

## Designing a resilient supply chain: An approach to reduce drug shortages in epidemic outbreaks

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### Abstract

**INTRODUCTION:** Supply network design is a long-studied topic that has evolved to address disruptive situations. The risk of supply chain disruption leads to the development of resilient supply chains that are capable of reacting effectively.

**OBJECTIVES:** In the context of public health, drug supply networks face shortage challenges in many situations, such as current epidemic outbreaks such as COVID-19. Drug shortages can occur due to manufacturing problems, lack of infrastructure, and immediate reaction mechanisms.

**METHODS:** The case study is solved with anyLogistix optimization and simulation software.

**RESULTS:** We present the results of a hypothetical study on the impact of COVID-19 on a regional supply network. The results of this research are intended to be the basis for the design of resilient supply chains in epidemic outbreaks.

**CONCLUSION:** Drug providers should consider strategies to prevent or reduce the impact of shortages as well as disruption spreads.

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**Keywords:** Supply chain design, resilient supply chain, epidemic outbreaks, COVID-19, drug shortages, Dynamic Simulation.

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### 1. Introduction

The Mexican health system has gone through several reforms, one of the most important being the reform of the General Health Law of 2003 that gave rise to the Social Protection System in Health, which would operate through the Popular Insurance as a public insurer officially starting operations in 2004.

The configuration of the public health system in Mexico was integrated by three large institutions, the ISSSTE that provides social security to state workers, the IMSS that provides coverage to workers in the private sector, and the Popular Insurance that integrates the open population without import your work or social status.

In addition to these reforms, the demographic and epidemiological profile of the Mexican population has changed. The epidemiological transition that Mexico is going through and the aging of its population are determining factors in the demand for specific health services, as well as the requirement for specific medications to care for the population [1]. There are additional risk factors such as for overweight and obesity, as well as an increase in the prevalence of chronic diseases. In 2018, it was recorded that 75.2% of the adult population (20 years and over) had problems with overweight or obesity. Further 10.3% of the population had diabetes and 18.4% suffer from hypertension [2]. This implies an increase in overweight and obese people, and people with chronic diseases, affecting the mortality of the Mexican population and generating significant pressures on the Health System.

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Concerning demographic transition in 2020, the average age of the Mexican population was 29.2 years in contrast to the year 2000 where the average age of Mexicans was 22.9 years. According to data from the Economic Commission for Latin America and the Caribbean (ECLAC), the population aged 65 and over in Mexico increased from 6.1% in 2010 to 7.6% in 2020 [3]. The increase in the adult population likewise generates greater pressure. to the health system, in addition to inverting the population pyramid. Fig. 1 shows the population pyramid of Mexico in 2012 and the data projected to 2030 by the National Population Council (CONAPO).

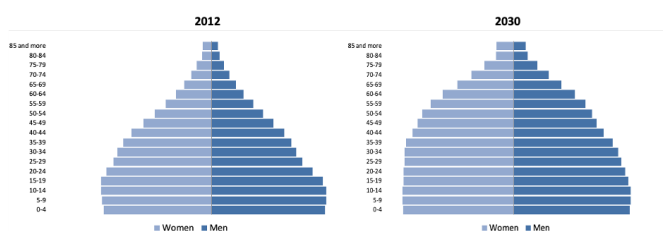


Figure 1. Mexico population pyramid, 2012-2030.

In a framework of limited resources, it generates significant pressures on the financing of the system. In 2017, health spending as a percentage of GDP represented 5.5%, of which 52% corresponds to public spending, 43% to pocket spending, and 5% to private prepaid [4].

### 1.1. Analysis of drugs supply in the public sector

As part of the new configuration of the health system in Mexico, the goal was to achieve universal coverage through effective access to health services. Addressing priority problems in the health sector, such as the supply and complete supply of medicines in public health services. The quality care process is completed at the moment the patient receives the prescription medications that will allow them to recover their state of health.

The issue of drug supply and supply in Mexico is a topic that has been worked on for many years, through the implementation of various strategies that allow the supply and supply of 100% of the drugs prescribed to patients. In 2012, the percentage of full prescriptions filled in the public sector was 65.2%, which implied that 34.8% of the prescriptions were not filled. For 2018, this indicator was 69.9%, with 30.1% of recipes not filled. The percentage of complete prescriptions filled has improved in the last 6 years, however, the established goal of 90% has not been reached (Fig. 2).

Various strategies have been implemented to improve the medicine supply chain and to guarantee the supply

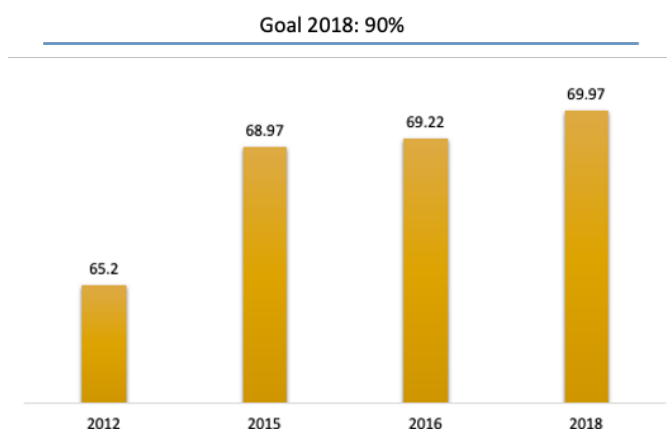


Figure 2. Percentage of a complete supply of drugs, 2012-2018.

and complete supply of prescriptions. As we can see in Table 1, this table summarizes the main among some strategies implemented to improve the supply and supply of medicines in the public sector in Mexico [5].

Table 1. Policies implemented at the federal level

Policies	Description
Coordinating Commission for the Negotiation of Medicine Prices and other Health Supplies	Intersectoral commission for the negotiation of medicines and other single-source supplies. Negotiations take place annually.
Consolidated purchase of medicines	Consolidated purchase of medicines integrating the requirements of the main public health institutions, as well as entities from the federal and state levels.
Reference prices	Reference list for the purchase of medicines financed with resources from the Social Health Protection System, the objective is to reduce the variance in the public purchase prices acquired by the federal entities.
Generic release policy	Prioritization of the issuance of health records for high-priority generic products. This will allow there to be more competitors in the shorter term in the market and will generate a decrease in the prices of medicines whose patent has expired.

These policies have generated positive results in the medicine supply chain in the health sector, but according to the indicators, there are still important gaps to be resolved. An example of this is household out-of-pocket spending on medicines, since failing to supply the public sector in the best of cases patients must go to the private market to purchase their medicines. According to data from the National Survey of Household Income and Expenditure (ENIGH for its acronym in Spanish) in 2018, Mexican households spent around MXN\$34,332 million on medicines. This represents 31.3% of out-of-pocket spending on health of Mexican households, which represented MXN 109,700 million in the same year, followed by spending on outpatient care (28.0%) and hospital care (21.1%), fig. 3.

The medicine supply chain is a complex process and with a very particular operation unlike the supply chain of other products. Both supply and demand interact with various agents, who participate in the supply process and those who participate in the patient care

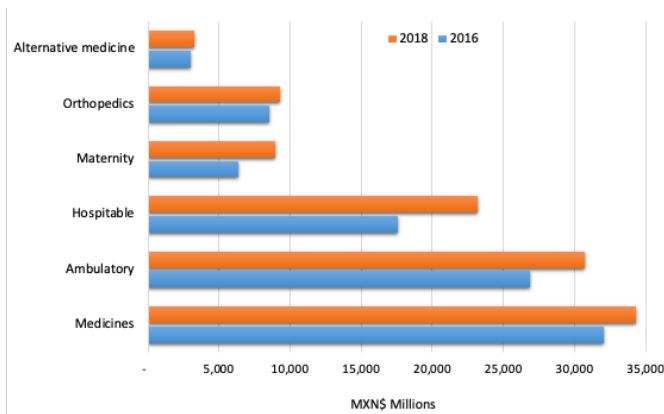


Figure 3. Out-of-pocket expenditure on household health in Mexico, 2016-2018.

process (Fig. 4). In the case of the public sector, the federation only controls part of the supply chain, so there are inherent risks and the probability of failure at each link in the supply chain. Furthermore, the participation of the pharmaceutical industry is highly relevant because it participates in the entire process through various direct and indirect strategies. From

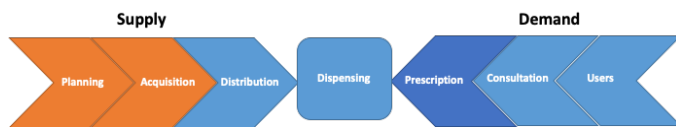


Figure 4. Drug supply process.

the analysis of the main problems presented in the supply of medicines in the public sector, five main areas of risk of failure in the operation were integrated: 1) planning, 2) acquisition, 3) distribution, 4) prescription and 5) dispensing. Any failure in any of these stages compromises the efficient operation of the supply chain and in turn, implies that the supply of prescription drugs is not complete for all patients.

Fig. 5 shows the analysis of possible problems in the five stages considered, highlighting the distribution process with delays in the delivery of medicines, shortages in pharmacies of medical units, lack of adequate communication between warehouses and medical units as well as different models of drug distribution. Distribution models refer to the scheme in which the distribution of the drug is managed after its acquisition, for example, the most widely used schemes are outsourcing or direct distribution.

The analysis of the problems in the medicine supply chain in the public sector shows areas of opportunity at each stage. However, the main limitation for establishing an efficient supply chain lies in the

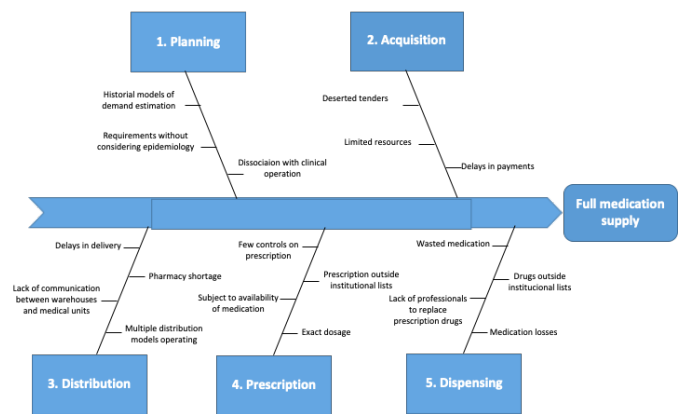


Figure 5. Problematic of the full drug supply.

operation of multiple agents at each stage of the process. Therefore, it is necessary to establish regulatory entities that make it possible to integrate the operation of these agents if it is not in the daily operation, but a framework of a public health emergency such as an epidemic.

The Mexican health system is fragmented, this determines a particular configuration in its operation and therefore in the related medicine supply chain. According to what is described in this section, it can be seen that Mexico faces an important demographic and epidemiological transition, as well as structural problems in the supply of medicines in the public sector. On average 30% of the recipes generated in the public sector are not filled or are not filled. Various strategies have been implemented to improve the supply level; however, much remains to be done. Therefore, it is necessary to be prepared in the face of a disruptive event such as an epidemic and design a supply chain for both supplies and medicines that allow for an efficient response to contingencies.

## 2. COVID-19 pandemic in Mexico

In the context of an epidemic, it is necessary to have a resilient medicine supply chain design. However, in the case of Mexico, we start from a supply chain of medicines with structural problems, since a percentage of unsorted prescriptions derived from the structure of the health system and the operation of the medicine supply system is maintained. In this context, at the beginning of 2020, Mexico faces an enormous challenge due to the COVID-19 pandemic. According to information issued by the Ministry of Health, as of April 28, 77,005 possible cases were registered [6]. Preliminary data subject to validation by the Ministry of Health through the General Directorate of Epidemiology. The information contained corresponds only to the data obtained from the epidemiological study of a suspected case of viral respiratory disease

at the time it is identified in the medical units of the Health Sector. The records are made by sentinel surveillance, of the System of Health Units for Monitoring Respiratory Diseases (USMER for its Spanish acronym). The USMERs include first, second, and third-level medical care units.

The information on suspicious cases reported to the epidemiological surveillance system is validated based on the tests carried out for the confirmation of positive cases with COVID-19, the distribution of the data shows that as of April 28 of the 77 thousand case records 16,752 were confirmed by diagnostic tests, 49,000 cases were discarded as COVID-19, and 11,000 cases are still pending confirmation due to the time required to carry out the tests. Of the total confirmed cases, 42% correspond to women and 58% to men. (Fig. 6).

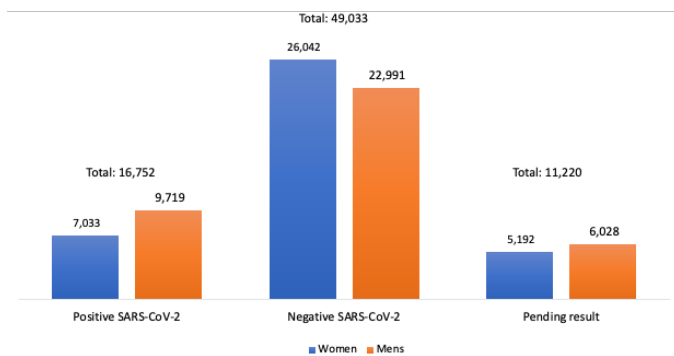


Figure 6. Total cases registered by the epidemiological surveillance system as of April 28, 2020.

The proportion of confirmed cases represents 22%, negative 64%, and pending results 15%. It is important to note that although only 22% of the total registrations as of April 28 were positive, it was necessary to give attention to the 77 thousand cases received. This implies that given the health emergency, a greater number of users go to health services due to the suspicion of being infected with COVID-19, which in turn generates a significant increase in the demand for health services.

The distribution of cases by state entity shows Mexico City (5,261 cases), the State of Mexico (1,966 cases), and Baja California (1,410 cases) as the entities with the highest number of confirmed cases. As of April 28, 2020, it is observed that cases are presented in all the federal entities, with Colima (25 cases), Durango (57 cases) and Nayarit (61 cases) being the entities with the fewest confirmed cases (Fig. 7). According to the confirmed cases, there is a distribution of their severity, of the total of confirmed cases, 61% are ambulatory cases, and 39% required hospitalization. When analyzing the age groups of the confirmed cases, we observe that there is a higher concentration of

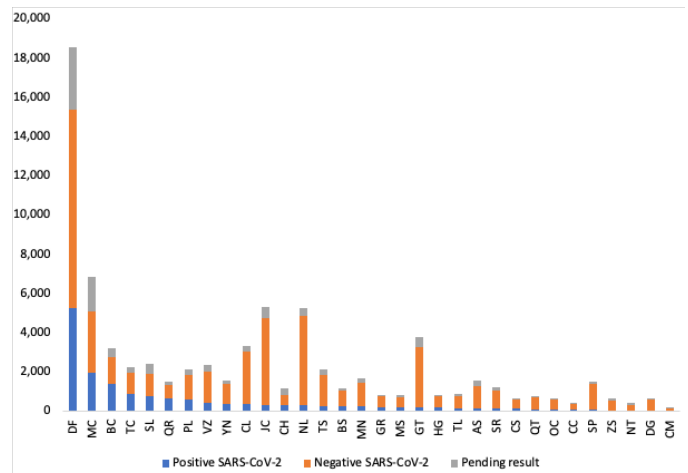


Figure 7. Distribution of cases by state as of April 28, 2020.

cases in ages ranging from 30-54 years, concentrating 57% of the total number of cases, which implies that the highest proportion of patients is concentrated in patients in working age. Patients aged less than 30 years accumulate 14% of the total number of cases and patients older than 54 years represent 30% of the cases. (Fig. 8).

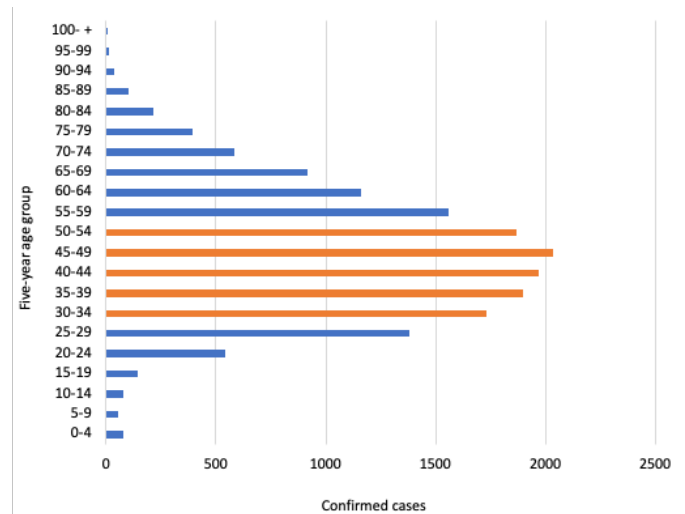


Figure 8. Distribution of cases by five-year age group as of April 28, 2020.

Of the total confirmed cases, a total of 1,569 patients have died, which represents 9.4%, which expressed in terms of a gross mortality rate per 1,000 inhabitants, represents 93.3 deaths per thousand inhabitants. Presenting the highest number of deaths in adults over 40 years. The highest mortality rates are observed in the groups of 75-79 years with 230 deaths per 1000 inhabitants, the group of 80-84 with

227 deaths per 1000 inhabitants, and the group of 90-94 years with 222 deaths per 1000 population (Fig. 9).

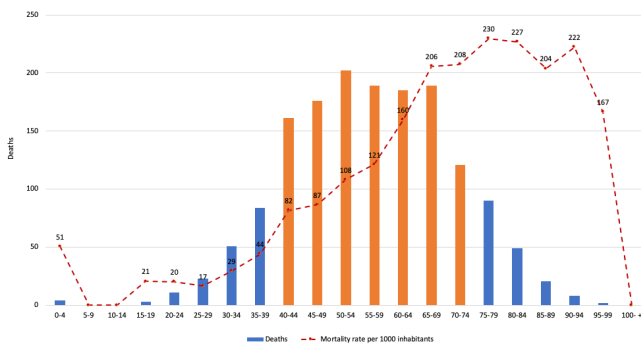


Figure 9. Deaths and mortality rate by age groups as of April 28, 2020.

Based on the information generated up to April 28, 2020, some important elements are identified, referring to the states with the highest number of cases, the mortality observed in groups of older adults, as well as the presence of diseases related to additional risk factors. In patients identified as obesity, hypertension, diabetes, and smoking. Of the total of confirmed cases, 30% developed pneumonia, 22% have hypertension, and 18% diabetes. 21% of confirmed patients are obese and 9% report smoking. About specialized services, a low proportion of confirmed patients has required ICU services 4.3% and 4.2% have been intubated (Table 2). The evolution of the COVID-19 pandemic in Mexico

Table 2. Related diseases, risk factor and specialized care of confirmed cases

Related diseases	Cases	% of confirmed cases*
Pneumonia	4,942	29.5%
Hypertension	3,640	21.7%
Diabetes	3,064	18.3%
Other complication	696	4.2%
Asthma	585	3.5%
Cardiovascular	473	2.8%
COPD	421	2.5%
Chronic kidney	388	2.3%
Immunosuppression	314	1.9%
<b>Risk factors</b>		
Obesity	3,463	20.7%
Smoking	1,496	8.9%
<b>Specialized care</b>		
ICU	720	4.3%
Intubated	709	4.2%

is still in evolution, there is no evidence that as of April 28, 2020, the maximum peak of cases has been reached, so it is necessary to follow up on the available information issued by the Secretariat of health. The

available information shows an increase in the demand for health services given the spread of the pandemic and that service users come to present some related symptoms. This implies that there is an unusual peak in demand in public health services as well as supplies and medicines. Since the registration of possible cases implies some attention to the patient (Fig. 10).

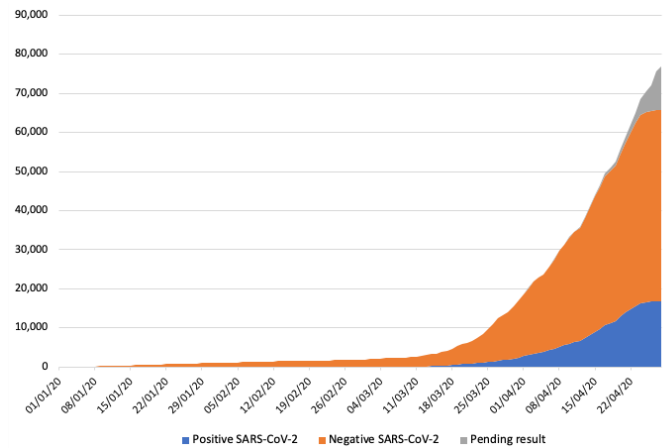


Figure 10. Evolution of the cases registered in Mexico as of April 28, 2020.

In the framework of a structural problem in the supply chain of medicines (and supplies) in the public sector in Mexico, it is necessary to define alternative schemes to solve episodes of sanitary crises such as the current one. For this, it is necessary to opt for the integration of innovative technologies and methodologies that allow a rapid response to a contingency, seeking to lessen the impact on the health system.

### 3. Literature review

In the case of a Health system such as that of Mexico that has structural problems and a 70% full supply of medicines, facing a public health challenge such as the COVID-19 pandemic implies making value-added proposals that allow face contingencies like the current one. The design of a resilient medicine supply chain that can serve as a response to unexpected risks in the health system requires the participation of the different agents involved in the supply chain, in addition to the stewardship of the health department that allows the integration of wills and joint actions.

In the framework of an epidemic, it is necessary to guarantee medical supplies (medicines, vaccines, supplies, etc.) in addition to basic products (food, water, etc.). To guarantee the supply and supply of these products, it is necessary to have strategic storage and distribution centers that communicate with the expected demand points in the event of a contingency.

It is precisely a problem of designing an emerging logistics network in the face of disruptive events. For this, it is necessary to define the number and location of distribution and collection centers, unloading places and the location of demand centers, and the selection of optimal distribution algorithms that guarantee the best performance of the network. As well as the definition of the required optimal inventory levels, replacement policies, transportation, and distribution according to the health contingency that is being faced.

For the proper design of a network of this nature, it is necessary to have precise estimates of the demand required according to the contingency. Studies have been carried out combining demand estimation models related to epidemiological models of disease progression. Authors such as [7] propose a multi-objective programming model for the selection of emergency centers and the quantities of drugs to be transported from the supply sources to the demand points. In [8], they extend the vision of multi-objective programming towards a stochastic model using genetic algorithms for its solution. In [9], they integrate the analysis of system dynamics to model the dynamic behavior of the refueling, reception, and dispensing sources in the case of an anthrax attack. In [10], they propose a dynamic optimization model with variable replacement and transport times using heuristic methods for its solution. Other approaches consider logistics network designs with one-time supply and replenishment points [11]. Similarly, there are different versions of the modeling depending on the objective of the network, which can be to minimize inventory and transport costs or to minimize response time as a priority [12] and [13].

Various studies use the hybrid approach where they combine disease modeling through simulation and supply chain design through optimization models, [14] applies this approach to an anti-bioterrorism system. In [15], they analyze the distribution of medical supplies in affected areas considering a desirable minimum level of supply as well as maximum response times in addition to the associated costs. Similarly, vehicle routing problems are integrated into a context of epidemic control, works such as [16], [17] and [18] have addressed this problem in their logistics designs.

In [19], they show the development of a coordinated supply chain for the distribution of the influenza vaccine. Taking into account the non-linear demand given the behavior of the disease and the most effective immunization strategies, combining the epidemiological model with the supply chain. In addition to the necessary coordination between the government and the vaccine provider, through shared risk schemes.

The study shows in [20] presents a systematic review of the health and disaster supply chain literature, especially in the case of natural disasters. They highlight the

development of methodologies to abort the problem, based on operational management, information technology, inventory and control management, strategic management, and service management. As well as the application of new technologies for inventory management such as the use of RFID.

In [21], they develop a systematic review of relief distribution networks. Highlighting the contributions made about three stages defined in an emergency: a) preparedness and mitigation, b) response, and c) recovery. To attend to each stage, methodological contributions focused on location and network design, transportation (relief distribution and casualty transportation), and location and transportation are distinguished. Through exact and heuristic methods.

In [22], they present a literature review focused on epidemic control and logistics operations. Highlighting as a necessary attribute in the face of a health contingency the need for a quick response and coordination between the sectors involved to guarantee the supply of medical supplies, human and financial resources. Highlighting the time horizon in which you intervene, pre-event, or post-event. Bioterrorism, natural outbreaks, and disaster aftermath are considered as possible catastrophic events. The intervention considers as basic stages: 1) Preparedness, 2) Outbreak, 3) investigation, 4) Response, and 5) Evaluation. Table 3 shows the main logistical operations and decisions during the phases of an epidemic outbreak. The main methods

**Table 3.** Most important logistics operations and decisions during the phases of the outbreak

Phase	Most important logistic operations
Preparedness	Identification of sources Contract management Inventory management Periodical review and updating of medical supplies Facility location of stockpiling centers Network design transportation/distribution Selection of facilities/health Availability of funds
Outbreak investigation	Provision of appropriate materials Training of clinical workers Provision of commodities and resources to the outbreak response Collection, transportation, and storage of specimens Procurement, handling, storing and distribution of laboratory commodities
Response	Selection of facilities (PODs) Review and updating of supplies Transportation/distribution of supplies and commodities Procurement of supplies once depleted Dispensing of medical supplies, supplementary materials, and commodities to the public Establishment of a cold supply chain for essential medical supplies Management of human resources Scheduling available vehicles Adjustments to the capacity of health care facilities to hospitalize infected people Management of patients in triage centers
Evaluation	Identification and assessments of possible bottlenecks of delays Evaluation of timelines that should have been respected Follow-up and monitoring of patients for the effectiveness of treatments Identification of patients requiring dose modification of alternative treatment Development of indicators to evaluate the performance of logistics control operations Assessment coordination issues Establishment and operation of rehabilitation procedures

used to analyze the problems associated with the health supply chain are simulation, game theory, mathematical modeling, economic analysis, cost-effectiveness analysis, optimization, and analysis of multi-criteria decisions.

A recent study by [23] analyzes a reverse logistics network design for the treatment of medical waste, in

the framework of the COVID-19 pandemic in Wuhan (China). The study is of great importance due to the identification of a high rate of contagion as well as the residence time of the virus in objects that had contact with infected patients. Rapid response to the management of these wastes represents an opportunity to contain the spread of the epidemic. A multi-objective and multi-period model of mixed-integer programming is proposed for the design of the reverse logistics network.

The challenge is not less considering the complexity in the prediction of epidemic outbreaks, however, based on historical data, it has been possible to adequately model the probability of occurrence and possible scenarios of the magnitude of the problem. Stochastic variables and different simulation approaches must necessarily be included to obtain robust models. From a technical point of view, it is necessary to integrate innovative elements in supply chain management, such as the integration of:

- Multi-paradigm simulation schemes
- Discreet simulation
- Dynamic simulation
- Agent-based simulation
- Optimization algorithms
- Disruption event modeling
- Risk analysis in the supply chain

The use of data science tools, simulation, and optimization methodologies will allow efficient and timely management of the supply chain for medicines and supplies in a contingency. Currently, there is a specialized software that allows integrating different paradigms into hybrid models that allow generating technical evidence for public health decision-making.

#### 4. Resilient supply chain model

In this section, we develop the supply chain design model for a resilient supply network. We consider the model into a generalized network. The model is a mixed-integer linear problem.

Let  $K$  be the set of manufacturing plants. An element  $k \in K$  identifies a specific plant of the company. Let  $I$  be the set of the potential cross-docking warehouses. An element  $i \in I$  is a specific cross-docking warehouse. Finally, let  $J$  be the set of distribution centers, a specific distribution center is any  $j \in J$ . Let  $\mathbb{Z}$  denote the set of integers  $\{0,1\}$ .

#### 4.1. Parameters

- $Q_k$  = Capacity of plant  $k$ .
- $\beta_i$  = Capacity of cross-docking warehouse  $i$ .
- $F_i$  = Fixed cost of opening cross-docking warehouse in location  $i$ .
- $G_{ki}$  = Transportation cost per unit of the product from the plant  $k$  to the cross-docking warehouse  $i$ .
- $C_{ij}$  = Cost of shipping the product from the cross-dock  $i$  to the distribution center (CeDis)  $j$ .
- $d_j$  = Demand of the distribution center  $j$ .

#### 4.2. Decision variables

We have the following sets of binary variables to make the decisions about the opening of the cross-docking warehouse, and the distribution for the cross-docking warehouse to the distribution center.

$$Y_i = \begin{cases} 1 & \text{If location } i \text{ is used as a cross-docking warehouse,} \\ 0 & \text{otherwise,} \end{cases}$$

$$X_{ij} = \begin{cases} 1 & \text{If cross-dock } i \text{ supplies the demand of CeDis } j, \\ 0 & \text{otherwise,} \end{cases}$$

$W_{ki}$  = The amount of product sent from plant  $k$  to the cross-dock  $i$  is represented by continuous variables

We can now state the mathematical model as a (P) problem. See [24].

$$\min_{W_{ki}, Y_i, X_{ij}} Z = \sum_{k \in K} \sum_{i \in I} G_{ki} W_{ki} + \sum_{i \in I} F_i Y_i + \sum_{i \in I} \sum_{j \in J} C_{ij} d_j X_{ij} \quad (1)$$

Subject to constraints:

Capacity of the plant

$$\sum_{i \in I} W_{ki} \leq Q_k, \quad \forall k \in K \quad (2)$$

Balance of product

$$\sum_{j \in J} d_j X_{ij} = \sum_{k \in K} W_{ki}, \quad \forall i \in I \quad (3)$$

Single Cross-docking warehouse to distribution center

$$\sum_{i \in I} X_{ij} = 1, \quad \forall j \in J \quad (4)$$

Cross-docking warehouse capacity

$$\sum_{j \in J} d_j X_{ij} \leq \beta_i Y_i, \quad \forall i \in I \quad (5)$$

Demand of items

$$pY_i \leq \sum_{k \in K} W_{ki}, \quad \forall i \in I \quad (6)$$

$$p = \min\{d_j\} \quad (7)$$

$$W_{ki} \geq 0, \quad \forall i \in I, \forall k \in K \quad (8)$$

$$Y_i \in \mathbb{Z}, \quad \forall i \in I \quad (9)$$

$$X_{ij} \in \mathbb{Z}, \quad \forall i \in I, \forall j \in J \quad (10)$$

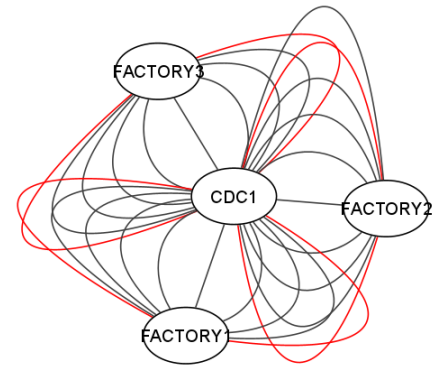


Figure 11. CDC-Factory links.

The objective function (1) considers in the first term the cost of shipping the product from the plant  $k$  to the cross-docking warehouse  $i$ . The second term contains the fix cost to open and operate the cross-docking warehouse  $i$ . The last term incorporates the cost of fulfilling the demand of the distribution center  $j$ . Constraint (2) implies that the output of plant  $k$  does not violate the capacity of plant  $k$ . Balance constraint (3) ensures that the amount of products that arrive to a distribution center  $j$  is the same as the products sent from the plant  $k$ . The demand of each distribution center  $j$  will be satisfied by a single cross-docking warehouse  $i$ , this is achieved by constraint (4). Constraint (5) bounds the amount of products that can be sent to a distribution center  $j$  from an opened cross-docking warehouse  $i$ . Constraint (6) guarantees that any opened cross-docking warehouse  $i$  receives at least the minimum amount of demand requested by a given distribution center  $j$ . Constraint (7) ensures that the minimum demand of each distribution center  $j$  is considered. Finally, constraints (8), (9) and (10) are the non-negative and integrality conditions.

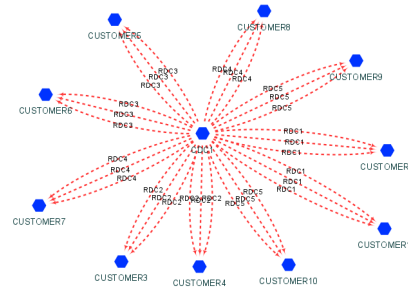


Figure 12. CDC-RDC-CUSTOMER.

## 5. Case study

In this section, we describe the case study. In particular, we consider the pharmaceutical supply chain in Mexico. The supply chain is made up of four echelons: two factories, one central-distribution center, three regional-distribution centers and thirty-two wholesale drug distributors. These facilities and clients are scattered throughout the country. Figs 11 and 12 represent the current structure of the supply chain.

The case study consists of finding a resilient solution that allows the supply chain to react efficiently to a disruption. The distribution centers will be the facilities subjected to hypothetical scenarios of disruption.

Table 4 shows the disruption scenarios considered.

All network diagrams were implemented in cytoscape software, see [25].

Table 4. Scenarios addressed in the case study

Scenario	Disruption	Breakdown time
I	One factory is closed due to health contingency	45 days
II	One DC is closed	30 days
III	All facilities are closed	15 days

### 5.1. Solution methodology

The solution methodology used in this research is based on simulation-optimization. The anylogistix software was used to develop the "what if" methodology. This software uses CPLEX as an optimization engine to find the best solutions within a set of possible solutions. First, the current situation of the pharmaceutical company's supply chain is modeled. Subsequently, the elements or facilities that make up the supply network are optimized. Several operating policies of the chosen supply network are simulated. Finally, disruptive events are generated to test the resilience of the proposals to the previously defined disruption scenarios, see fig 13.



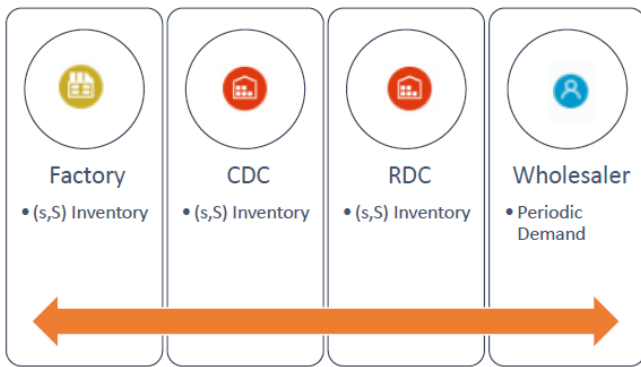


Figure 13. Inventory Policies and Demand

### 5.2. Computational results

Considering the three different scenarios, it was found that scenarios I and II are those that cause the greatest negative impact on the operation of the supply chain. For this, and for reasons of extension of the document, analysis of results shows the performance indicators for scenario I and scenario II. After running the optimization and simulation routines, the results obtained are as follows.

In the first instance, performance indicators for the current structure of the company were analyzed without disruption. Afterwards, the various scenarios were simulated. The variation experiment function, incorporated in ALX, was used to compare various key performance indicators. Fig. 15 shows the current supply chain network structure.

For scenario I, the service level by product, the available inventory of all the facilities and the average delivery time are shown in figs. 17, 18 and 19, respectively.

Scenario II, see fig. 12, as mentioned above, was the one with the greatest disruptive effects and it is the scenario that generates less profits. As seen in fig. 20, the level of service deteriorated to levels of 60% and 40% for each product. Figs. 21 and 22, shows the available inventory and lead-time.

Once scenario II has been optimized, see fig. 14, the results of the key performance indicators are reflected in Table 5. In this scenario, the highest profits are generated with a service level above 95%, see fig. 23. The available inventory and lead time are shown in figs. 24 and 25. Finally, the proposal to optimize scenario II is shown in fig. 16.

### 6. Conclusions

According to the scenarios outlined for the company, the epidemic outbreak of COVID-19 in Mexico caused several disruptions in the supply chain of medicines.

Table 5. Key performance indicators of proposal solution

Available Inventory	682342.6764	pcs
Demand (Products Backlog)	0	pcs
Demand Placed (Products) by Customer	1061896.722	pcs
Demand Received (Products)	2483056.467	pcs
Fulfillment Received (Products On-time)	1050395.745	pcs
Fulfillment Received (Products)	1421159.745	pcs
Fulfillment Shipped (Orders)	393	Order
Peak Capacity	989528	pcs
Products Produced	1545502.421	pcs
Profit	3.52E+08	USD
Service Level by Products	0.989169401	Ratio
Total Cost	3715253.767	USD
Transportation Cost	3715253.767	USD
Traveled Distance	41252.88728	km

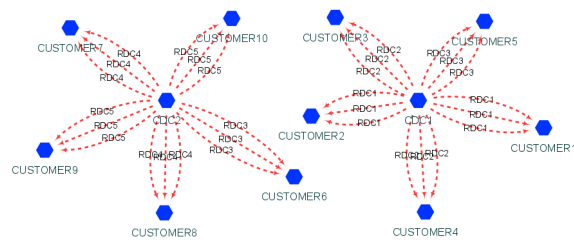


Figure 14. Several CDCs.

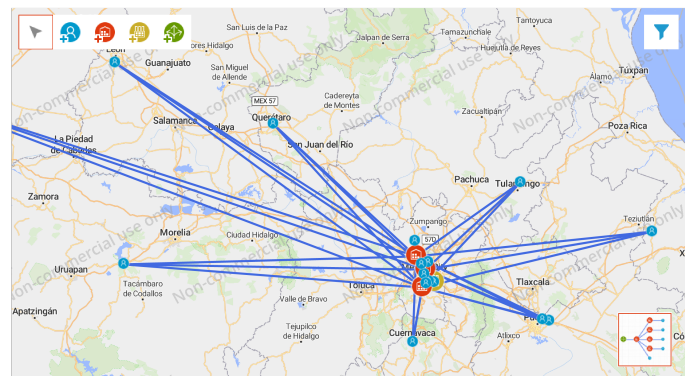


Figure 15. Current Supply Chain Network.

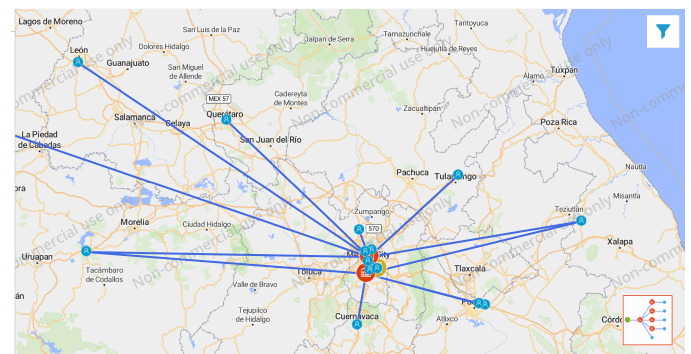


Figure 16. Supply Chain Network proposal.

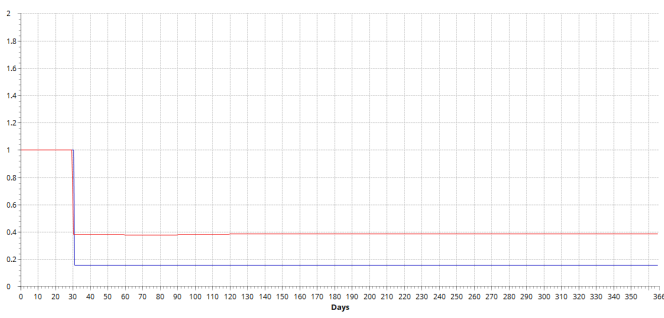


Figure 17. Service Level of Scenario I.

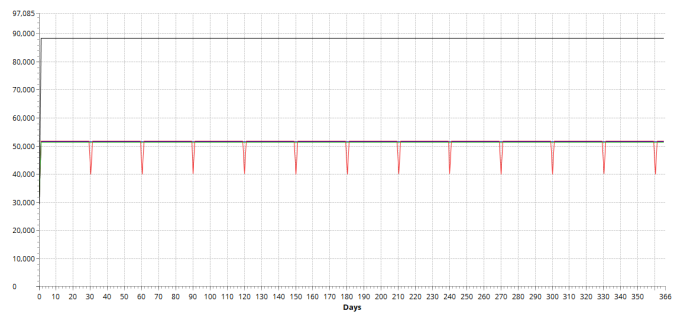


Figure 21. Available Inventory of Scenario II.

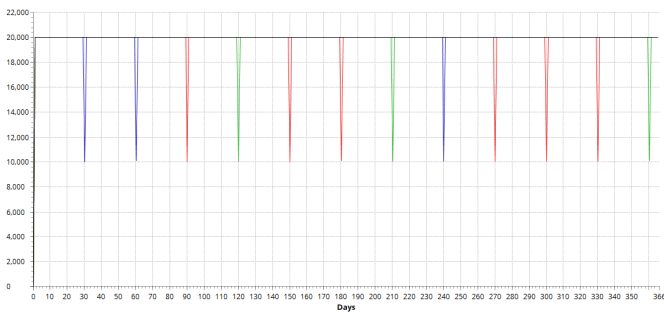


Figure 18. Available Inventory of Scenario I.

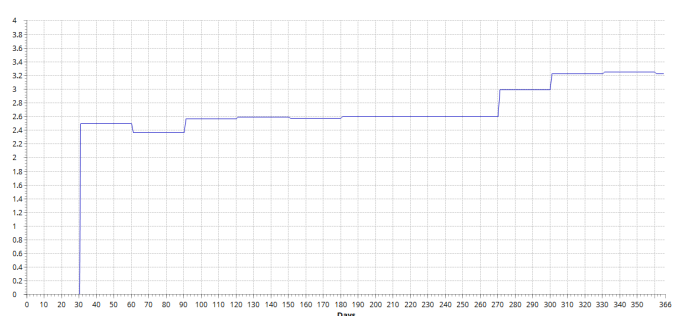


Figure 22. Lead-Time of Scenario II.

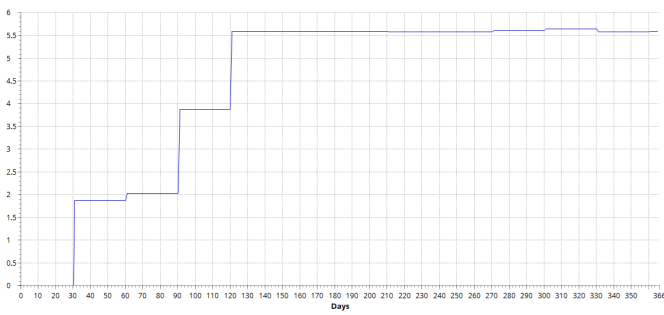


Figure 19. Lead-Time of Scenario I.

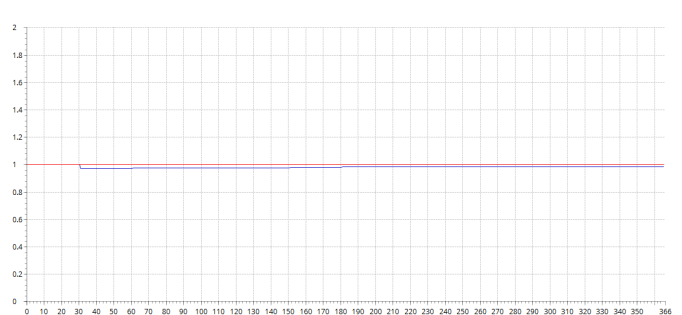


Figure 23. Service Level of Scenario II Optimized.

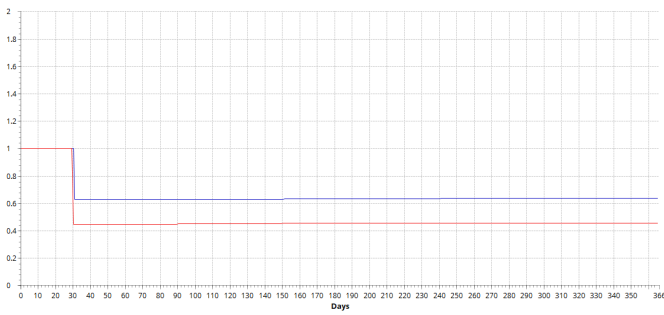


Figure 20. Service Level of Scenario II.

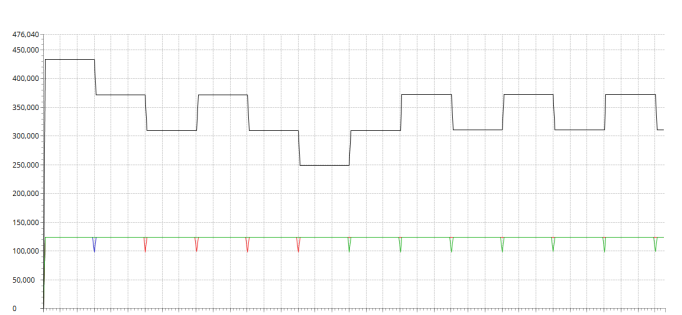


Figure 24. Available Inventory of Scenario II Optimized.

The solution methodology based on a simulation-optimization approach, allows analyzing the impacts

of the different recovery strategies for a subsequent

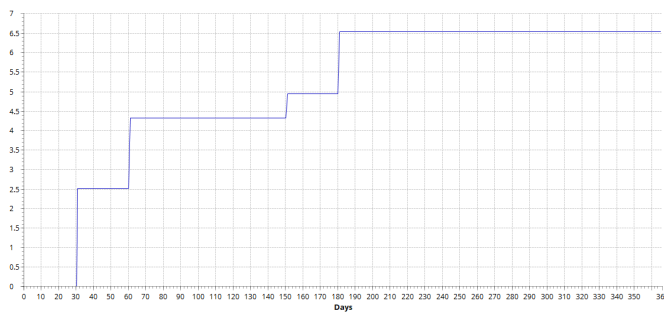


Figure 25. Lead-Time of Scenario II Optimized.

epidemiological outbreak. Additionally, the proposed approach allows enable a comprehensive view of the supply network, as well as fast and efficient responses to risky situations and changing.

Mexico has great health challenges, it is going through a demographic and epidemiological transition where chronic degenerative diseases predominate. The public sector medicine supply chain in Mexico has several structural problems related to the characteristics of the Health System. In 2018, the percentage of a full supply of medications represented 70%, historically maintaining a percentage of prescriptions not filled, which implies that the patient must expend out-of-pocket expenses to acquire their medications or not take treatment.

Starting from this deficient structure of the medicine supply chain in the public sector, facing an epidemic such as the case of COVID-19 represents a very important challenge for the Mexican health system. The present pandemic has represented a significant increase in the demand for public health services. As of April 28, 2020, a total of 77 thousand probable cases were registered in the epidemiological surveillance system, of which 16,752 cases were positive with COVID-19. The crude mortality rate represented 93.3 deaths per 1000 inhabitants, and adults and older adults with some chronic disease are mainly affected.

In this context, the need for a supply chain for medicines and supplies that allows dealing with external events such as a pandemic is evident. For this, it is necessary to take into account innovative concepts of supply chain management, simulation, risk analysis, and optimization. Being able to have robust and efficient designs will allow us to react quickly to a contingency.

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