A Standardized Simulation Model with Strategic Approach for Distribution Networks

A Case Study in Mexico

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***Abstract*— Considering that analytic tools are not completely suitable to analyze supply chain and distribution networks, simulation is considered a better alternative. Some theories about discrete simulation have been suggested, especially those related to the use of standardized models and the use of strategic planning process in simulation. This paper presents a standardized simulation model based on a simulation programming language rather than a graphical simulator, to be used as a decision-making tool for the top management due to its strategic approach. The model is validated in a real business case, where tangible results were achieved.**

Keywords-Simulation; standardized model, distribution network, strategy

I. Introduction

Considering the opportunities that distribution network presents to create value and profits to any organization, specific tools to analyze and improve distribution must be used in today's business environment. Most tools might be classified as analytical tools (those using a closed-form solution based on a mathematical algorithm) or simulation tools [1]

Simulation is considered as a suitable tool because the integration of dynamic and stochastic issues of real life processes is a critical task. Standardized simulation models are those which can be applied to a broad range of systems and, at the same time, they can be adjusted to different scenarios and performance criteria, becoming specific when data for a particular system is loaded [2]. Therefore, a model is suggested, based on a common logic used to evaluate the configuration of a distribution network. This evaluation is focused on a strategic planning approach, using a general purpose simulation programming language.

Any model must be evaluated through specific key performance indicators, which should be similar to the intended use case.

This paper is organized as follows: a literature review about simulation, strategy and supply chain is presented, supporting the proposed idea; then, the methodology used to define a standardized model, including the objectives, logic and specific considerations of the code is described. The validation through a real business case in Mexico is included, and finally, some conclusions and future research are presented.

II. Literature Review

Any organization can been considered as a series of related operations where its assets must be adapted to the actual and future demand, in several levels of aggregation and time horizons [3]; therefore, the supply chain management becomes an integral part of the strategy of the organizations. In particular, the distribution network plays a vital role because successful firms have been supported by competitive advantages related to the optimization between demand and delivery [2]. Reaching flexibility in distribution and evaluating the potential scenarios that can be faced in delivery [4] are also relevant issues in the supply chain.

Another important issue in supply chain deals with the integration of suppliers, producers, warehouses and point of sales. This integration also deals with the manufacturing and distribution of goods or services on time, on the exact amount and in the precise place, considering a minimum cost and a suitable service level [5]. Inventories are also a critical issue affecting the supply chain, and become an even more relevant factor in retail industries [6].

Any supply chain is a stochastic, dynamic and complex system facing a high variability and uncertainty, as well as a disperse configuration [7]. Therefore, it is mandatory to consider strategic decisions and specialized tools to support decision making process [3], focusing in either costs or differentiation [8].

The integration of all the activities within a distribution network provides opportunities in creating value, reducing costs, raising productivity and maximizing profits; however, this integration cannot be evaluated using analytic models [10]. Some analytic models can be used with a limited confidence and within specific constraints in the integration of variability [9], but are not very useful.

Gongtao and Gavirneni [11] have suggested a model to evaluate distribution policies based on Erlang distribution; an analytic model based on a recursive approach to analyze demand, inventories and deliveries, but limited to normal distribution, is presented in Kim et al. [12].

Considering that analytic models cannot accurately represent the real and complex behavior of the supply chain, simulation is considered as a suitable technique to analyze and evaluate it. Simulation provides a deep understanding of the system, as well as experimental ways to support a decision which considers variability [3]. It is important to notice that simulation does not provide an optimum result, but it provides the evaluation of several scenarios and how they affect some specific Key Performance Indicators (KPI), as stated by Fleisch and Tellkamp [13]. Also, the definition of specific and relevant KPI's is also a vital issue.

Some authors have suggested that simulation models based on Systems Dynamics (SD) theory can be used to evaluate strategies related to supply chain [4]. However, these models are focused on continuous behavior, with a high level of details and complex relations, making them more difficult to design, analyze and improve. In Labarthe et al. [9], the use of SD and agent-modeling has been suggested, but under an operational approach. Considering that most of the typical operations in a supply chain occur at specific points of time, the discrete simulation provides a better option to analyze it.

Siebert and Zubanov [14] have used discrete simulation to integrate fluctuations in demand throughout days, weeks and months, but using correlations, hence limiting the stochastic behavior of the model.

Zhang and Zhang [5], have proposed a base model, but restricted to three echelons due to the complexity of the integration of more echelons. Almeder and Preusser [15] have presented a simple simulation model, where a lineal-deterministic algorithm is optimized to prepare input data which is returned to the simulation model; however, this is not a simulation tool per-se, but a hybrid model.

Hafeez et al. [16] propose the decomposition of the supply chain in two echelons, mainly to simplify the model, but they do not provide any arguments to support this idea; they also suggested an inventory approach totalizing the inventory levels across the network, similar to multiechelon theory, without any deep analysis on this issue.

Some authors have proposed the use of standardized simulation models. These models, when used in distribution networks, must be flexible, based on parameters, efficient in computing requirements and repetitive so they can change the position within the network, as suggested by Longo and Mirabelli [17]. Standardized models are based on the idea that there are always some common processes within the distribution network that can be reused [7], and they must be focused on the specific elements of the supply chain that will be considered in the analysis [4]. However, they should consider the complete environment of the system, not restricted to a very limited approach [13].

Standardized simulation models present a challenge because most of the actual software available is highly graphics dependent and based on objects. These characteristics make software easy to use and learn, but implementing some logical processes (e.g., loops or complex conditionals) might be difficult; therefore, external applications or programming-languages must be used to fulfill a standardized model [18]. Simulation programming languages provide an easy way to create a detailed logic; Yang [19] even asseverates that actual software is based on the languages developed in the 60's and 70's and sometimes these old languages are even used to process the logic. As a matter of fact, SLAM [20], GPSS [21] and SIMAN [22] are examples of software that are used today and provide useful results. They are robust and they have been taught in universities, but their market-share is very low today, compared to newest software [19].

Considering that standardized models can be easily applied through the use of simulation programming languages, this paper proposes the design of a simulation model applied to a distribution network through the simulation language SIMNET [23]. This model is tested in a business case focused on health industry because this sector provides opportunities in inventories and continuous improvement [6] and it represents an important component of the gross domestic product [24]. It is also a relevant industry in developing countries [25].

III. PROPOSED MODEL

A standardized simulation model, codified in SIMNET II and under a strategic approach, is proposed in this section.

The model is based on a standard logic between a two-echelon structure of the distribution network, providing a base code. This code should be general enough to become specific with real data, and it must be used in a recursive way to develop the structure of the complete distribution network.

The methodology used in the design of this standard model is based on the analysis of the system and the definition of objectives and indicators; then, the standard logic must be outlined, and the specific characteristics of the model should be included in the structure of the programming code. Then, a process to verify and validate the code should be used, followed by the design of experiments to improve the systems. Finally, conclusions about the results obtained must be discussed.

The characteristics of the suggested model are presented in the following sections.

A. *Objective of the Model and Indicators*

The focus of the model is based on the cost strategy, as stated by Porter [8].

Considering the wide spectrum of decisions facing in SCM, a selection of specific KPI related to cost strategy, must be defined before starting the analysis. Two KPI are proposed:

- The inventory levels and,
- The transportation cost.

The integration of both the inventory levels and transportation costs will be made through a total cost indicator. This indicator will be the sum of the cost of holding inventory, the financial cost and the transportation cost. Some inputs for the model must be processed by analytical means in external tools, and the conjunction of simulation and analytical methods might provide the basis for a future hybrid model, as stated by Shanthikumar and Gargent [26].

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B. Standard logic

Considering the ideas of Pundoor and Hermann [7], the model encompasses some common processes found on most of the inventory and replenishment systems in all major SCM systems. These processes constitute the main logic that is considered in a two-echelon situation, where one supplier and "n" clients are found. The main logic is the following:

a) At the start of each week, the clients, accordingly to their desired maximum inventory level and the on-hand inventory of the last week, place an order to the supplier.

b) The supplier, also accordingly to its desired maximum inventory level, places an order in to his system, and receives his order from the previous week.

c) When the supplier receives his order, his initial inventory position is calculated, adding to the actual inventory level the received order.

d) The clients receive their orders from the supplier, according to one of the following conditions:

- If the supplier's initial inventory level is greater than the sum of all orders received, the clients receive the total amount of pieces requested.
- Otherwise, the clients receive a proportional amount of their order, based on the per cent that each order represent of the sum of all orders requested to the supplier.

g) Orders are transferred from the supplier to the clients, and stock base at the supplier is updated.

h) The initial inventory of the week is updated for each client.

i) A demand is generated for each client, and the final inventory of the week is calculated.

j) The average inventory level of the week is calculated for each client.

k) The units sold for each client are calculated, and if needed, emergency orders are placed to the suppliers to fulfill the complete demand. These emergency orders are supplied from the stock base in the supplier, and if the stock base is not enough to fulfill all emergency orders, they are prorated based on a percentage basis (in this last case, the stock base ends at zero).

l) The average inventory level at the supplier is updated.

This two-echelon logic can be replicated into a series of suppliers-clients structure, where a supplier becomes a client of another supplier, as seen in Fig. 1.

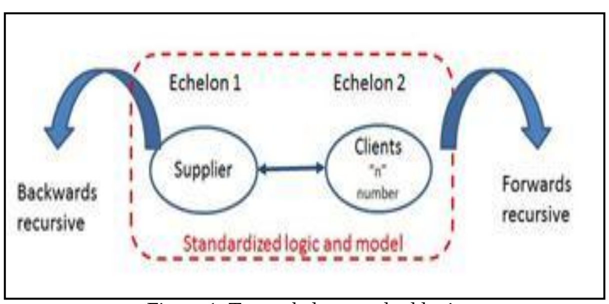

Figure 1. Two-echelon standard logic

However, in order to recreate the structure of a distribution network, the replication should also be used in a parallel framework. For example, a network structure might be based on a Master Distribution Centre (MDC) which serves some Regional Distribution Centres (RDC), and these RDC might serve Regions or Clients. Therefore, the model should start at the end of the network, considering the aggregated demand of the regions, and then move backwards to the MDC in a series of phases, as stated in Fig. 2.

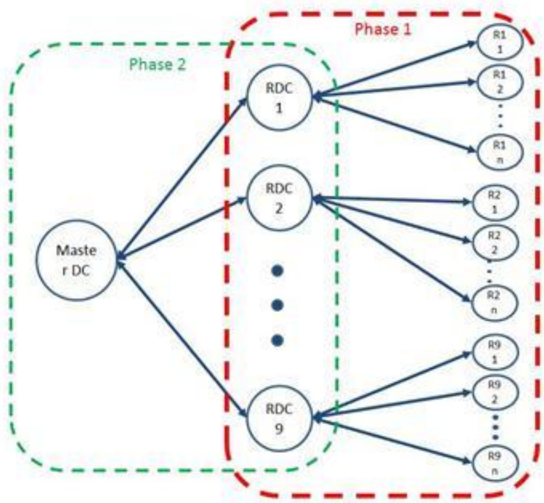

Figure 2. Replication of the standard logic

C. Model characteristics

Some of the opportunities identified in the literature for the usage of simulation in supply chain are included in the model. In particular, the idea to reuse a generic model based on a common logic, as stated by Fordyce et al. [3] and the strategic approach cited by Chang and Makatsoris [27] and by Pundoor and Hermann [7]. The simplification approach to improve the computational performance is also include, as suggested by Longo and Mirabelli [17]. Other characteristics of the model are cited below.

1) Aggregation and strategic approach

Considering the design of a distribution network as a strategic issue, some assumptions must be made. In particular, some operational issues and issues that affect the long term results must be included. For example, all the pieces and products to be demanded must be added into a single aggregated demand, without distinguishing between individual items. This approach allows to be focused in the total items hold in inventory throughout the whole system, and also in the performance of the inventory levels of the complete network.

2) Unitary transportation cost

Distribution network might use different types of vehicles and routes. Therefore a unitary transportation cost for each RDC should be defined.

3) Discrete operation

Because most operations considered in any supply chain occur at specific points of the time, a discrete approach is used. According to this, all variables are considered as observation based ones, even those typically considered as time based variables (computational rules have been defined to provide this conversion).

Strategic issues also provides a justification to this conversion because the detailed behavior of the inventory level is not required, due to the aggregate approach of the analysis.

The model is based on a single control entity that flows through the code and executes each of the logic steps previously defined.

All the previous characteristics also supports the foundation of a simulation model that is completely integrated and do not require connection to external data. Another benefit of this model is the fast execution because memory allocation of observation based variables is considerable lower than time based ones.

4) Time framework

Considering that the focus of the analysis is the entire cycle of operations based on a discrete time scope, the model uses a non-temporal time framework. Therefore, the case to be analyzed might be based on a week, a month or a day, depending on the desired simulation analysis.

5) Simulation software

The standard logic must deal with several conditionals, mathematical operations and loops between some relations supplier-clients. Therefore a straightforward way to carry out the model is required, in both serial and parallel operations. Most graphical simulators available (e.g., Arena, ProcessModel, Simio) provide an easy-of-use environment, but cannot deal with loops and conditionals in a simple way.

A simulation programming language is not as friendly as a graphical simulator, but it provides several important advantages:

- Additional flexibility,
- Allows a self-contained code,
- All logic, operations, calculations and data exchange can work in an integrated way within the model,
- Easy debugging and,
- The model can run faster.

The proposed model is developed using SIMNET II, a simulation programming language owed to Dr. Hamdy Taha. SIMNET II is based on the use of four special nodes linked by branches. The nodes used in SIMNET II are:

- A source where entities arriving into the model are created,
- A queue which serves to house waiting entities,
- A facility, where service is performed and,
- An auxiliary, which is a special node with infinite capacity providing additional flexibility to the simulation.

Branches connect the nodes and control the flow of entities. During the running of the model, branches can perform logic and several operations, including special routing of entities, evaluation of conditionals, execution of loops (for—next and do-while), evaluation and assignments of control variables, collection of statistical variables or exporting/importing data.

A specific characteristic of SIMNET II is the use of the so-called PROCEDURES. These structures deal with the modeling of repetitive segments in a compact and efficient way, and can be considered as the foundations of a standard model, considering a logic that can be automatically replicated both in series or parallel, thus adding flexibility in reusing code. Through the use of procedures, the complete distribution network can be analyzed in small parts or in the whole, starting at the downstream of the supply chain and continuing upstream, just defining the appropriate input data.

IV. VALIDATION OF THE MODEL

In order to test the standardized model, a business case is used involving a Mexican company which runs a network of about 2000 drugstores in the whole country (about 25% own and 75% franchisees), and under the specific conditions of this firm.

The distribution network is based on one MDC serving nine RDC, each one serving specific geographical areas of the country (mainly complete States). Each State, and its complete number of drugstores included, is considered a "region".

This firm has its own-laboratory which produces most of the drugs and products to be sold. This laboratory is located next to the MDC, the only facility to which it serves, and there is no distribution cost to the MDC. The rest of the drugs and products are supplied by independent and external laboratories, which directly deliver to each of the RDC. The transportation cost of these products is carried out by the suppliers and included in the unitary cost to be paid by the company.

Each RDC directly serves and deliver products to own-stores, local warehouses and big franchisees. Due to the reduced amount of purchases, small and medium size franchisees are treated as final customers.

A graphical representation of the distribution network of this company is presented in Fig. 3:

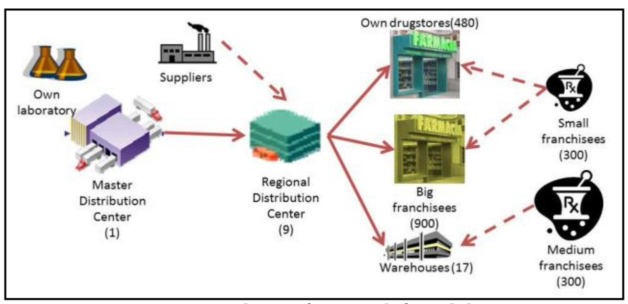

Figure 3. Distribution framework for validation

A special case is presented by small and medium size franchisees. As long as they are treated as customers, they must pick-up merchandise at specific drugstores or warehouses. Therefore they do not affect the distribution cost of the total network.

The distribution is made through an external delivery company, serving the whole network by trucks, and some

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areas by ferry. The routes are defined by each RDC and the process of putting orders and delivering products is made only once per week, with delivery time being less than three days (with average of two days in the complete network). A specific methodology to define a unitary transportation cost for each RDC is defined, regardless of the vehicle and route.

A periodic review system is used for the inventory control, based on a period of one week. The order-up-to-level approach is also employed, and the maximum level of inventory desired is based on a heuristically philosophy of 30 days of sales. Of course, this system produces a high level of inventory, but also provides a fill rate of 99.9%

The model is run to resemble the actual distribution network, under a steady state analysis with a 95% of confidence interval.

Considering the two KPI defined in section 2, the results of the model versus the historical data are within the 5% error-tolerance. Because numerical data of the company are confidential, comparisons are made using percentages, where 100% represents the historical data.

The inventory levels of each RDC and the complete network can be seen in Fig. 4, where an overall difference of about 2.7% can be found.

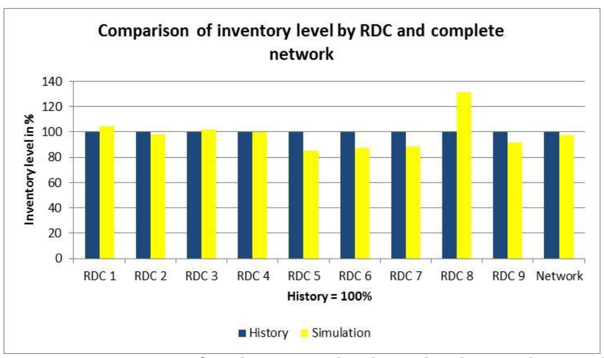

Figure 4. Comparison of total inventory level simulated versus historical data for each RDC and total network

There is one significant difference for RDC number eight in the previous figure. This is caused because this specific RDC was recently open and no enough data are available.

The distribution cost comparison is presented in Fig. 5, where the overall difference is about 3.2%.

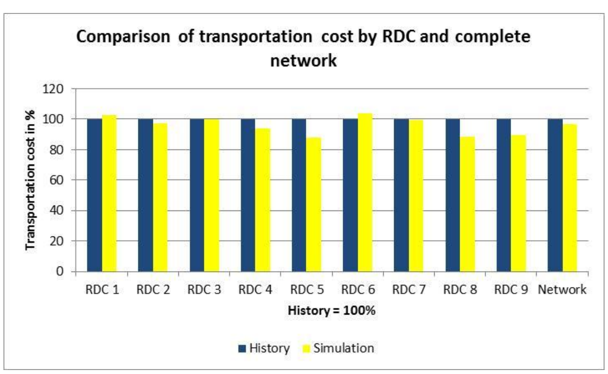

Figure 5. Comparison of total distribution cost simulated versus historical data for each RDC and total network

The analysis has demonstrated that the simulation model is valid and it resembles the actual behavior of the real system within the desired tolerances.

V. CONCLUSIONS AND FUTURE WORK

Considering that the maximum error found on the total inventory level is 2.7% versus the historical data, and deviation in the total transportation cost is only 3.2%, the standardized simulation model works properly and presents a reasonable precision on the assumed confidence interval.

The computational power needed to compile this model is minimum, due to the use of a simulation language versus a graphical simulator.

It has been demonstrated that the standard logic defined in this paper can be used as a base case for distribution network under similar conditions, and might be adjusted with minimum changes to other scenarios. Furthermore, the flexibility provided by the simulation language SIMNET II and its procedures have provided the fundamental bases for a standardized model.

A future research or application of the model might be its use as a decision tool to support the reconfiguration of the actual distribution network. Strategic issues, like evaluation of effects due to open, close and/or merge RDC, or reassignment of regions to each RDC, can be easily carried out in the simulation model, and multiple scenarios could provide a framework to define a new network.

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