Design of a Logistics Network Using Analytical Techniques and Agent-Based Simulation

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Abstract. Business Logistics, or Supply Chain, has acquired a notorious relevance in current business management, due to its highly significant impact on the success of the production and service sectors. This work proposes the design of a supply chain that considers disruptive scenarios and improves the level of service compared to the current situation. Discrete event simulation techniques are used in conjunction with agent-based modeling to define production orders. A hypothetical case study was developed to show the performance of the proposal.

Keywords: Discrete event simulation · Supply chain design · Agent-based simulation

1 Introduction and Literature Review

Logistics network design in organizations helps define or validate the location, capacity, optimal number of nodes (plants, primary and secondary distribution centers, and cross-docking centers) and the flows between these nodes. The objective is to minimize the total cost of the network (production, transport, handling) and achieve the required service levels.

The supply chain is the sequence of suppliers that contribute to the creation and delivery of a merchandise or service to an end customer. Many processes and flows are involved within and outside of each link. Designing the most efficient supply chain for a business is a complex task, requiring planning for multiple variables. There are no magic solutions or models that work for any business. It

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is necessary to know the characteristics of your company, its products and customers to create an optimal distribution chain. For example, in the pharmaceutical industry, which is one of the most complex supply chains, the combination of processes, operations and organizations involved in drug development and production is the perfect definition for the pharmaceutical industry [5]. Supply Chain problems often include both strategic and tactical decisions [3]. A characteristic of pharmaceutical companies is that the value of their inventory is of high value. This is to ensure a high level of customer satisfaction in the face of any operational disruption and to take advantage of any opportunities that arise (for example, increased demand during a disease outbreak). However, expensive inventories freeze capital and are undesirable for many reasons [7]. In practice, a periodic review inventory policy is not applicable for healthcare inventory management because customer demands and patient arrivals are uncertain. Therefore, efficient management of healthcare inventory systems requires a different approach than a periodic review order point model [8].

The mutual effects of the location of the facilities are related to inventory control decisions increasing the perishable factor. Product perishability is another critical problem in supply chains. Expired items can be overlooked and dispensed to patients, which could have potentially disastrous effects on both patient care as well as the reputation of the company [8]. Although designing an optimal supply chain becomes more complex when using perishable goods, few models take that factor into account [2]. In this study, the effects of opening a new production plant will be analyzed taking into account the location, management and handling of inventories, and cold chain distribution. You must take special care in inventory decisions that are made to ensure 100% product availability at the right time, at the right cost, and in good condition for customers. This will be done taking into account the inventory for a multiple product, a multiple period and a distribution network. Due to the dynamic and imprecise nature of the quantity and quality of the products manufactured. In a pharmaceutical industry supply chain, there is a high degree of uncertainty in the data when it is designed [4].

Therefore, in order to simulate various scenarios and see their effects, the model will be implemented in specialized software. Additionally, it is important to emphasize that we can generate profits taking in consideration the optimization of costs and make a green Supply Chain regulating CO_2 emission mainly with the transportation and distribution using methods like Center of Gravity and linear programming to establish the optimal location concentrating on Supply Chain sustainability. This impact will develop new opportunities based on protect the environment caused by the emissions of greenhouse gases (GHGs) and make more profits without the need to affect the environment.

Taking into account that an epidemic out-brake work in a similar way to a supply chain, some researchers address on how the simulation can help to predict the impact of this supply chain. Their studies are based on a global supply chain which includes multistage-suppliers, factory distribution center and customers in different continents. The models takes in consideration some assumptions, and some real facts, like the dates when the pandemic could have started. Taking into account three risks that make this type of supply chain special: long-term disruption existence and its unpredictable scaling, simultaneous disruption propagation and epidemic outbreak propagation and simultaneous disturbances in supply, logistics infrastructure and demand.

The methodology used to design the supply chain for a hypothetical case is presented below. We use discrete event simulation techniques to model the product flow in the network. Customer orders are modeled through agent-based simulation and the overall chain design is implemented in AnyLogistix software.

2 Methodology

The proposal considers a mathematical model to optimize product transport between the facilities that make up the logistics network. To verify the behavior of the model variables in the supply chain, a multi-paradigm simulation model is developed. This simulation model allows the parameters of the system to be varied dynamically in simulation time, it also allows describing and studying the impact of these changes. It is important to note that the simulation does not produce optimal solutions but rather describes the performance of the modeled system. After studying the performance of the system, it is possible to modify the structure of said system as well as the input parameters in order to optimize the overall performance versus the initial situation. In the design of the supply chain, the simulation carried out allows to optimize the configuration of the elements of the network, and suggests which and how many elements should be considered to make up the chain. The more details you consider, the more opportunities you have to find improvements. In companies, a very important factor is the planning of facilities and investments in equipment, material and physical spaces. The success of the operation of the company will depend on this planning. The software used allows us to implement the simulation proposal to identify the optimal locations to serve current and potential clients. Where more people live, the demand for the products is more likely, see Fig. 1.

In this work, this tool will be used and another location for a new plant will be proposed using a Greenfield Analysis (GFA). The software uses real terrain lines allowing a more exact optimal location solution. This resolution part takes into account the location of customers, products, demand for product and distance between customers, distribution centers and plants. For the study of the various alternatives, the different proposals (operating scenarios) must be simulated. These operating alternatives consider a different number of customers and their demands as well as the number and quantity of production orders. The alternatives considered are:

- Scenario 1A.- Optimal location GFA
- Scenario 2A.- Optimal location with + 30% demand
- Scenario 3A.- Optimal location with + 100% demand

Scenarios 1A only take into account current situation (demand). With this assumption, an increase in customers is not considered.

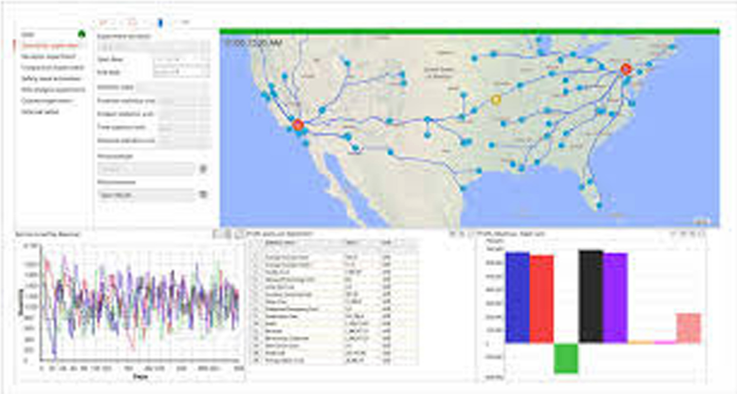

Fig. 1. AnyLogistix software

3 Mathematical Model

The proposed simulation model uses a mathematical model that optimizes the location of new facilities, for example factories and distribution centers. These facilities consider the locations of current customers and the quantity they demand. This optimization process is based on mathematical models of location called center of gravity models. The information that feeds these models is the following, see Fig. 2 and Fig. 3.

Greenfield Analysis is performed by solving a location model called Center of Gravity.

$$C_x = \frac{\sum_i d_{ix} w_i}{\sum_i w_i} \tag{1}$$

$$C_y = \frac{\sum_i d_{iy} w_i}{\sum_i w_i} \tag{2}$$

Where:
$d_i x = x$ coordinate of the locality i
$d_i y = y$ coordinate of the locality i
w_i = volumen for the locality i

The software used allows to geographically locate the points in space, which makes the proposals obtained consider real paths between the facilities, that is, no Euclidean or straight solutions are proposed. Therefore, it is an advantage that we have if we only use classic mathematical programming models [6].

CLIENTS	X	Y	PRODUCT 1 (PCS)	PRODUCT 2 (PCS)	VOLUME (PCS)
CLIENT 1	19.366986	-99.053344	24000	12000	36000
CLIENT 2	19.691144	-99.212146	18000	4200	22200
CLIENT 3	19.37213	-99.098921	4800	2400	7200
CLIENT 4	19.525414	-99.103442	2400	1800	4200
CLIENT 5	19.065549	-98.103715	3000	2160	5160
CLIENT 6	19.429033	-99.136257	1200	600	1800
CLIENT 7	19.508216	-99.158846	600	360	960
CLIENT 8	19.077665	-98.155057	2400	960	3360
CLIENT 9	19.762902	-97.250398	2400	600	3000
CLIENT 10	21.067031	-101.687242	2400	480	2880
CLIENT 11	19.36011	-99.118637	1200	240	1440
CLIENT 12	18.901396	-99.227063	1440	240	1680
CLIENT 13	20.597281	-100.381743	960	360	1320
CLIENT 14	20.14495	-98.340119	600	240	840
CLIENT 15	19.509386	-101.615386	600	120	720
CLIENT 16	20.85529	-103.4462	480	240	720
		TOTAL	66480	27000	93480

Fig. 2. Customer locations

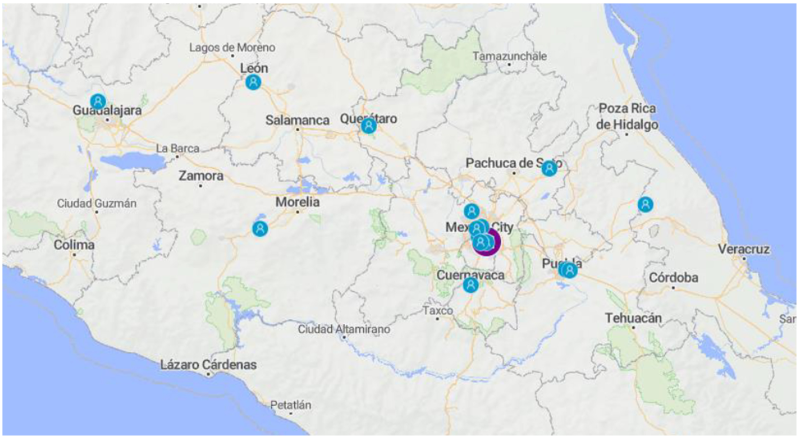

Fig. 3. Geographical customer locations

4 Simulation Models

In this section the simulation models used are presented. The process of transportation and flow of merchandise from plants to distribution centers and customers is modeled through the simulation of discrete events, see Fig. 4.

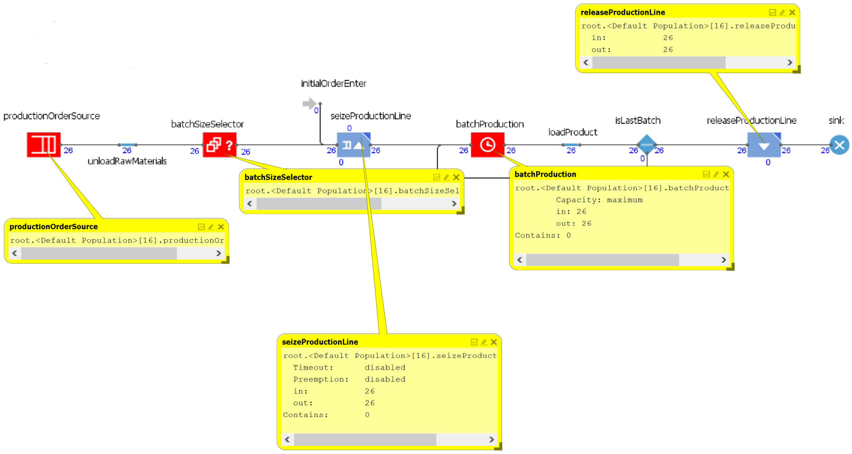

Fig. 4. Discrete-event simulation model

Agent based simulation is used to model product purchase orders by customers. This purchase order triggers production orders at the plants. The design of the supply chain is conditioned by the behavior of the purchase orders. This agent used allows considering disruptive events within it, that is, through the agent's behavior it is possible to simulate disruptive events in the supply chain. The agent based simulation is implemented in anylogic software, see [1]. Figure 5 shows the agent described above.

5 Software Used

In this work, the simulation models are implemented in a platform called Any-Logistix, which solves a variety of classic supply chain problems. The solution of these problems through simulation-optimization allows making accurate decisions in the supply chain, see [6].

The results of ALX consider the location of customers, their demands, types of products, periodicity of purchase orders, operating costs of facilities, transportation costs and inventory costs among others. So the solution obtained improves service levels, costs, profits, facility utilization rates and other key performance indicators.

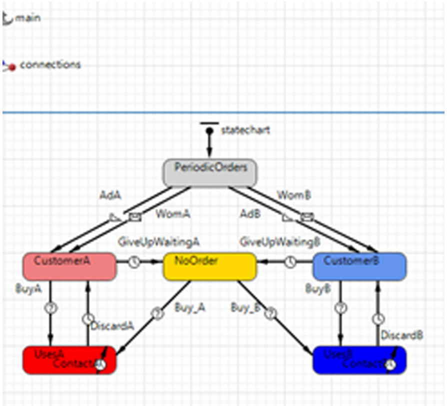

Fig. 5. Agent-based simulation model

Likewise, the proposed model allows us to analyze whether the performance indicators improve if we close, open, expand or relocate a facility. The uncertainty in the elements of the supply chain can be captured by using some ALX functions. With this uncertainty built into the analysis, the risk of supply chain operation can be assessed. The dynamic analysis allows estimating the performance of the operation as the simulation time progresses.

ALX uses analytical and simulation methods in a hybrid way to robustly model a network.

It is known that simulation techniques do not produce optimal solutions, however they allow to verify the overall performance of the system considering dynamic scenarios over time. The correlations of variables and parameters can be easily identified by running the simulation on this platform.

6 Results

Considering that ALX incorporates a georeference system, after modeling and running the simulation of the system, the results obtained show the following, see Fig. 6.

The results of the hypothetical case study show distribution centers located in different geographical areas, for example a simulation results in the location of a new distribution center at the coordinates at latitude 19.38 and longitude −99.06 coordinates.

Figure 7 shows the results for the three scenarios tested.

Figure 8 shows the distributors, the located distribution center and the supplier. The structure of supply chain is showed in Fig. 9.

SCENARIO	DESCRIPTION	X	Y
1A	Optimal location GFA	19.37	-99.05
2A	Optimal location with + 30% demand	19.38	-99.06
3A	Optimal location with + 100% demand	19.49351	-99.11

Fig. 6. Scenario results (Distribution center locations)

SCENARIO	DESCRIPTION	AVERAGE DISTANCE (km)	MINIMUM DISTANCE (km)	MAXIMUM DISTANCE (km)	DC NOT USED
1A	Optimal location GFA	100.77	4.52	477.17	DC 2
2A	+ 30% demand	109.28	4.44	477.17	DC 2
3A	+ 100% demand	237.29	2.9	2283.62	-

Fig. 7. Scenario results (distances)

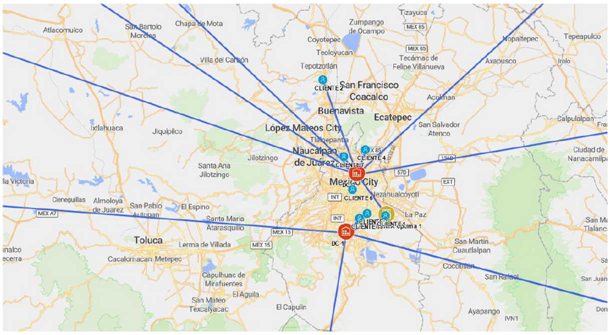

Fig. 8. Geo-referenced solution

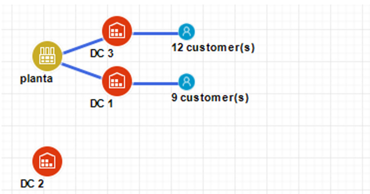

Fig. 9. Supply chain structure

7 Conclusions

This paper presents a proposal to design a supply chain. Multi-paradigm simulation is used to model the elements that make up the supply chain. Discrete event simulation is used to model the flow and transport of merchandise throughout the network as well as the operation of the distribution centers. Customer behavior is modeled through agent-based simulation and is incorporated into the global model through the AnyLogistix simulation platform. The results show that it is possible to use multiparadigm simulation to design a supply chain. As future work, the modeling of inventory policies of the distribution centers with agents that interact with the production plants can be considered.

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