Analysis of the Impact of the COVID-19 Pandemic on Key Supply Chain Processes Through System Dynamics

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Abstract
The pandemic caused by the COVID-19 virus has had negative effects on different industrial sectors, the world economy and especially on Supply Chains. The pandemic revealed the vulnerability of key logistics processes of companies and their Supply Chains as operational risks increased, causing breaks in inventories, production lines and the distribution process caused by increased customer demand. However, this pandemic makes it necessary to re-evaluate the models and strategies that companies had established as the standard, and more was needed to face the shortage of components, raw materials and inputs needed to keep the production processes active. Therefore, this article proposes developing a conceptual model under the System Dynamics methodology, which allows identifying the main impacts that the COVID-19 pandemic had on the performance of the Supply Chain through the design of Causal Loop Diagrams.

Keywords
COVID-19, Supply Chain, System Dynamics, Causal Loop Diagrams

1. Introduction
In December 2019, the first cases of atypical viral pneumonia were detected in Wuhan, China. Preliminary findings showed that all these cases had symptoms like H1N1 flu; however, studies determined that it was a new virus named SARS-CoV-2, and later, it was named COVID-19. Due to frequent air travel between China, Europe, the United States and other countries, the new virus spread in the following weeks among the world's population, and the World Health Organization declared it a pandemic, posing a devastating threat to human health (Al-Rohaimi & Otaibi 2020).

According to Pongutta et al. (2021), in addition to the negative effects it generated on the health of the population, COVID-19 also caused adverse effects on other aspects of life due to the measures implemented by governments to control the disease; for example, social distancing, the use of rubber bullets, closure of ports and port logistics activities, generating the delay of goods and disruptions in different global Supply Chain, stoppages in production lines to protect personnel from a massive contagion, causing product shortages, online classes, which was a way for schools to avoid massive contagions among students, but to keep the curricula active, among others.

The COVID-19 pandemic has been different from other pandemics, given that its appearance generated different risks that had an impact on globalized production systems, where small interruptions can trigger a series of unquantifiable impacts on the world economy, as well as on the functioning of Supply Chain, which are coupled and complex systems (Kontogiannis 2021).

Supply Chain has faced several severe disease outbreaks in the recent past; the World Health Organization (WHO) has 1,438 epidemics reported between 2011 and 2018 alone (Chowdhury et al. 2021); however, the COVID-19 pandemic is unique in that it has had even more severe, diversified and dynamic impacts than those of previous epidemic outbreaks, such as the 2003 SARS epidemic, which wreaked the greatest havoc in China, Hong Kong, Taiwan, Singapore, Vietnam and Canada (Thompson 2003), or the H1N1 epidemic of 2009, which was fortunately short-lived. In addition to China, the countries most affected by COVID-19 have been the United States, Italy and Spain, followed by Brazil, Russia and India (Al-Rohaimi & Otaibi 2020).

A report published by Fortune magazine (2020) (before the WHO reclassified the COVID-19 outbreak as a pandemic on March 11, 2020) revealed that due to the virus, 94% of companies were facing disruptions in their Supply Chain. Moreover, unlike other outbreaks, this pandemic affected all nodes (members) and edges (relationships) of a Supply Chain simultaneously; therefore, Supply Chain flow was substantially disrupted. For example, demand for necessary items such as personal protective equipment (PPE), fans, and dry and canned foods increased dramatically, while supply, transportation, and manufacturing faced numerous challenges that reduced their capabilities (Paul & Chowdhury 2020).

In global trade, companies obtain components, inputs and raw materials from all over the world; however, governments have imposed total or partial blockades in their countries, which have restricted the mobility of vehicles to limit the spread of the virus; such measures have substantially affected the ability of suppliers to deliver products on time to customers. In production management, supplier failures generate severe production interruptions and delays for companies. In addition, the production capacity of companies was reduced due to home office, restricted office hours and staggered schedules to avoid massive staff contagions (Chowdhury et al. 2021).

COVID-19 has affected the purchasing behavior pattern (demand) of consumers. In some cases, there was an increase in demand for commodities, such as food, medicines and fans (Paul & Chowdhury 2021), originating a temporary shortage of products (Deaton & Deaton 2020) and, consequently, delays in delivery to customers through traditional and online distribution channels, deriving in the loss of security in essential items, such as food (Siche 2020); conversely, non-essential products have seen a downward demand, because customers' incomes have decreased and they prefer to save money for an uncertain future (Abhishek et al. 2020). Hobbs (2020) mentions that such demand spikes include panic buying, uncertainty about the future, and stockpiling behaviors. A study by Yuen et al. (2020) identified the following factors as causes of panic buying: perceived threats, fear of the unknown, copying the behavior of others, and social psychological factors; as a solution, he suggests that information that generates panic buying should not be disseminated to the public. The sudden fluctuation in demand creates ambiguity and uncertainty in Supply Chains, affecting forecasting, decision-making, and product pricing. At the same time, the price of essential products increases and non-essential products decreases (Gunessee & Subramanian 2020).

For the reasons mentioned above, this article proposes to identify the impacts generated by COVID-19 on the key logistic processes of the Supply Chain, for which a conceptual model was designed using the System Dynamics methodology, which allows analyzing these relationships from a systemic approach.

2. Literature Review

2.1 Supply Chain Risks

Risk is a possibility of negative economic impact, physical damage, or delays due to the uncertainty associated with the actions developed (Osorio et al. 2017). In the context of the Supply Chain, the risk is the potential loss of a Supply Chain in terms of its target values of efficiency and effectiveness due to the uncertain evolution of the chain characteristics when triggering events occur (Heckmann et al. 2015). Risks cannot be eliminated, which makes organizations need to manage all the factors that increase and reduce them to achieve strategic advantages at minimum cost. Figure 1 shows a classification of risks (Ivanov 2021),

There are various ways of categorizing the types of risk, but the most relevant in the Supply Chain are risks external to the company, internal to the chain and external to the chain. According to Tang (2006), there are two types of risks in the Supply Chain:
Operational Risks.
Disruptive Risks.

Operational Risks
Operational risks refer to the inherent uncertainty about what happens daily in operations.

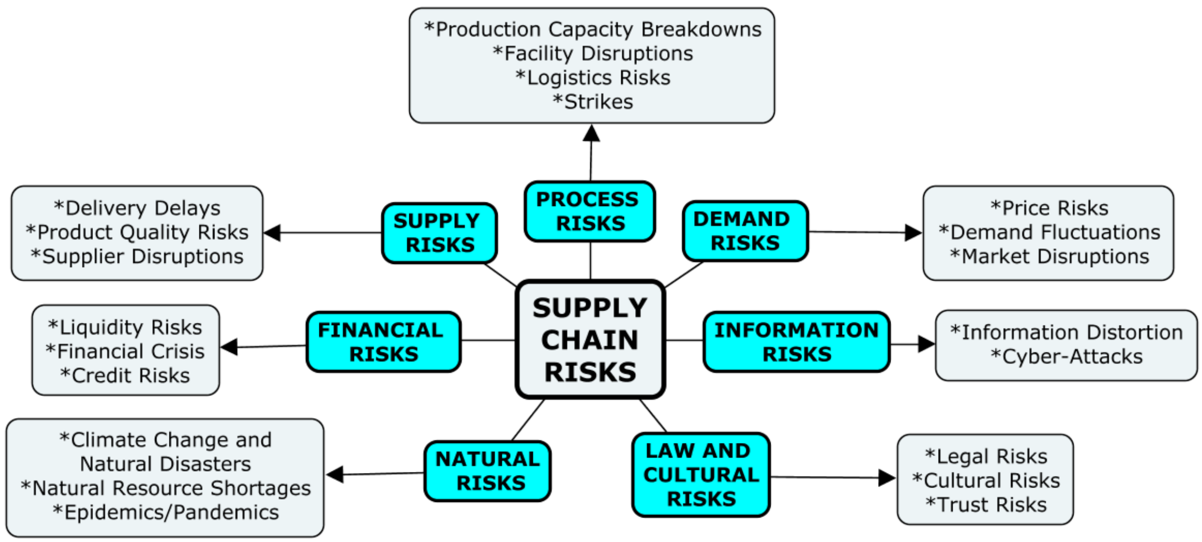

Figure 1. Operational Risks. Source. Adapted from (Ivanov, 2021).

Disruptive Risks
A disruption is an unexpected event that interrupts the normal flow of goods and materials in a Supply Chain network and has a severe negative impact on Supply Chain operations and performance. Disruptive risks are events caused by natural catastrophes, such as hurricanes, earthquakes or man-made threats, such as terrorist attacks or labor strikes. Disruptive risks vary unpredictably in type, scale, and nature; they are intermittent and irregular, making them difficult to identify, estimate and forecast, and have negative short- and long-term effects. An example of this is the COVID-19 pandemic (Ivanov 2021).

In most cases, the business impact associated with disruptive risks is much greater than operational risks. However, although operational risks have a relatively small impact on the Supply Chain, if not addressed correctly and promptly, the risk will be amplified throughout the chain (Osorio et al. 2017).

2.2 Supply Chain and COVID-19
Sawick (2022) identifies the main impacts generated by COVID-19 on Supply Chains:

- Increased demand for essential commodities, goods and health products.
- Shortages of essential commodities, goods and health products
- Decrease in demand for non-essential products
- Shortages of raw materials and inputs
- Reduced production capacity
- Limited availability of workers
- Reduced logistics capacity of logistics companies and suppliers
- Loss of physical distribution channels

- Delays in transportation and distribution

Likewise, Sawik (2022) proposes some resilience strategies to mitigate the impact of COVID-19 pandemic disruptions in supply chains, which are:

Multiple and backup suppliers in diversified locations.
Prepositioning of Raw Material Inventory and reserve capacity
Relocation and reassignment to the country of origin from a foreign country to shorten the global supply chain and rebuild domestic supply chains
Digitization and automation

Ivanov (2021) identifies that the pandemic (COVID-19) has revealed that Supply Chains have different areas of opportunity, such as:

- Reducing lead times and designing better strategies for calculating safety inventories.
- Improving forecasting techniques to respond to demand peaks or panic buying.
- Synergy with other sectors, such as government, from which support can be obtained when pandemic scenarios arise.
- Improve logistics collaboration networks between elements of the Supply Chain.

A summary of some proposed strategies to improve the performance of supply chains in the face of pandemic events is presented in Table 1 (Chowdhury et al. 2021; Chowdhury & Quaddus 2016; Ponomarov & Holcomb 2009). These strategies impact a supply chain's resilience in three dimensions: preparedness, response, and recovery. A strategy is a preparedness if it is preemptive to future disruptions; a strategy is considered responsive if it can help supply chain members react quickly by minimizing immediate impacts, and recovery if the strategy can help the supply chain return to its original state or even better.

3. Methodology

The methodology used to develop the conceptual model to identify the impacts of the COVID-19 pandemic on Supply Chains is described below, taking into consideration the methodology proposed by Cedillo & Sanchez (2008) for the structuring of models in System Dynamics; since the objective of the article is to develop a conceptual model, the first phase will be used, which is the conceptualization, in which the key variables of the system are identified and through a causal diagram, the relationships between them are identified.

In the conceptualization phase, the variables that allow the construction of the causal diagram are identified, classified and described, in this case, to help identify the impacts generated by the pandemic in the key logistic processes of the Supply Chain.

Table 1. Strategies for managing the impacts of the COVID-19 pandemic on the Supply Chain. Source: Adapted from (Chowdhury et al. 2021; Chowdhury & Quaddus 2016; Ponomarov & Holcomb 2009).

Strategy	Resilience dimensions		
	Preparedness	Response	Recovery
Gradual increase in production		●	
Development of temporary production capacity		●	
Flexible manufacturing systems	●	●	
Modification of product characteristics		●	
Customized production/redesign of emergency items		●	
Maintaining and improving transport capacity.		●	
Sharing resources with other actors in the chain		●	●
Improve visibility through supply networks	●	●	●
Consider backup suppliers	●	●	●

Emergency sourcing		●	●
Nearshoring	●		●
Narrow supply chains	●		●
Online sales	●	●	●
Digitization and intelligent communication channels	●	●	●
Automated production systems	●	●	●
Contactless and self-service payment systems	●	●	●
Developing new supply chain partnerships		●	●
Supply chain collaboration and relationships	●	●	●
Synchronization of strategic processes			●
Knowledge management and information sharing		●	●
Real-time changes with dynamic responses	●	●	●
Price reduction		●	
Personnel security measures		●	

The variables are identified through an analysis of the state of the art and field visits and are classified into exogenous and endogenous. For the proposed causal diagram, the exogenous variables (they are part of the system, but there is no control over them) are as follows:

- *Percentage of direct distribution channels:* proportion of direct distribution channels.
- *Locals of direct purchase's availability*: number of stores open for direct service.
- *Airports availability*: percentage of airports in service.
- *Road availability*: percentage of roads with access.
- *Port availability*: percentage of ports in service.
- *Railway stations availability*: percentage of railway stations in service.
- *Transport percentage in circulation*: percentage of transport in circulation.
- *Materials availability*: quantity of raw materials, inputs and other materials.
- *Vendor inventory*: raw material in supplier's inventory.
- *Supplier lead time*: the amount of time estimated by the supplier to deliver raw materials.
- *Supplier delays*: the time estimated by the supplier to deliver raw material.
- *Disruption days*: number of days with production stoppages.
- *Covid-19 infections*: number of people infected by COVID-19.
- *Employees reported sick*: number of employees who have contracted COVID-19.
- *Confinement days*: number of days of social isolation.
- *Employment Rate*: ratio of the employed population to the working-age population.
- *Essential product demand:* the total quantity of essential products the population requires.
- *Non-essential product demand:* the total quantity of non-essential products the population *requires.*
- *Demand fluctuation:* quantities of the product above or below the forecast requirement.
- *Product price: the* amount of money that allows the acquisition of products or services offered.
- *Per capita income:* average gross domestic product per capita.
- *Uncertainty:* magnitude of the randomness of occurrence of unexpected events.
- *Forecast Effectiveness:* percentage of accuracy of expected demand.
- *Tabloid ads:* some ads with false information promote panic among the population.
- *Panic shopping:* proportion of excessive purchases of products offered in the market.
- *Availability of products in the market:* quantity of products available for purchase by the customer.
- *Damaged products:* quantity of products with physical or chemical composition alterations.
- *Fulfilling customer demand: the* ratio between customer demand and actual quantity delivered.
- *Customer satisfaction percentage:* degree of fulfillment of customer expectations after receiving a product.
- *Customer's complaints:* number of non-conformities received from the customer.
- *Penalties costs: the* amount of money paid by the company to pay penalties for non-delivery of orders.

The endogenous variables (variables that can be controlled or managed in the system) identified are as follows:

- *Percentage of digitization of distribution*: the ratio between electronic distribution channels and the total number of direct distribution channels.
- *Investment in electronic means of distribution*: the amount of money spent on acquiring ICTs and software as distribution channels.
- *Support Provider Orders*: lot size of raw material ordered from an alternate supplier.
- *Backing Stock*: additional lot size of raw material ordered from the base supplier.
- *Order providers*: quantity of raw material orders requested from the supplier.
- *Supplier lot size*: quantity of raw material ordered from the supplier.
- *Raw material inventory's desired level*: minimum quantity of raw material to be kept in stock.
- *Nearshoring Investment*: the money spent on outsourcing projects in nearby countries.
- *Associations with companies*: proportion of agreements with other companies for resource sharing.
- *Integrated Warehouse Parts*: number of parts coming from other warehouses.
- *Reused parts*: the ratio between the proportion of reused materials and the total materials used to manufacture a product.
- *Raw material inventory*: quantity of raw material in stock in the company's inventory.
- *Personal protective equipment investment*: the amount of money spent on purchasing personal protective equipment for employees.
- *Schedule Working*: the amount of time allocated to carry out the company's productive activities.
- *Temporary employees*: number of employees available who do not belong to the company.
- *Shift workers*: number of workers present per working day.
- *Machinery's investment*: the amount of money spent on purchasing machinery.
- *Temporary production capacity*: production capacity available with other companies.
- *Production capacity*: capacity of the production unit to produce its maximum product level with a set of available resources.
- *Production capacity reserve*: capacity not intentionally used so that it is available in an unforeseen event that demands faster or greater production.
- *Production line*: the set of operations through which raw material flows to be transformed.
- *Production plan*: estimated production quantity to be obtained for a given period.
- *Finish product inventory*: quantity of product ready to be shipped to the customer.
- *Production flexibility percentage*: the ratio between the company's production and the number of alternative products produced.
- *Alternative products manufactured*: quantity of alternative products produced.
- *Customer Shipments*: quantity of product shipped to the final customer.
- *Customer delivery time*: expected time to deliver the finished product to the customer's premises.
- *Delivery time backing*: the amount of time intentionally added to the amount foreseen to deliver the finished product to the customer.
- *Distribution efficiency percentage*: number of trailers, cars or other external means of transport used to deliver the finished product to the customer's premises.
- *3LP Transport*: actual number of orders delivered in a given period divided by the number of expected orders.

The Causal Loop Diagram was designed (Figure 2) using the variables described above.

4. Results and Discussion

The Causal Loop Diagram in Figure 2 identifies the impacts generated in the key logistic processes of the Supply Chains caused by the COVID-19 pandemic. Fifty-eight feedback loops are identified, the most important of which are described below:

4.1 COVID-19

Loop B1: The B1 balancing loop comprises *Covid-19 infections* and *Confinement days*, considered most relevant as it is a key strategy to eradicate the pandemic. If *Covid-19 infections* increase, then *Confinement days* will have to increase; therefore, if *Covid-19 infections* decrease, then *Confinement days* will also decrease.

Loop B2: The balancing loop comprises *COVID-19 infections*, *Confinement days*, and *Employees reported sick*. It is considered important because it provides a strategy to curb or decrease the sick worker population and thus decrease labor shortages. *If COVID-19 infections* increase, then *Confinement days* will have to be increased. Likewise, if *Confinement days* increase, then *Employees reported sick* will tend to decrease and; if *Employees reported a sick* decrease, then *Covid-19 infections* will decrease.

Loop B3: The balancing loop comprises *COVID-19 infections* and the *Percentage of means of transport in circulation.* The relationship between these variables is fundamental since the consequence of a minimum percentage of transport would severely impact the procurement process by limiting the availability of raw materials and other inputs. If *COVID-19 infections increase*, then *the Percentage of means of transport in circulation* will decrease; conversely, if *the Percentage of means of transport in circulation* increases, then *COVID-19 infections* will rise.

Loop R19: The reinforcement loop consists of *Uncertainty, Tabloid ads* and *Panic shopping*. If *Uncertainty* increases, then *Tabloid* ads will increase; if *Tabloid ads* increase, then *Panic shopping* will also increase.

Loop R20: This loop comprises *Demand fluctuation* and *Forecast Effectiveness*. If *Demand fluctuation* increases, then *Forecast Effectiveness* will decrease, and if *Forecast Effectiveness* decreases, then *Demand fluctuation* will increase.

Loop R32: The reinforcement loop consists of *Covid-19 infections* and *Employees reported sick*. If *Covid-19 infections* increase, then *Employees reported sick* will increase. Similarly, if *Employees report sick increases*, then *Covid-19 infections* will also increase.

4.2 Supply Process

Loop B7: The B7 balancing loop comprises *Raw material inventory*, *Order providers* and *the Raw material inventory's desired level*. If *the Raw material inventory* decreases, then the *Raw material inventory's desired level* will be below the required amount of raw material, and then if the *Raw material inventory's desired level* decreases, then *Order providers* will increase.

Loop R23: The reinforcement loop R23 consists of *Materials availability, Vendor inventory, Order providers, Raw material inventory, Raw material inventory's desired level, Supplier lot size, and Support provider orders*. If *Materials availability* decreases, then *Vendor inventory*, *Order providers* and *Raw material inventory* will also decrease. *If the Raw material inventory* decreases, then the *Raw material inventory's desired level* will be below the desired quantity; then, if the *Raw material inventory's desired level* is below the required quantity, *the Supplier lot size* will increase. If the *Supplier lot size increases*, then *Support provider orders* will increase. Finally, if *Vendor inventory* increases, then *Materials availability* will also increase.

Loop B23: This balancing loop comprises *Nearshoring investment* and *Materials availability*. If *Nearshoring investment* increases, then *Materials availability* will increase; however, a delay is identified in this relationship due to the negotiations involved in implementing this strategy. Likewise, if *Materials availability* decreases, then *Nearshoring investment* should increase.

Loop R8: The reinforcement is conformed to *Integrated warehouse parts* and *Associations with companies*. If *Integrated warehouse parts* increase, then *Associations with companies* will have to increase. Likewise, if *Associations with companies* increase, then *Integrated warehouse parts* will increase; however, a delay is identified in this relationship due to the time involved in the negotiation process.

4.3 Production Process

Loop B30: This loop *comprises raw material inventory, Production capacity,* and *Production Line*. If *Raw material inventory* increases, then *Production capacity* will increase. If *Production capacity* increases, then *Production Line* will increase; however, if *Production Line* increases, then *Raw material* inventory will decrease.

Loop B28: The balancing loop is conformed for *Production Line* and *Finished Product Inventory*. If *Production Line* increases, then *the Finished Product Inventory* will increase; conversely, if the *Finished Product Inventory* increases, then *Production Line* will have to increase.

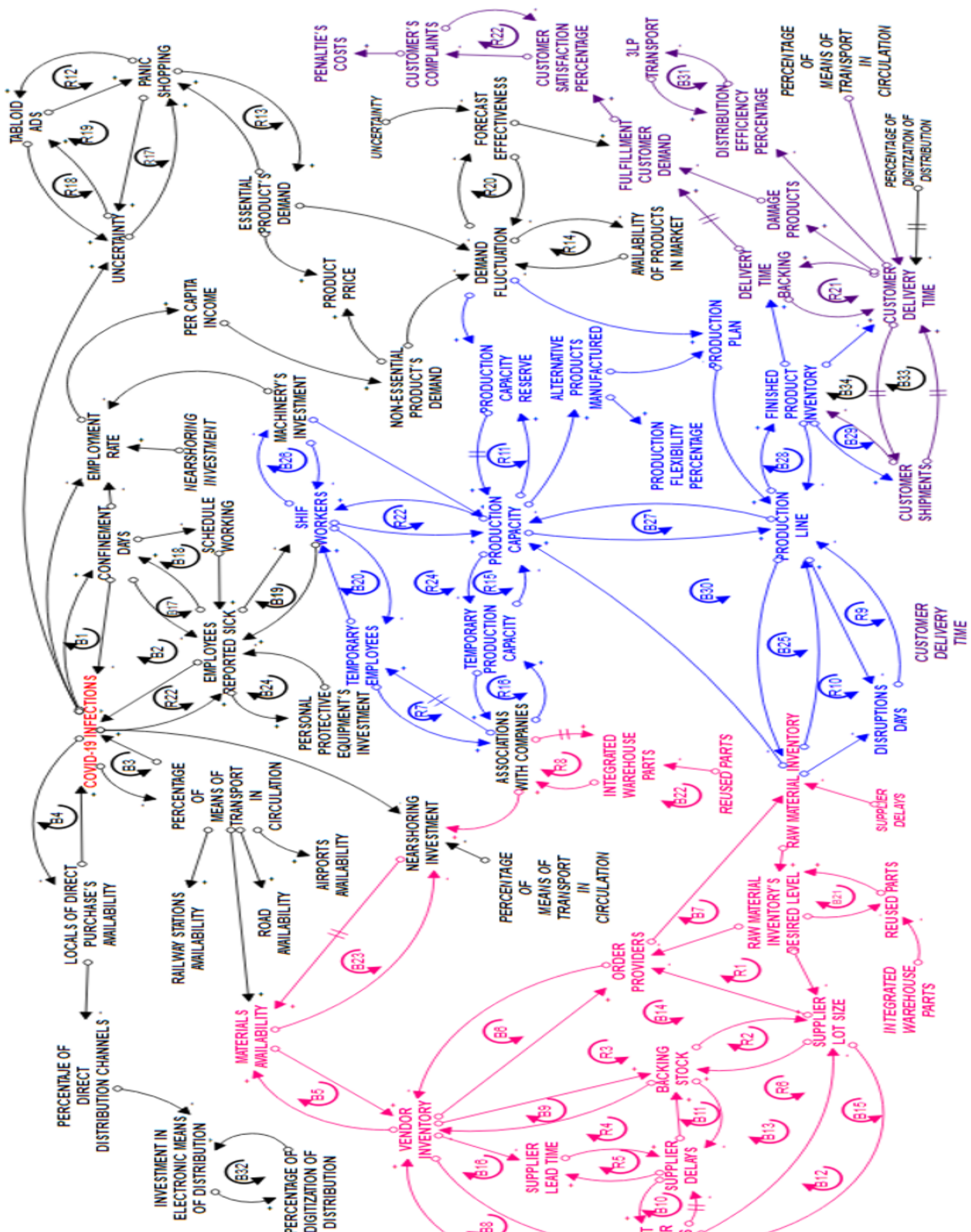

Figure 2. Conceptual Causal Loop Diagram

4.4 Distribution Process

Loop B33: This balancing loop comprises *Customer shipments* and *Customer delivery time*. If *Customer shipments* increase, then *Customer delivery time* will increase; in this relationship, a delay is identified due to the shipments that elapse, causing the delivery time to be extended. Therefore, if *Customer delivery time* increases, then *Customer shipments* will decrease, also identifying a delay since the customers of the last shipments will be dissatisfied with the delivery time and stop placing orders.

Loop B34: In this balancing loop, If the *Finished Product Inventory* decreases, then *Customer delivery* will increase. If *Customer delivery time* increases, then *Customer shipments* will decrease, and if *Customer shipments* increase, then *the Finished Product Inventory* will increase.

Loop B31: This balancing loop comprises *Distribution efficiency percentage* and *3LP transport*. If the *Distribution efficiency percentage* decreases, then *3LP transport* will increase, so if *3LP transport* increases, then *the Distribution efficiency percentage* will also increase.

Loop R22: The reinforcement loop consists of *Customer complaints* and *Customer satisfaction percentage*. If *Customer complaints* increase, then *the Customer satisfaction percentage* will decrease; on the contrary, if *Customer complaints* decrease, then *the Customer satisfaction percentage* will increase.

4.5 Study Case

To validate the causal diagram presented in Figure 2, a company located in the State of Veracruz, Mexico, producing ethanol was considered a case study.

4.5.1 Company context

The company, which for confidentiality will be called Company A, produces ethanol from molasses generated in sugar cane refining by the sugar mills. The company's supply process consists of the accumulation of molasses (inventory), its main raw material. Depending on the harvesting time (sugarcane harvest), it only allows for a continuous supply throughout the year.

Figure 3 shows the ethanol production process supply chain, starting with the sugarcane harvest, which is the raw material for the sugar mills, which produce sugar and the residue of this process is molasses, which becomes the raw material for company A, which through a fermentation and distillation process produces approximately 430 thousand liters of ethanol daily, in different grades of quality, ranging from medical use to biofuel for automobiles.

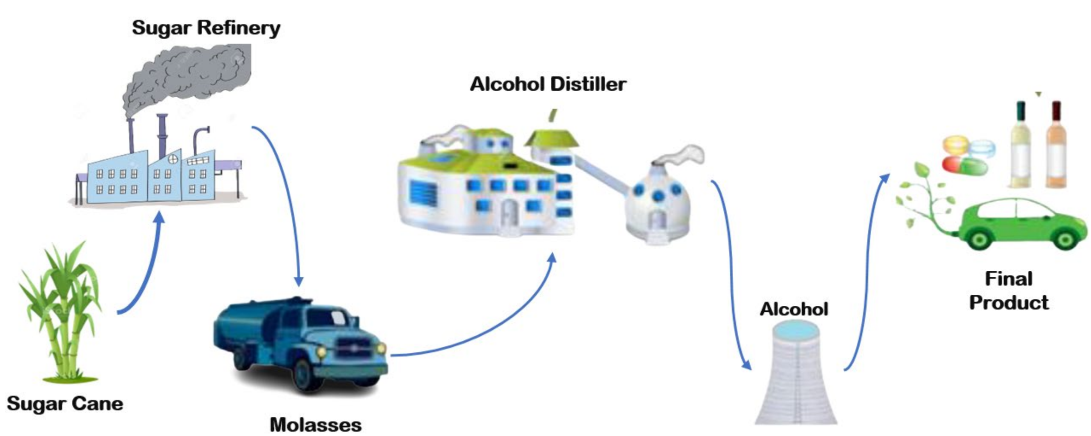

Figure 3. Ethanol Supply Chain.

The following section will evaluate how COVID-19 impacts the company's operations by analyzing the production process. With the support of the causal diagram in Figure 2, a simulation model of company A's supply chain was developed, and different analyses were carried out using STELLA ARCHITECT® software.

4.5.2 Simulation results before COVID-19

Figure 4 shows the behavior of the daily ethanol production of company A (Production Line) before the COVID-19 pandemic, which is approximately 430 thousand liters per day. It is important to mention that the company plans a 15-day technical shutdown for cleaning the distillation towers and plant maintenance, a period in which production is zero, as shown in Figure 4.

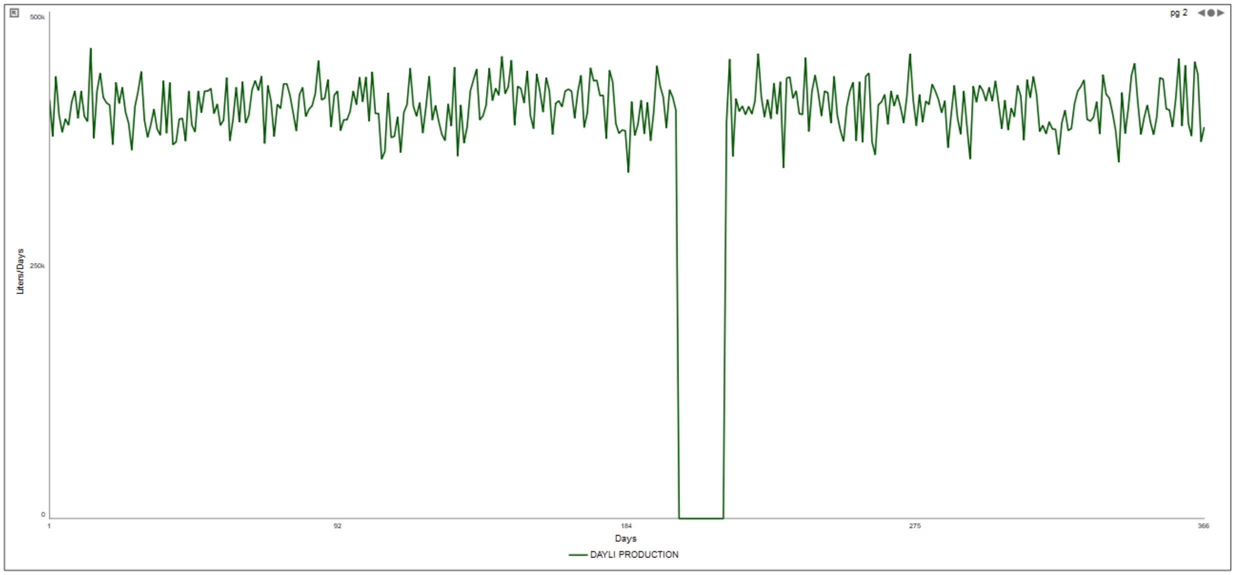

Figure 4. The behavior of the production line before COVID-19

4.5.3 Simulation results with COVID-19

During the first quarter of 2021, Mexico was experiencing the second pandemic peak, and the vaccination process was in its early stages; although the companies had different safety and health protocols, there were still infections among their workers, as was the case in company A. In Figure 5, the blue line represents the contagion process among the company's employees. As can be seen, the contagion curve increases progressively and directly impacts the decrease in daily production (green line) due to employees' absence. When the company identified that the number of infections did not decrease, it suspended activities from entering a quarantine process to avoid a massive contagion.

Figure 5 shows that the peak of infections reached 30 employees, and during the quarantine process, the production process showed 8 days of disruption (red line). Once the quarantine period is over, the production process starts its operations gradually until it reaches the stabilization of the production process as before the pandemic. In the following months, the vaccination campaign for COVID-19 in Mexico began for the entire population, helping to reduce the number of infections.

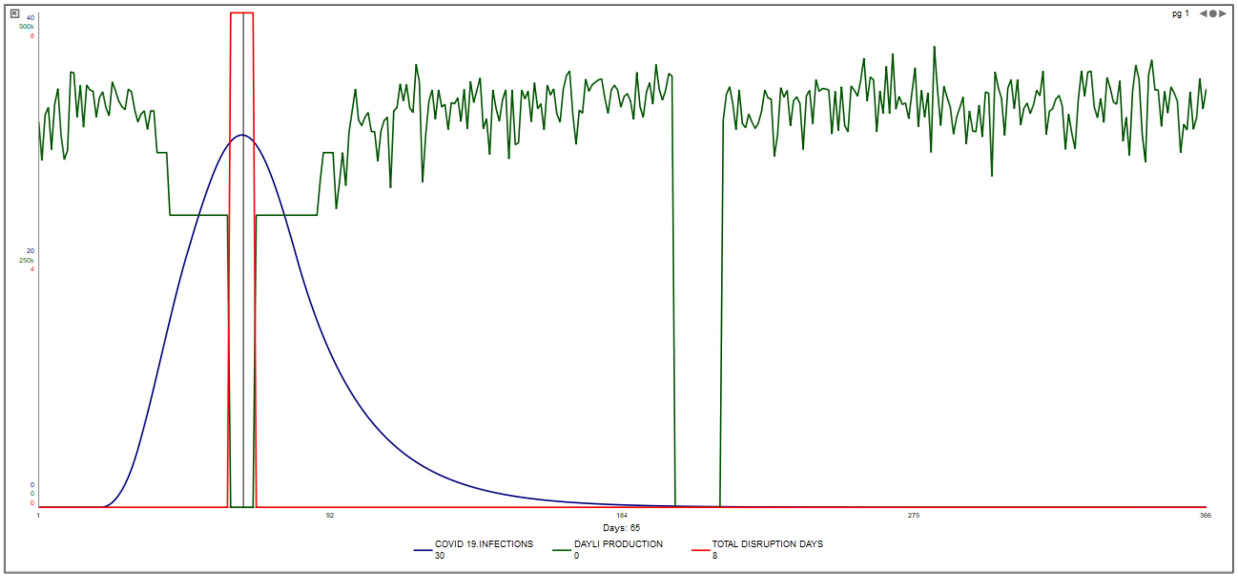

Figure 5. The behavior of the production line during COVID-19

4.5.4 Scenarios

With the proposed model, two scenarios were evaluated, considering what would have happened if the employees of Company A had been vaccinated during the second peak of the pandemic. For this purpose, the percentage of vaccinated employees was added to the simulation model. In the first scenario, 50% of employees were vaccinated; in the second scenario, 80% were vaccinated.

Figure 6 shows the behavior of the first scenario, in which it was proposed that 50% of the employees of company A would have been vaccinated. It can be seen that the daily ethanol production process (green line) only has two days of disruption (red line), and the maximum peak of infection is 10 employees (blue line). According to the model, vaccination would positively affect the daily alcohol production process since there would be fewer infections, and production would be more stable.

Figure 7 presents the second scenario, in which it is proposed that 80% of the employees of company A be vaccinated. According to the simulation model, although the maximum peak of infections would be 5 employees (blue line), these would not have a negative impact on the daily production process (green line), so there would be no disruptions in the production process (red line). As in the previous scenario, vaccination would positively impact the production process since it would reduce the massive contagion of employees, and although there would be cases of COVID-19, these would not affect the production process.

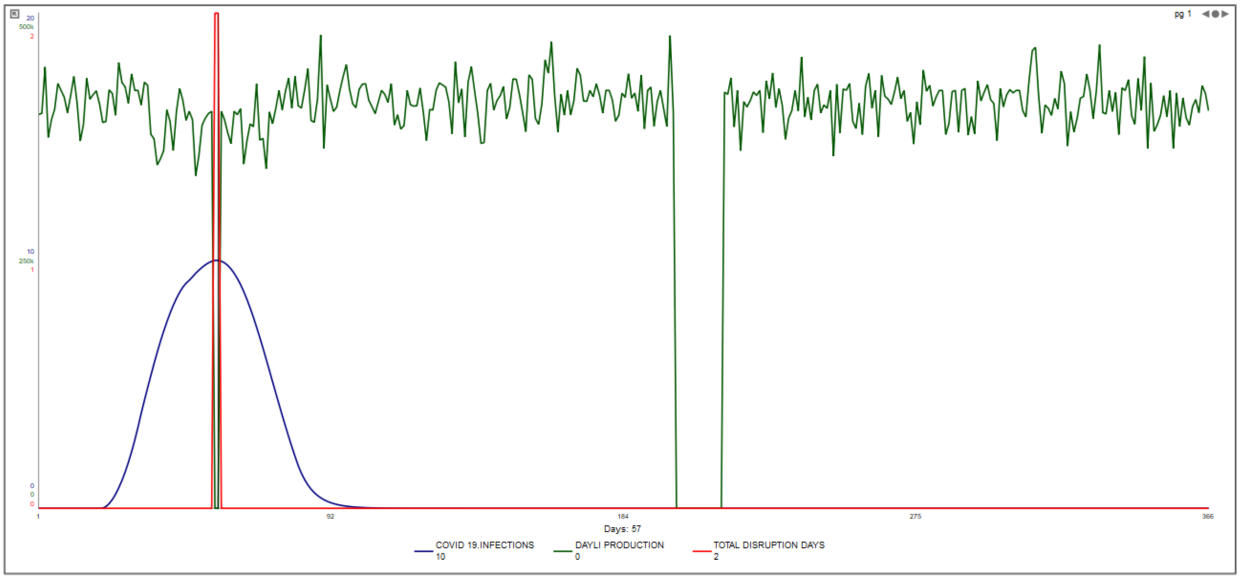

Figure 6. Scenario 1, 50% of employees are vaccinated.

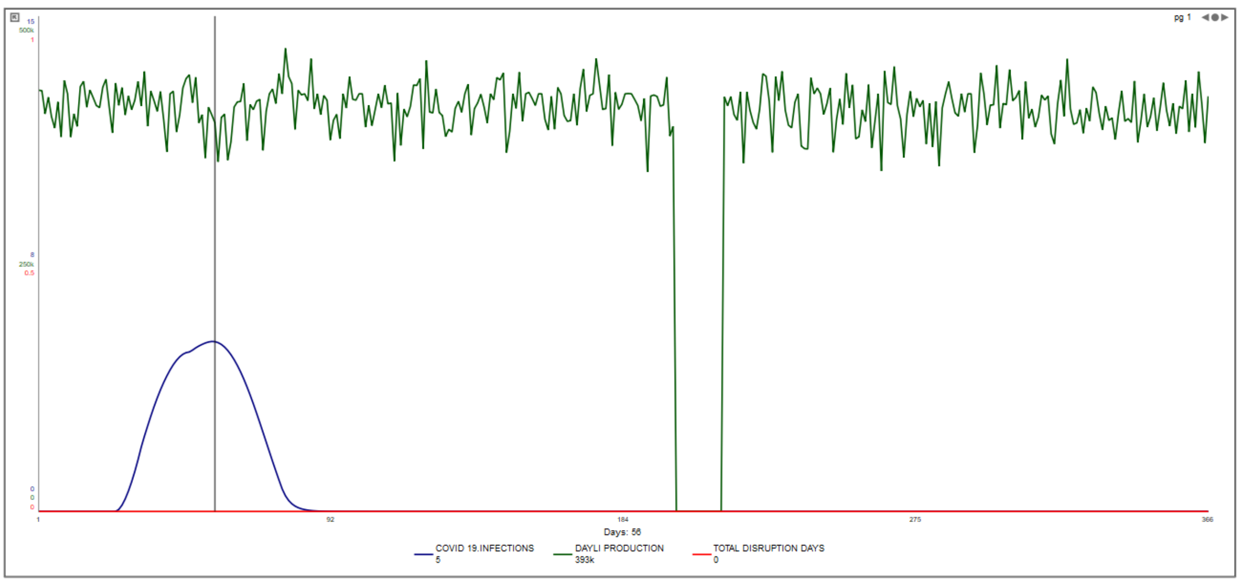

Figure 7. Scenario 2, 80% of the employees are vaccinated.

5. Conclusion

Causal Loop Diagrams are a System Dynamics tool that allows for identifying the causal relationships between the key variables of a system. In this article, it was possible to identify the impacts generated by COVID-19 on the key logistic processes of a Supply Chain, which are: procurement, production and distribution. 58 feedback loops were identified, of which 24 are reinforcing, and 34 are balancing.

With the proposed causal diagram, a simulation model was developed using STELLA ARCHITECT ® software. The simulation model allowed us to analyze and evaluate some causal relationships, such as the impact that COVID-19 has on the employees' contagion and how their absence can affect the production process. Likewise, two scenarios were proposed; the first one evaluated what would happen in the production process if 50% of the employees had been vaccinated, with the result that this would have a positive impact on the production process since there would be less contagion and production would remain stable. The second scenario evaluated what would happen if 80% of the employees had been vaccinated; the simulator showed that although there would be contagions in at least 5 employees, these would not affect the company's operations, and the ethanol production process would remain continuous.

In future work, it is proposed to evaluate other loops of the proposed causal diagram, such as COVID-19 on the company's distribution process, the selection of other suppliers in case there is a shortage of raw materials, and to consider financial indicators.

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