation studies, using the proposed conceptual models, can be applied to different type of supply chain analysis, such as to study and predict the bullwhip effect, and to test collaboration principles among the supply chain peers. In fact, these studies are currently under investigation by the main author. Analysis of new inventory management policies, to search for new ways to save costs, is also a study to be performed using SC simulation.

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