Integrated Distribution Network Design through Simulation

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AMO and SOCM designed the study, developed the simulation model, performed analysis of results and wrote the first draft of the manuscript. Authors DSP and PCO revised the technical aspects of the simulation model, the obtained results and the first draft to approve the final version of the manuscript.

Original Research Article

ABSTRACT

Simulation is important to validate quick-response scenarios, providing an extent on how technology can effectively upgrade a process. Thus, computer simulation is a crucial aspect for supply chain management. The present paper analyses a distribution problem which involves inventory supply planning. Then, a simulation model was developed to evaluate its current performance and to provide a better operation scheme. The advances of this work extend on the modelling and simulation of distribution networks that must comply with retailers' demands at end points.

Keywords: Distribution networks; computer simulation; arena; inventory management; supply chain.

1. INTRODUCTION

Modeling uses virtual elements to simulate conditions. Applied into engineering, it offers the opportunity to design a sequence of events that equal real life scenarios which help test and validate specifications for troubleshooting or decision-making. The importance of Simulation

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comes hand-to-hand with multidisciplinary systems where optimal system execution is pursued, significantly shortening design costs while providing immediate feedback on decisions, alternatives and performance of each individual component. During design both, simulation language knowledge and logic processing, is important to accurately describe non-linear processes and hybrid continuous-discrete events, through the collaboration with multi-disciplinary specialist groups [1].

Through the years, a variety of simulation languages and software have been developed, although only a few seem adequate for multi-disciplinary systems. The first ones were based on CSSL (Continuous System Simulation Language) and offered low-level answers in terms of differential equations. Then, these were evolved into two main branches: declarative (equation-based) modeling and object-oriented modeling [1] which led to distinguish two categories for system modeling: continuous systems (who vary continuously in time), and discrete systems (who vary in discrete times) and which can be either deterministic or stochastic, static or dynamic [2].

Deterministic modeling produces a unique set of results given a set of inputs, and stochastic modeling considers probability, hence results are an estimate of the real scenarios. Since randomness is the base of stochastic modeling, it should be considered through modeling too. Furthermore, when talking about static or dynamic modeling, time variability and its impact on system performance must be considered as dynamic modeling depends on time variability, while static modeling does not. Discrete event simulation allows the representation and study of physical system behavior and it is built on two main blocks: objects and events. The objects represent the physically real objects (entities), meanwhile the events have two possible functions: they either modify the state of an object, or schedule future events. Simulations can be either sequential (an activity list in timing cycles) or parallel (multiple processing nodes) [2]. In our case, it is applied into a supply chain representation.

A supply chain (SC) is defined as a system which includes material suppliers, production facilities, distribution services and customer linked together via the feed forward flow of materials and the feedback flow of information. In this aspect, supply chain management (SCM) goes further than logistics by integrating all aspects of business and their capabilities, executing research and development, and supporting internal and external functions in product processes. Its main purpose is to minimize the probability of inventory stockout, distribution failure, and over production of goods [3].

Overall, when just-in-time (JIT) was proposed, stock keeping tendency consisted into eliminating warehousing, since it was understood that inventory added no value to the product or business. Later, new trends proved that warehouses and distribution centers add value into SC and customer service by facilitating inventory availability, returns and customization. Additionally, the proximity of these to customers, and internal short turnarounds and transportation, helped to establish a physical presence in the market and reduce inventory and times by shipping in smaller quantities more frequently or serving as consolidation points that assembly or accumulate small shipments into bigger ones [4]. Consolidation centers are understood as locations where products are transshipped and stored, with small loads entering and bigger loads exiting, and they can exist on road, ports, airports or rail terminals [5]. Here is when computer simulation represents a problem-solving tool, developed to analyze and study the practical implications of assumptions into system's complexity, qualification and validation, particularly when facing stochastic demands [6].

A step further to overtake stochastic demand is known as a quick response method (QRM). Its foundation is on the use of speed to gain competitive advantage by seeking lead time reduction in all operations. QRM is applicable externally by reacting to customer's need rapidly and internally in terms of organizational significance and lead time reduction, for it espouses a relentless emphasis on lead time reduction that has a long-term impact on every aspect of a company [7]. QRM might become a crucial factor in competitiveness improvement because it makes the entire chain directly dependent on market expectations, warranting a better client service, stock reduction and reduction on forecasting errors. QRM aims to speed up information flow through each link on the system by sharing sales, purchase orders and stock information through all entities on the chain. By doing this, JIT principles are spread through the supply and operative chain, substituting inventory with information, and reducing oscillations on the final demand [8].

According to Tyler and Al- Zubaidi [6], multiple benefits can be attained from QRM implementation, such as:

- Increased sales volumes;
- Reduced mark-downs;
- Reduced stock-outs;
- Reduced costs and prices;
- Greater price validity at retail and improved financial performance and increased competitiveness with overseas suppliers.

However, despite benefits, industry has been slow when putting QRM in practice due to the following reasons:

- The length of time needed for the development of truly trusting partnerships within the pipeline (including sharing the financial benefits of QRM);
- The difficulty and cost of assessing specific store and product-line rewards;
- The considerable cost and risk of installing QRM procedures;
- A lack of understanding of how best to manipulate point-of-sale (POS) data.

A way to approach QRM is through a stochastic inventory control model. In this case, a continuous review model is appropriate. In general, this approach is expressed as:

$$Q_0 = \sqrt{\frac{2DCo}{Ch}} \tag{1}$$

$$A = 1 - \frac{Q_0\, Ch}{pD} \tag{2}$$

$$z = \Phi^{-1}(A) \tag{3}$$

$$R_1 = \mu_{LT} + z\sigma_{LT} \tag{4}$$

$$n(R_1) = \sigma_{LT}L(z) \tag{5}$$

$$Q_1 = \sqrt{\frac{2D[Co + pn\,(R_1)]}{Ch}} \tag{6}$$

Where:

Q = Lot size to be ordered to reduce stockout and replenishment costs.
R = Reorder point.
D = Cumulative demand
C_o = Order Cost per lot
C_h = Holding Cost per unit
p = Non-supplied unit cost
σ_{LT} = Standard deviation during lead time
μ_{LT} = Mean demand during lead time

$n(R_1)$ = Estimated non-supplied units
$L(z)$ = Loss function.

Re-calculation of Q and R should iterate until no significate change (less than 1–5%) is observed in R [9]. If properly applied, simulation conjoined with QRM offers a glance into current guidelines that can be shaped into upgrades, obtaining the most benefit of ordering, lead-time, and good client service, without most of risk associated costs and system changes, while still applicable to all SC elements, and being handy for industrial engineers and SC managers through decision-making and cost balancing.

However, by itself, modeling will not guarantee a 100% assurance of reality replication. Designers, users and decision makers who utilize simulation are constantly concerned by the results and their credibility. This concern is addressed by verification and validation. Verification is defined as ensuring that the computer program of the computerized model and its implementation are correct, while validation is meant to be understood as the substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model. Put differently, the validity of a model is based on its outputs and if these are within an acceptable range (accuracy required) that should be previously specified to model development. If working with random variables, then means and variances are usually used for determining the validity of a model [10].

Supplementary, there is also model accreditation and model credibility. A model is accredited when it satisfies specified model accreditation criteria according to a specified process, while model credibility is concerned with developing in (potential) users the confidence they require in order to use a model and in the information derived from that model. In all cases, a model shall be created for a specific reason and its validity based on that same reason, given that a same model might be inadequate for other applications [10].

Regularly, different versions of a same model are conceived before obtaining the adequate, verified and valid one. Consequently, verification and validity are to be considered as part of model construction process. Hence, first a conceptual model is born along its conceptual model validation, and this process is repeated until a suitable conceptual model is found. Then, a

computerized model is designed from the conceptual model, in addition to its computerized verification, which will be run until satisfactory convergence is achieved. Once satisfactory, validation of the computerized model results takes place. If any changes on the conceptual or computerized models are needed, then verification and validation processes must be completed for all stages [10].

Multiple case studies have been published supporting SCM through simulation modeling. Their main objective being the construction of models that consider a range of stochastic behaviors into different branches of industry to evaluate and improve the unpredictability of the scenario through an analytical tool, in our case, that computes QRM performance and their associated costs. Some findings are listed below:

- When talking about shipment sizes and transport chain choices: It is feasible to simulate the goods flows in a (not too large) country at the level of individual firm-to-firm and shipments within a reasonable run time. This micro-level logistics model does require aggregate flows between production zone and consumption zone (the disaggregation of these to the firm level can be part of the logistics model) as inputs as well as inputs from transport network models [5].
- When talking about seasonal clothing: The modelling work has reinforced the widely accepted view that operating a QRM strategy is dependent on good information flows. Unless there is careful planning and co-ordination of supply chain activities, large uncertainties about end-of-season stocks will continue. If companies are to deliver small batch sizes and work to short lead times, there must be contracts of sufficient size spread over the year to allow commercial viability [6].
- When talking about retailing: Stochastic simulation allows the exploration of a wide range of procedures quickly and cheaply. It provides insight into the interactions of such aspects of the business as SKU levels, stockouts, markdown extent and timing and plan error [11].
- When talking about complex projects design: Increased understanding of realistic behavior of engineering design processes can be achieved through modeling information flows and predicting distributions of project lead time [12].

- When talking about lot sizes in constrained facilities: A deterministic model can be used in a practical situation to calculate lot sizes on a single machine producing several different items. By using a decision rule with runout times, these models would be applicable when demand is stationary stochastic [13].

As reviewed, computer simulation is a crucial aspect for SCM. This paper presents the analysis of a distribution problem which involves inventory supply planning. The description of the problem is presented in the next section.

2. DESCRIPTION OF THE PROBLEM AND SIMULATION LOGIC

A simulation model has been developed to resemble the inventory and lead times through a SC of a given product going through consolidation and distribution centers, having continuous review inventory management and lead time validation as main objective.

Software tool chosen for this problem is Arena ® by Rockwell. This tool enables the modelling of large and complex processes, permitting throughput increase, bottlenecks identification, logistics improvement and the evaluation of potential changes in live processes through discrete event simulation by portraying processes where variability, limited resources or complex interactions are present, without interrupting ongoing activities [14]. Important to mention that modeling restrictions can be offset with the addition of variables into simulation. A variable is a piece of program memory which stores data, and which can be retrieved. Different types of variables exist and are regularly programmed to store a specific kind of data – main difference being the range of values they can hold [15].

As in all supply and operative chains, simulation is triggered by demand directly impacting inventory through consumption. Demand's variability is calculated utilizing its mean and standard deviation and order point (or re-order point) is calculated through continuous review model (1) - (6). Our study case incorporates:

- Two suppliers: one providing local delivery (s1), and another (s2) which works through international shipments. In both cases, lead time calculations are based on weeks

and are assumed to be normally distributed.

- One consolidation and distribution center: Consolidation process consists of merging six parts from supplier 1s with two parts from s2 to create one unit of finished good. Then, 20 units of finished goods, set on a single box are consolidated into containers. Final counts are measured on number of delivered and undelivered containers.
- Consolidation and shipment loading time are computed as constant due to automatization.
- Distribution center vehicle capacity includes a two trucks fleet and three drivers hired 8 hours shift each.
- Four retailers whose truck fleet is compound by three trucks per center. Lead time is given in weeks and uniform distribution.
- Nine end-clients for which projected demand is assumed to be normally distributed.
- Additional information: product cost before consolidation $78 USD per set. Cost after consolidation $96 USD. Retailers purchase value $115 USD. Sales value $190 USD. Penalty per missing unit $50 USD.
- This case requires simulation to run through 3 months and to determine if the current vehicle fleet can support the efficient distribution to end-clients while avoiding stockout risks.

Variables were utilized to store system inputs and outputs which model inventory consumption and replenishment as per continuous review calculations given from the case. Entities were created to collect estimated numbers of how finished goods behave through the SC. Processes were defined to represent lead times, consolidation, shipment and vehicle assignment; resources picture trucks fleet and their utilization; and overall system queue helps us to identify saturation.

For illustration purposes, Figs. 1-3 present the general diagram and settings of the simulation model developed in Arena ®. For convenience, Fig. 1 presents the whole model while Figs. 2 and 3 present the settings for each section of the whole model. As showed in Fig. 2A, the suppliers are defined as coming from USA and the city of Guadalajara in Mexico. As previously described, the products from these suppliers are consolidated into the city of Mexico. As showed

in Fig. 2B, if demand is to be supplied, the inventory level is updated through the levels determined by the QR model. Once the inventory reaches R, a lot quantity Q is ordered and, when ready, the different lots are shipped to the requesting Mexican states of Guerrero, Oaxaca, Veracruz and Chiapas (see Fig. 2C).

Once the products arrive at the regional distribution centers of these four states, these are shipped to the end-clients (retailers) as presented in Fig. 3. It is important to mention the use of conditions and equations associated to the QR model, the modelling with probability functions for delivery or lead times and demand, and for the assignment of resources as the trucks for shipment.

3. RESULTS AND DISCUSSION

As previously discussed, simulation provides a powerful tool when seeking real and handy information in the gray area of uncertainty created by variability in real life scenarios. Combined with continuous review, it has served the purpose of understanding actual condition in search of a substantial improvement in the model set.

Our first look at general situation, Fig. 4 illustrates efficiency for inventory renewal, and inefficiency while executing delivery to retailer center demands, pushing them lower stock zero before the first replenishment shipment is completed for most of the cases.

From the outset, raw material stock taking runs smoothly, validating the continuous review model functioning for preventing stock-out and guaranteeing optimum inventory levels. Combined with the next part of the process, now unpredictability inquiries the continuous review ability to permeate successfully the entire SC. Here, simulation offers evidence of opportunity areas that lead to further analysis and decision making.

This leads to the economic analysis presented in Table 1 which considers the final consolidated products that ultimately were delivered to the end-clients of the four regional centers. As presented, the achieved deliveries do not prevent red numbers to be incurred with loses reaching the -$244,00.00 USD to penalties originated from stockout and represent additional -$150,760.00 profit losses for all regional centers.
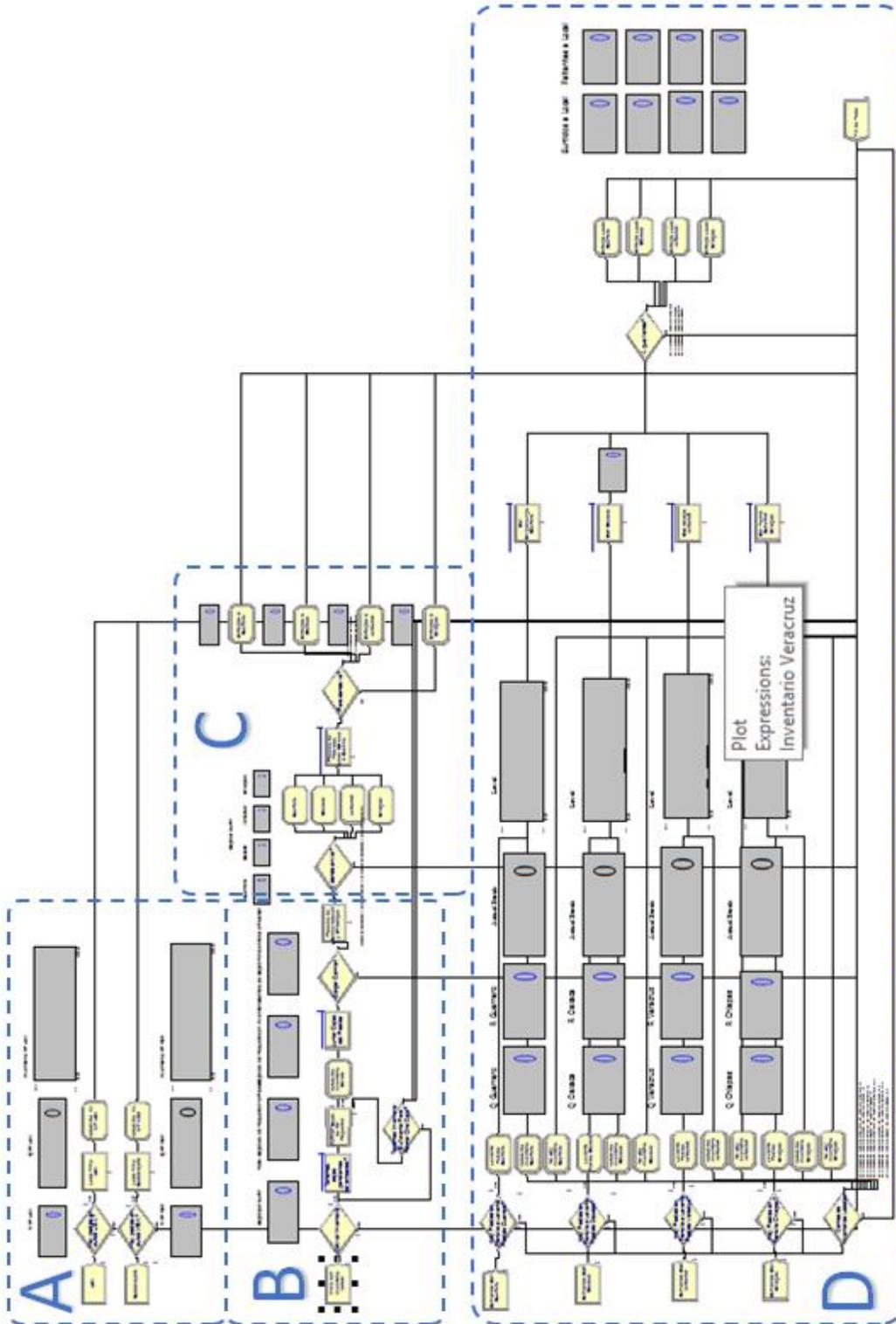
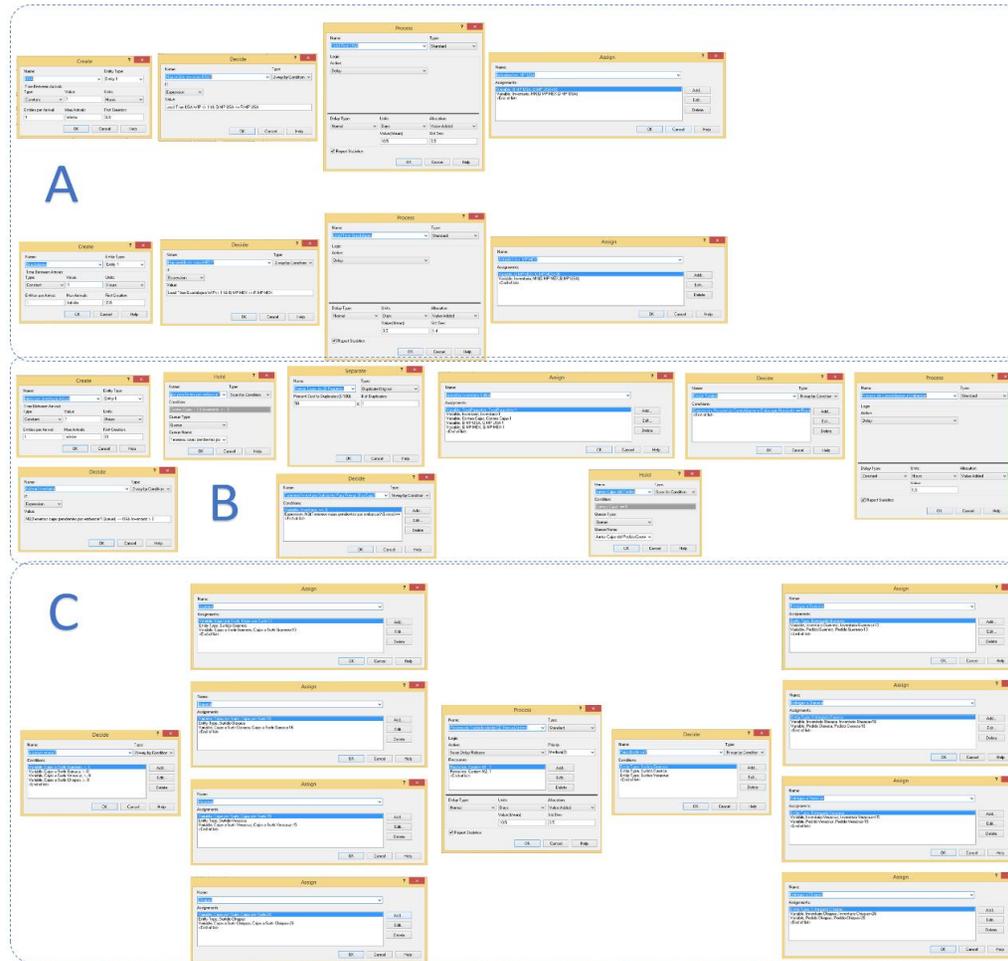**Fig. 1. General simulation model of the Original Scenario**

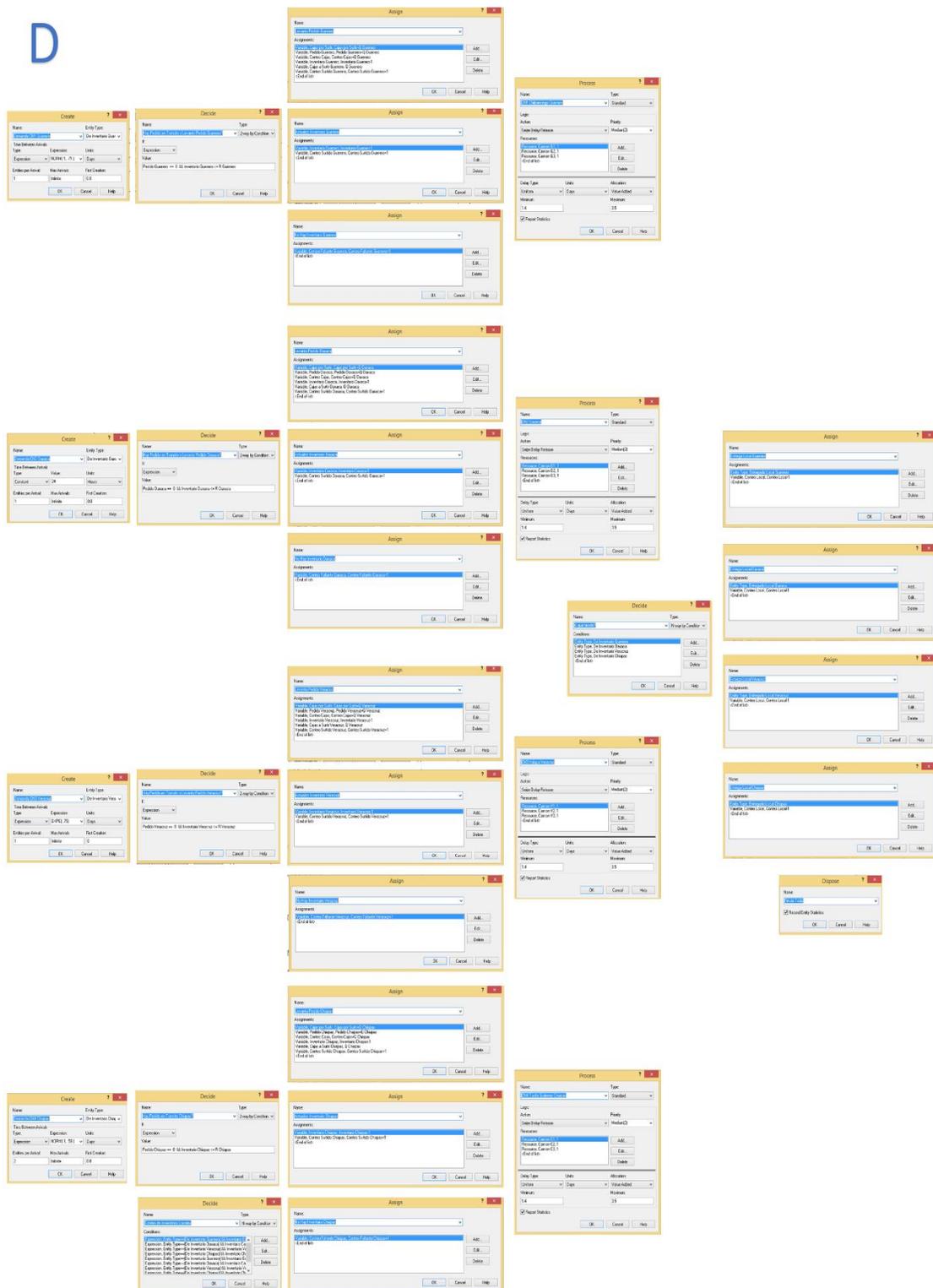**Fig. 2. Settings for sections A, B and C of the general simulation model of the Original Scenario**

Fig. 3. Settings for section D of the general simulation model of the Original Scenario
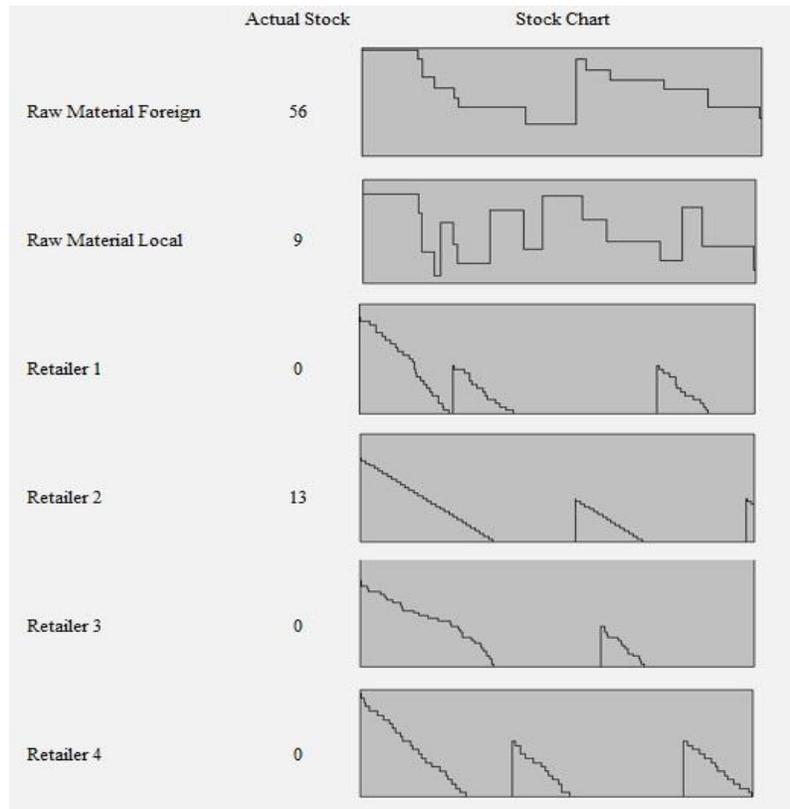
Fig. 4. Original Scenario Results from Simulation: Inventory Replenishment Pattern with Stockout

Consequence from deficiencies, quantities supplied to the end-clients of these four regional centers ran short. As observed in Fig. 5 all demands within the considered period (quarterly) are higher than the actual delivered product. Thus, stock out is highly present, which reveals that current shipping times must be revised for the upgraded model if an improvement is intended to deliver products quickly and avoid stock out and the associated penalties.

The second flag raises from resources' utilization, which is understood as the effective use of resources such as trucks, drivers, facilities and can be estimated as a percentage of use within the labor time. The utilization estimated by the simulation model (see Table 2) confirm a bottleneck which is to be expected from the vehicles belonging to consolidation center, who reach 88.59% utilization average (very high use). The "Number Waiting" metric recognizes the average number of shipments awaiting vehicle assignation and "Waiting Time" averages the number of hours each shipment waits for a vehicle to be assigned. Saturation on these might be the main reason behind delivery non-compliance to retailers and should be reestablished and reevaluated after lead times.

Table 2 also provides evidence of the under use of the regional centers' fleet with ultimately deliver the consolidated products to their end-clients. They represent an expense that needs to be offset with other usages for all values show less than 20% utilization. A variable that could be considered for a follow up study is vehicle's capacity. Current model is focused in optimizing inventory replenishment through simulation, but subject to follow up investigation could be evaluation of vehicle's capacity optimization while working with continuous review modeling through simulation.

For the improved model, adjustments were tested aided with simulation and the following upgrades were obtained when reassessing lead times and utilization through the whole SC. As presented in Fig. 6, by adjusting the lead times the occurrence of stockout is fully eliminated at all levels, while optimum inventory levels are maintained.

Table 1. Penalty costs of original scenario

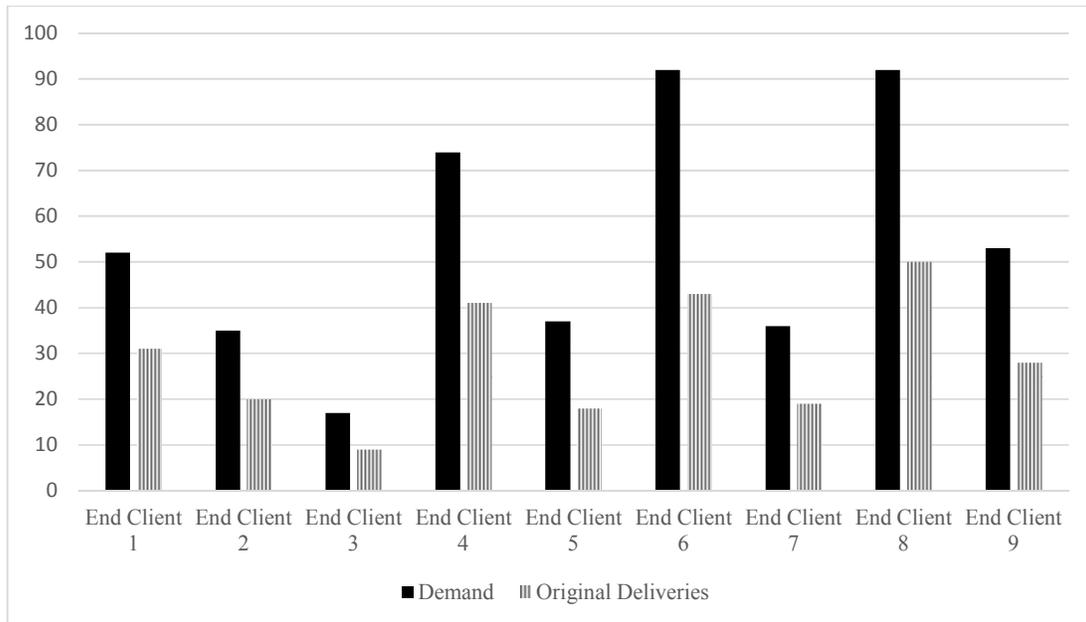| Destination	Delivered	Not Delivered	Consolidation Cost	Price to Retailers	Penalty Cost	Profit
Retailer 1	51	45	-$ 79,560.00	$ 97,920.00	-$ 45,000.00	-$ 26,640.00
Retailer 2	50	41	-$ 78,000.00	$ 96,000.00	-$ 41,000.00	-$ 23,000.00
Retailer 3	61	84	-$ 95,160.00	$ 117,120.00	-$ 84,000.00	-$ 62,040.00
Retailer 4	97	74	-$ 151,320.00	$ 186,240.00	-$ 74,000.00	-$ 39,080.00
Total					-$ 244,000.00	-$ 150,760.00

Fig. 5. Demand and effective deliveries of product to end-clients on the Original Scenario

Table 2. Utilization of Vehicles of the Original Scenario

Consolidation Center		Utilization	
Vehicle 1		88.59%	
Vehicle 2		88.59%	
Number Waiting		2.36	
Waiting Time (Average)		7.89	
Retailer 1 Resources	**Utilization**	**Retailer 2 Resources**	**Utilization**
Vehicle 1	9.14%	Vehicle 1	9.28%
Vehicle 2	9.14%	Vehicle 2	9.28%
Vehicle 3	9.14%	Vehicle 3	9.28%
Retailer 3 Resources	**Utilization**	**Retailer 4 Resources**	**Utilization**
Vehicle 1	10.97%	Vehicle 1	18.01%
Vehicle 2	10.97%	Vehicle 2	18.01%
Vehicle 3	10.97%	Vehicle 3	18.01%

The outcome of eliminating stockout is that no penalties due to undelivered consolidated products to the four regional centers are present. The respective economic analysis is presented in Table 3 and, as expected, there are no penalty costs which lead to positive profits up to $ 174,960.00. Also, as presented in Fig. 7, in contrast to the original scenario, with the improved model the deliveries to end-clients are met at a 99.5% rate for the same quarterly period.

By adjusting the lead time, it is also observed in Table 4 that utilization of the vehicles is improved at all levels. In example, for the main vehicles that depart from the consolidation center to the regional centers, utilization is reduced due to less driving time and fast delivery. On the other hand, the number of vehicles from each regional center to their end-clients is reduced from three to one for centers 1, 2 and 3, and to two for center 4. This represents important savings due to a smaller fleet and their more effective use. Furthermore, consolidation center's fleet can practically eliminate number of units waiting and waiting time for shipments (which adjusts to JIT principles).
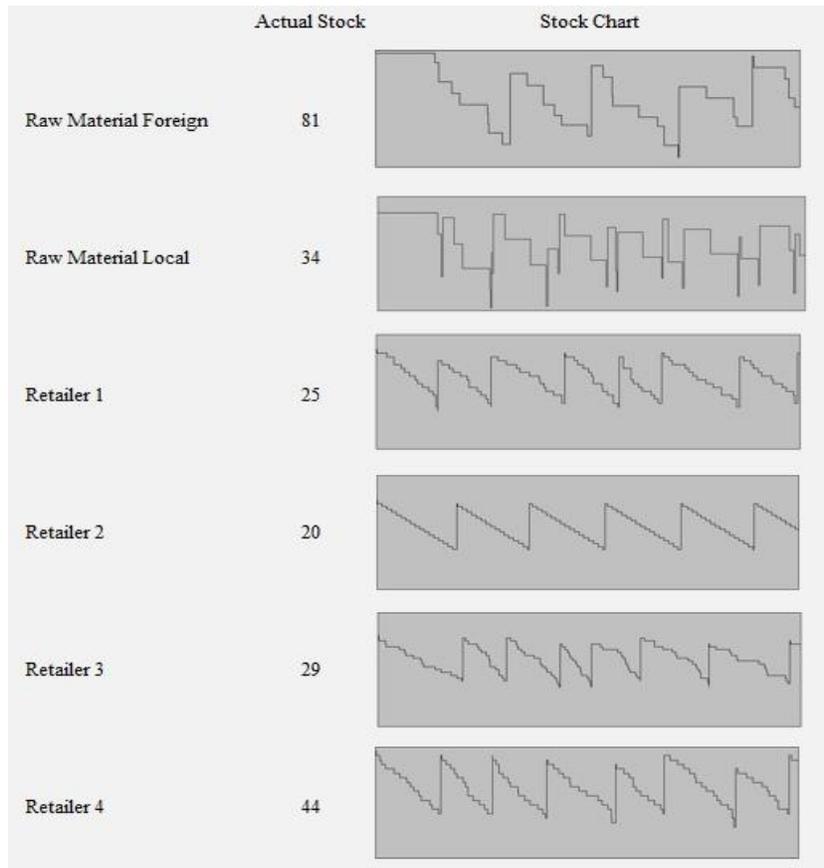
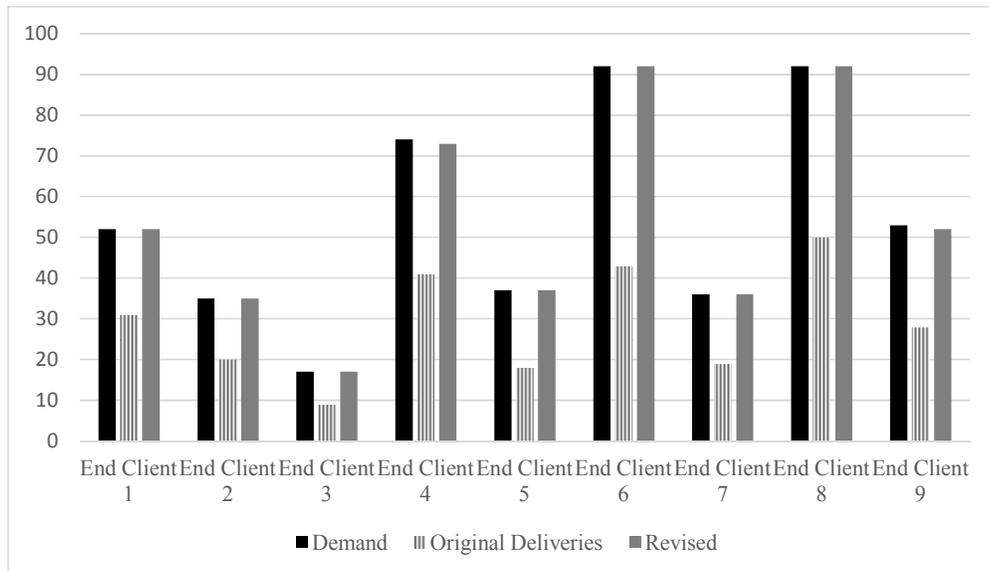**Fig. 6. Adjusted Scenario Results from Simulation: Inventory Replenishment Pattern without Stock out**

Fig. 7. Comparison of demand and effective deliveries of product to end-clients between the Original and the Adjusted Scenario

Table 3. Profits of Adjusted Scenario

Destination	Delivered	Not Delivered	Consolidation Cost	Price to Retailers	Penalty Cost	Profit
Retailer 1	87	0	-$ 135,720.00	$ 167,040.00	$ -	$ 31,320.00
Retailer 2	90	0	-$ 140,400.00	$ 172,800.00	$ -	$ 32,400.00
Retailer 3	129	0	-$ 201,240.00	$ 247,680.00	$ -	$ 46,440.00
Retailer 4	180	0	-$ 280,800.00	$ 345,600.00	$ -	$ 64,800.00
Total					$ -	$ 174,960.00

Table 4. Utilization of Vehicles of the Adjusted Scenario

Consolidation Center		Utilization	
Vehicle 1		14.53%	
Vehicle 2		14.53%	
Number Waiting		0.01	
Waiting Time (Average)		0.01	
Retailer 1 Resources	**Utilization**	**Retailer 2 Resources**	**Utilization**
Vehicle 1	17.76%	Vehicle 1	23.70%
Vehicle 2	N/A	Vehicle 2	N/A
Vehicle 3	N/A	Vehicle 3	N/A
Retailer 3 Resources	**Utilization**	**Retailer 4 Resources**	**Utilization**
Vehicle 1	19.81%	Vehicle 1	40.56%
Vehicle 2	N/A	Vehicle 2	40.56%
Vehicle 3	N/A	Vehicle 3	N/A

4. CONCLUSION

Simulation is an art. It requires originality, time and patience from the programmer. It is a tool that, due to its flexible nature, allows you to observe the whole in the blink of an eye; that is precisely where its difficulty lies. By allowing so many realities to be viewed in parallel, it is easy to get lost inside of it. Here, it is convenient to rest, re-analyze or ask for a second opinion.

It is important to recognize the difference between programming errors and model errors. Therefore, it is recommended to carry out constant reviews that re-evaluate the model we intend to implement under different assumptions. It helps a lot to be focused on the simulation objective.

Simulation allows you to see solutions that you didn't know existed. While exploring the simulation, it is advisable to safeguard an original copy of your progress that allows you to compare and decide, knowing that you can always step back and start again without losing progress.

The limitations of the simulation test the imagination of the person who develops it. Finding other ways of doing things goes beyond learning the language of the software that is used, it requires open-mindedness towards new ideas – and working on improvements, which demands more of it during implementation.

For our research, modeling affords a glimpse of first quarter expectations, allowing analysis, re-formulation, and establishment of new working criteria, before incurring the delays, non-fulfilments, or penalties. In a relatively short time at a cost-effective value, simulation opens a window that helps determine precise investment in vehicle fleet, human resources, lead times, and cost related implications, within easy reach.

Specifically, in our research, we were able to model the original scenario corresponding to a distribution network with inventory planning. This model led to corroborate significant shortage periods (stockout) in the considered planning horizon (see Fig. 4) which resulted in estimated penalties of up to $ 244,000 which negatively affected the profits by $ 150,760.00 (see Table 1). As such, demand of the end-clients was partially fulfilled (see Fig. 5).

These results helped us to determine the possible caused for improvement. The utilization analysis (Table 2) supported the assumption that delivery was taking too much time. This is associated to the distribution fleet using too much time which can be caused by lack of inventory planning and vehicle routing considering long commute times.

Once the QR supply strategy was applied appropriately, and a proposal was made to use the available vehicle fleet, the results obtained previously were improved. Thus, shortage periods were eliminated (see Fig. 6), which eliminated penalties and increased profits (see Table 3). Finally, the uses of vehicles in the distribution network were improved (see Table 4).

As future work the following aspects are considered:

- Given that the QR model was evaluated, and that simulation results, delivery times and the number of vehicles per fleet were modified, it is proposed for future studies to explore in greater detail the effect and vehicle capacity than in this work, being that here it was located in second place.
- Within the same network, considering the same scenario, a more detailed study can

be carried out on the effect that modifying the Q and R points would have, should there be a need to conserve delivery times together with the current vehicle fleet. Recalculating them may have an impact on higher inventory costs, but not on an investment in the acquisition of additional vehicles, which could be another feasible solution scenario for the company.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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