Dynamic Analysis of Supply Chain Disruptions Caused by Criminal Acts.

Alfredo Bueno-Solano
Department of Industrial Engineering and Manufacturing Science. COMIMSA (National Council of Science and Technology), Ciencia y Tecnología No. 790, Saltillo, CP 25290, Coahuila, MEXICO.

Miguel Gastón Cedillo-Campos
Department of Logistics and Supply Chain, Autonomous University of Nuevo Leon (UANL), Avenida. Universidad S/N, C.P. 64451, San Nicolás de los Garza, Nuevo León, MEXICO.

Corresponding author’s e-mail: gaston.cedillo@mexico-logistico.org

Elías Jimenez-Sánchez
Mexican Institute of Transportation (IMT) Logistics and Intermodal Transportation Unit Km 12 Carretera Querétaro-Galindo, 76700 Sanfandila, Queretaro, MEXICO.

Rosa Guadalupe González Ramírez
Industrial Engineering School, Pontifical Catholic University of Valparaiso, Av. Brasil 2251, Valparaíso, CHILE.

Gabriel Pérez-Salas
Infrastructure Services Unit ECLAC, United Nations Av. Dag Hammarskjöld 3477 Vitacura, Santiago de Chile, CHILE.

Abstract
Understanding the phenomenon of propagation of disruptions regarding security is a critical factor for designing of robust export supply chains. From a system dynamics approach, this research analyses the effects of the materialization and simultaneous propagation of disruptions of security at various points in export supply chains (ESC). The model allows understanding why the production sites locate operations in Mexico even when the index of robbery in cargo trucks is high. Additionally, as a result of the phenomenon of propagation of the disruptive effect, it can be found that although the integrated supply chains are fast and cost-efficient, they are susceptible to shocks that can rapidly escalate from localized events into broader disruptions.

Key words: Supply chain risk, System dynamics, Propagation of disruption, Criminals Acts, Transportation.

I. INTRODUCTION
Supply chain security is becoming a central issue for the competitiveness of the global economies that goes beyond the prevention of terrorist acts or drug trafficking. In fact, the CEPAL published in January 2013 that, the interruption of a logistic chain, either by criminal acts, lack of stock of supplies or any event that hinders the distribution of supplies or products, not only leads to economic losses by that failure in particular, but has also a ripple effect to the rest of the chain, affecting ultimately, national competitiveness [1].

In this regard, the White House recently released “The National Strategy for Global Supply Chain Security (NSGCS)”. The document recognizes that the development of Nations depends on international efforts to save and ensure the transit of goods through the global system of supply chains. In addition, it exposes the need to assess and understand the effects of disruptions mainly generated by three factors: i) natural disasters; ii) criminal acts, and iii) terrorist acts. However, despite the clear current interest in understanding the effects of the disruptions, several authors [2, 3, 4, 5, 6], have identified that there is actually no clear consensus regarding the elements that should be analyzed to contribute to an effective management of the risk of disruptions in supply chains. In addition, there is no evidence of quantitative models to dynamically compute the propagation effect of the disruptive impacts from the materialization of a given risk.

In fact, important authors [2, 3, 4, 5, 6, 7, 8] demonstrate that the research area in the field of risk spreading in supply chains remains relatively unexplored. In 2004, Giunipero and Eltantway [9]
valued the changing complexity of the disruptive effect when a risk materializes in the supply chain, suggesting that under the conditions of uncertainty, it is particularly important for decision makers to dynamically assess risk through the logistic processes. In this sense, Knemeyer, Zinn, and Eroglu [10], proposed the need for a dynamic analysis model to evaluate the risk simultaneously at multiple stages of the supply chain.

Under the challenge of linking security and efficiency under a single goal, the aim of this article is to propose a dynamic assessment model, able to establish analysis scenarios in order to measure the impact regarding cost and service level in a global supply chain as a result of the disruptive effect spreading caused by the materialization of risks in an export supply chain. To do so, and from a general application approach, it began with a comprehensive literature review which identified the key variables to measure its effect on performance in a global supply chain. In the same way, with the interest of contributing to the dynamic analysis of this type of impacts in the supply chain, the technique of the system dynamics was used. Indeed, a systemic tool allows the analysis of a large number of variables in dynamic interaction. Thus, not only the disruptive impacts in the supply chain could be measured quantitatively, but evaluation scenarios could also be established. The purpose of such an approach has allowed providing logistical knowledge that contributes to the analysis of one of the three scenarios of interest embodied in the NSGSCS: disruptions resulting from criminal acts. Thus, from a global perspective of risk, the results provide information about the propagation of risks and costs, which can be used by logistics decision makers in the proactive planning within the global supply chain risk management.

The rest of the document is organized as follows. Section 2 presents a review of risk factors that currently threaten the supply chain, making a brief analysis of the different methodologies proposed to assess risks spreading in supply chains. Section 3 describes the model developed, taking as a case study a company operating in Mexico and a supply chain operating in Brazil. In section 4, the results obtained through the simulation of different policies and decision scenarios will be discussed. Finally, section 5 presents the conclusions obtained and analyses regarding the proposed model. In the same way, promising future lines of research will be showcased.

II. Literature Review

As a result of unfortunate events occurred over the last decade in which global supply chains have been the target of disruptions, such as terrorist attacks, natural disasters, changes in behavior of the client and economic crisis among others; the interest to understand risk and how to deal with the effects of the disruptions in supply chains has arisen. In this way, important works have been oriented to the development of techniques for the identification of areas of vulnerability in the chain [6, 8, 11, 12].

As supply chains develop operations in a greater number of international markets, these have become more complex, which is hindering the early detection of the disruptions, thereby delaying its prompt recovery and affecting its resilience [2, 4, 6, 7, 8, 13]. However, even when decision-makers recognize that the impact of the disruptions can have devastating consequences throughout the supply chain, at global level, in most organizations, strategies to mitigate them are generally not properly developed or are not even initiated [14].

In fact, in 2008, Handfield and McCormack [8] presented a disconcerting statistic in which they estimated that only between 5 and 25 percent of the 500 world richest companies could handle a crisis by disruptions in the supply chain. This means that in the best of cases 75% of the best companies are not prepared to handle security crisis and in the worst-case scenario, 95% of them could not face a disruption in an appropriate way. This information is confirmed by the results of recent studies that claim that only 25 percent of the companies have a proactive approach to risk management [15].

Stecke and Kumar [16] have argued that the problem in risk management is that decision-makers are not clear on how to face and deal with disruptions. Waters [7] argues that the effects of the risk can be localized on a specific point or that they can propagate through a network, causing damage with global impacts in the supply chain. According to Sodhi and Waters [6, 7], the basic problem for risk management lies in the fact that it can manifest itself in many different ways, virtually affecting any link in the chain from the initial provider to the final customer. This feature is also identified by Wu, Blackhurts and Grady [2], who assure that the understanding of propagation in the supply chain is the prerequisite for an effective integration of supply chains.

In this sense, several authors [11, 17, 18, 19] argue that risk management should not focus on the specific nature of the disruption. They claim that those responsible for the chain cannot foresee every potential threat and much less determine how likely that threat could materialize. Therefore, they suggest that it is better to focus efforts to manage risk in assessing the impact generated by the disruptions in supply chain operations. They conclude that a wide variety of disruptive events including natural
disasters and terrorist attacks, tend to have similar effects on the supply chain. On the other hand, other authors [2, 3, 10] suggest to analyze if the effects of the disruptions have local influence or if they may propagate to other members of the chain. As a result of the complexity of an analysis considering multiple variables evolving over time, the use of a systemic and dynamic approach is indispensable.

In this sense, some authors [20, 21, 22, 23], have developed analysis of complex problems from a dynamic approach using System Dynamics as a tool to assess the impact of different policies in supply chains. In fact, Wilson [19] suggests the use of system dynamics to analyze and simulate disruptive events in transport chains. However, their analysis does not measure the propagation effect of a disruptive event, nor the “border effect”, (whether it is crossing through land borders or the arrival of goods to seaports), whose assessment is fundamental to the development of our research.

In this sense, Koh [24] argues that supply chains in a just in time system, widely practiced today, highly depends on the efficiency of the border crossing. The author argues that the introduction of strict controls at international borders, product of greater attention to terrorism, can cause a significant decrease in the export of goods. He concludes that this decrease could adversely affect the economic growth. However, his research is descriptive and does not propose any methodology to help assess the quantitative impact of the border as a disruptive source.

In this context, a system dynamics model to identify and understand the dynamic interplay of variables that influence the propagation of disruptive security risks will be presented in the next chapter. It contributes to logistical knowledge within the framework of the NSGSCS’ goals: i) promoting the safe goods movement and ii) building resilient supply chains.

III. MODEL DESCRIPTION.

A. Model structure

As a result of the goal raised for our research and due to the variables of interest identified during the literature review, as well as during the case study, the multiple relationships between the different steps were identified. Therefore, we took the decision to refine a basic structure of supply chain, enabling the dynamic analysis of impacts propagation of the risk materialization in a supply chain. Consequently, the supply chain model built from the case study of the ABC Company presented and analyzed by Cedillo-Campos, Sanchez and Villa [25] was made of the following basic components: (a) supplier of raw materials; (b) component supplier; (c) international border; (d) Buffer managed by the component supplier; and manufacturing (see figure 1). The customer demand flows from the lowest stage (manufacturer) of the supply chain, to the upper stage of the chain (supplier of raw materials).

In fact, the complexity of a global supply chain is multiplied by integrating a greater number of links. But, the entities are actually involved at the same time in several chains that have in turn, different requirements and objectives [2, 31]. Although supply chains are considered complex systems where the linear relationship between the flow of goods and information are rare, the delimitation of the proposed supply chain structure was valid due to several key aspects: i) No pre-existing quantitative work considering global supply chains were identified and ii) our main research objective was to develop a first basic model capable of establishing dynamic analysis scenarios to measure the impact on cost and level of service.

A relevant way of analyzing complex systems is their process simulation through the technique of system dynamics. This tool is used when the analyst realizes that the structure of a system counts with multiple variables interacting dynamically, making the understanding of its performance very complex and, therefore, to predict its future behavior [22]. In fact, since the risk analysis does not answer a simple cause-effect relationship, the use of system dynamics to assess the propagation of disruptive risks derived from multiple events in global supply chains is suitable. Its flexibility to analyze multiple interactions over time through the causal or structural analysis (structure of relations of influence between variables, parameters and data) of the addressed problem, allows obtaining an ordered representation of the studied system [22, 32].

Causal diagrams are maps that show the causal relationships between variables of the system by means of arrows seeking to explain the fundamental modes of behavior of the model. The arrows indicate the causal direction of influences and the signs on the arrows (+ or -) indicate the polarity of the relations. In this way, a positive polarity, indicated by "+", means that growth in the independent variable creates growth in the dependent variable. As well as a decrease in the independent variable causes a decrease in the dependent variable. The negative
signs mean that an increase (or decrease) in the independent variable generates in the dependent variable a decrease (or increase) [20].

From this approach, it is also possible to identify the polarity of a loop. A loop has a cyclical structure, which contributes to present in an organized way the causal relationships of the variables that describe the behavior of the subsystem in analysis. In fact Sterman and Forrester [20, 26], argue that it is the training and understanding of loops which allows to establish the dynamic hypothesis, which is a key element in the dynamic analysis of logistic systems.

When the polarity of the loop is positive (self-strengthening), it is represented by R, or if it is negative (balancing), it is represented by B. It is determined that a loop is positive when the number of negative polarities in the relations of the cycle is even. On the other hand, a loop is considered negative when the polarities are odd [26].

As a result of the interviews, field work and the literature review, key variables at each stage of the system were identified. Two basic subsystems were identified, the first one (of strengthening) made of the generation of orders (demand) and the second one (balancing) made of the process of supply, where the different relationships were described as follow:

- Customer Demand (Ds): It is the customer demand for each corresponding period (s). Where s=1…180 periods and s-1 represents the demand of the previous period.
- Total Orders Placed (TOP): It is the total demand to be sorted by the inventory level and is calculated as:
  \[ \text{TOP} = \text{Ds} + \text{OB} \]  
  (1)
- Order Backlog (OB): It is the amount of orders that are still outstanding to be delivered to the client and is computed as:
  \[ \text{OB} = \text{Ds} - \text{GSC} \]  
  (2)
- Goods Shipped to Customer (GSC): It is the amount of goods sent in each period to the instant client. GSC is computed as:
  \[ \text{GSC} = \min (\text{IL}, \text{TOP}, \text{MGS}) \]  
  (3)
Where MGS is the maximum capacity of goods to move from one stage to another and is set in ±33% of Ds units.
- Inventory Level (IL): It is the behavior of the stock level for each stage of the supply chain. IL is calculated using:
  \[ \text{IL} = \text{ITI} - \text{GSC} \]  
  (4)
- In Transit Inventory (ITI): It is the amount of inventory in transit. It represents GSC of the upper echelon. ITI is computed as:
  \[ \text{ITI} = \text{TBD} - \text{GSC} \]  
  (5)
- Total Buffer Demand (TBD): represents the total period demand. TBD is determined by the following equation adapted from Rong, Shen and Snyder (2011):
  \[ \text{TBD} = \max (0, \hat{\phi} + \alpha (\text{SS} - \text{IL}) + \beta (\text{DITI} - \text{IL})) \]  
  (6)
Where IP is the inventory position and is calculated as follows:
  \[ \text{IP} = \text{ITI} - \text{IL} \]  
  (7)
\( \hat{\phi} \) represents a forecast of demand and is calculated:
  \[ \hat{\phi} = n \hat{\phi}_{s-1} + (1-n) \hat{\phi}_s \]  
  (8)
- Safety Stock (SS): It is the desired IL. It helps you make the adjustments necessary to maintain the desired inventory level to avoid it growing or fall without control.
- Desired in Transit Inventory (DITI): It is the desired level of inventory in transit. It helps make the adjustments necessary to maintain the level of desired in ITI

According to [26] “n” is the demand smoothing factor \(0 < n < 1\). As in our model the demand distribution is known. Thus it is not necessary to compute a forecast of “n” and then:
  \[ \hat{\phi} = \hat{\phi}_{s-1} = D_{s-1} \]  
  (9)

The constants \(\alpha\) and \(\beta\) are parameters controlling the change in the TBD when the actual inventory level and the supply line, respectively, deviate from their desired levels. For our research, they are set as follow \(\alpha=0.1\) and \(\beta=0.2\).

Once identified the variables of interest, we continued to build the causal diagram to understand the relationships that govern the behavior of the system. The causal diagrams are shown and described below. (fig. 2)

B. Dynamic hypothesis

In the Causal diagram, we can identify two processes that turn around the variable of interest "Inventory level". On the one hand, there is the loop of demand, which has a positive polarity and is identified in the causal diagram as R1, R2 and R3. On the other hand, we can see the provisioning loops which are represented by B1 and B3 and also possess a sub process corresponding to the inventory in transit (ITI), respectively named B2 and B4. It should be noted that these last four loops show
negative polarity and the behavior of each one keeps balancing the subsystem on a goal which in this case is the desired level of inventory (service). The first goal corresponding to B1 and B3 is to maintain the inventory level around the variable "SS", seeking to avoid breakdowns by shortage of inventory in the supply chain. The second goal for B2 and B4 helps to maintain stable supplies line, preventing the shortages of goods with the client. This is accomplished by comparing the desired in transit inventory with the level of inventory in real traffic.

In the Loops R1, R2 and R3, we can note that the variable "TOP" is positively influenced by "Ds" and the "OB" accumulated from previous periods. Likewise "TOP" has a negative relationship with the inventory level that is responsible for meeting the customer's demand. The variable "GSC" represents the amount of goods sent to the client and is equivalent to the minimum amount of goods between total demand and the level of available inventory. Thus, backorders accumulate in the variable "OB". Finally the accumulation of pending orders increases the amount of order for the next term. This contributes to its having a self-strengthening cycle involving on the one hand the inventory level and decreasing the increase in "TOP". As a result, the loop leads to the entropy of the system.

Likewise, Loops B1 and B3 consist in providing the level of inventory, and as described above, both have the structure of a search engine goal. This condition maintains the level of inventory around a desired inventory level, which allows to constantly balancing the subsystem. While in loops R1, R2 and R3, we note that "IL" decreases as goods are sent to the client, we can now identify that "IL" increases as it receives "ITI". This inventory in transit actually represents the goods that were sent by the immediate provider to the client. Thus, if the "ITI" is high, the difference with respect to the level of "SS" and "IL" will be less. Likewise, Loops B1 and B3 consist in providing the level of inventory, and as described above, both have the structure of a search engine goal.

This condition maintains the level of inventory around a desired inventory level, which allows to constantly balancing the subsystem. While in loops R1, R2 and R3, we note that "IL" decreases as goods are sent to the client, we can now identify that "IL" increases as it receives "ITI".

This inventory in transit actually represents the goods that were sent by the immediate provider to the client. Thus, if the "ITI" is high, the difference with respect to the level of "SS" and "IL" will be less. This condition implies that fewer orders are placed with the supplier and that the system will have a smaller amount of goods in transit in the following period. Accordingly, the "IL" will receive fewer "ITI" and comparing again the "IL" and the "SS", there will be a bigger difference with respect to the desired level. This new condition generates a greater amount of orders being placed with the supplier, generating subsequently an increase of the "IL", thus constantly balancing the system around the desired security level. Finally, Loops B2 and B4 observe the ITI, which directly influences the amount of orders. Thus the order amount is based on the difference between DITI and current ITI.

Figure 2. Causal diagram of the interaction relations between the Manufacturer, Buffer, Supplier y Raw Material.
IV. DISCUSSION OF RESULTS

By integrating simulation processes into supply chain security operations, we argue that it is possible to identify items of concern and solve them as early in the process as possible. Thus, with the interest of doing an in-depth analysis of the proposed model, both for the testing phase, as for the achievement of results, one of the three disruptive scenarios set out in the NSGSCS was selected. This scenario consists in the interest of evaluating the disruptive effects caused to supply chains when a criminal act materializes.

Currently, criminal gangs operating on the truck transport do not recognize borders and are continually moving in search of areas with lower security levels where their actions are facilitated. It is therefore important to develop international strategies regionally coordinated to improve logistics security. From the point of view of the companies, the lack of security affects their operational costs, increasing lead time, inventory levels, value of insurance premiums, among other items, which ultimately raise the price of the products and make them less competitive globally.

In this sense, CEPAL 2013 reports Mexico, Brazil, South Africa, United States of America, Russia, India and United Kingdom, as the seven most dangerous countries for the road transport of goods according to the number of claims reported to the authority. The truth is that estimating a real magnitude of economic losses caused by theft goods in inland transport is complex, mainly because the statistics tend to heavily underestimate the problem. Nevertheless, CEPAL estimated that globally the theft of goods from road transport represents USD 30 billion in annual losses [1].

This lack of information about the real dimensions of the problem, both around the world but especially at the national level, makes crimes against land-based supply chains a low priority on the political agenda. Furthermore, they are often seen as a cost of logistics activity. The lack of up-to-date, homogeneous, comparable and timely information for decision-making hinders the proactive management of the supply chain.

In this research the impacts were measured as a result of measuring inventory performance, and total costs. Within the costs analysis, we considered the costs of inventory management and costs of failing to comply with orders of the client, as well as the ones generated by the loss of goods as a result of disruption in the supply chain. In addition it is important to remark that one of the most relevant dimensions pointed by the private sector was the effect that the lead time has on the final cost of the chain. So for the simulation process we evaluated performance of two different scenarios where the only variation was the lead time. This was in order to measure in a quantitative way the effects of disruptions caused by criminal acts and their potential impact in the behavior of the inventory levels.

The simulation of the model was carried out under STELLA 9.1.3, in a 180-days period of time corresponding to a six-month planning horizon. This was according to what was explained by Sheffi [29], who argues that less-than-a-year planning periods, allow managers to incorporate flexibility into supply chain, enabling exploit it to optimize the performance of the same. It should be noted that since daily orders were received, the interval of time between calculations “STEPTIME” equals one. Thus, to illustrate how uncertainty on crossing times affects the safety stock in a cross-border supply chain, we considered different scenarios taking data from the ABC Company, to Tier 1 automotive company studied by Cedillo-Campos, Sanchez and Villa [25]. According to them, we are going to consider the next data for the simulation of the model. The manufacturer daily demand of this product ($\psi$) was considered as the input to the model. This demand is usually delivered, with 1,296 units per day and a standard deviation of 50 units. In fact, the assembly plant requires the maintenance of a 5-day safety stock in the ABC warehouse (buffer). Finally, we considered using random border crossing times, which according to [25], the crossing time vary from 1.77 hrs (best case) to 16.77 hrs (worst case).

The analysis considers simulating two different scenarios. In both cases it is necessary to keep a safety stock with the buffer on the US side. The first scenario, assume that the MEX supply chain is located in Mexico. In this case, four days are necessary to re-provide the inventory level with the buffer on the USA side. Since the SS must cover at least five days of the customer demand, the average level of inventory with the buffer must be of 6,474 pieces. On the other hand, for the second scenario, the BRA Company is located in Brazil. Considering that seven days are necessary to replenish the inventory level with the buffer and in order to commit with the assembly plant requirement of 5 day of safety stock, the level of average inventory with the buffer is set in 9,072 pieces.

In both scenarios, the average flow of goods from buffer to customer (GSC) was of 1,296 pieces. Under these conditions the base behavior demonstrates that there are not any OB. Demonstrating that the balance of the system among units to their demand and customer shipments exist (Fig. 3 and Fig. 4). The main difference between the scenarios was found in the total cost of the supply chain. In the first case the
cost of the chain is 6,621,350 and on the other hand, the analysis of the scenario 2 show that the cost of the chain rises to 8,941,190. It means that if we only focus on the lead time and if we also consider that all the other parameters are equals between the two chains, the difference of total cost is around 35 percent. The initial values for the simulation of the proposed model are shown in table 1.

### Table 1. Supply Chain Values.

<table>
<thead>
<tr>
<th>Component</th>
<th>Supplier</th>
<th>International Border</th>
<th>Buffer (Warehouse)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITT</td>
<td>IL</td>
<td>Goods in Transit</td>
<td>Crossing Times</td>
</tr>
<tr>
<td>Initial Inventory (units)</td>
<td>1300</td>
<td>1500</td>
<td>1300</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>1300</td>
<td>1500</td>
<td>1300</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>1300</td>
<td>1300</td>
<td>1300</td>
</tr>
<tr>
<td>Transit Time (days)</td>
<td>1</td>
<td>1.77 hrs.</td>
<td>2</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>4</td>
<td>1.77 hrs.</td>
<td>2</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>4</td>
<td>1.77 hrs.</td>
<td>2</td>
</tr>
<tr>
<td>Handling Cost (USD)</td>
<td>2.5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Cost of ITT Lost (USD)</td>
<td>175</td>
<td>175</td>
<td>175</td>
</tr>
<tr>
<td>Cost of ITT Lost (USD)</td>
<td>125</td>
<td>125</td>
<td>125</td>
</tr>
</tbody>
</table>

**A. Analysis under disruption scenarios**

As we exposed before, one of the most critical variables in the analysis of disruption is the effect of the lead time on the cost of the supply chain. Our goal was to evaluate the impact of criminal acts and the propagation of their effects through the global supply chains.

In this sense, we simulated three different situations for each scenario. The disruptive event consisted in varying the frequency of a criminal act (a cargo robbery). According with Perez [1], the in transit inventory is the most vulnerable element in the supply chain; however, there was not enough information available to simulate a real case. Consequently based in a Mexican Association of Insurance Institutions (MAII) report, we developed a simulation case where the supply chain suffered the robber of one truck in the period 50 of the simulation horizon. Using a system dynamics perspective we evaluated the consequences for the complete supply chain in a simultaneous way.

We observed that for the scenario 1, a cargo robbery represented at least 6 day disruption; this was because the base lead time was of four days. If the criminal act had occurred on the 3rd day, the supply chain would have needed at least three days to recover a base state. At the same way, for the scenario 2, if a cargo robbery occurs on the 6th day and the chain needs at least three days to recover, then the lead time changes from 7 to 9 days during a disruption. In both cases we considered that in a disruptive context the supplier used an aircraft to send the merchandise and fulfill the customer demand. As a result, we obtained two different impacts on Buffer IL. (Fig. 5 and Fig. 6).

Regarding the analysis of the behavior of inventories, all periods of disruption can confirm the steps expressed qualitatively by Sheffi [29]. For the first disruption scenario of 6 days, a period of "normal" operation before the impact. For this simulation the impact occurs in the 50 day, was presented at an early stage. In a second phase, a delay effect affects the IL of the company. There is a gradual reduction of IL as a result of maintaining the flow of deliveries to the client, but without being re-provisioned because of the closure of the border. Finally a third period shows how the behavior of the IL regulates itself on day 110. In the case of the global manufacturer company in study, thanks to the coverage of 5 day inventory, the order backlog stayed in control and the customer demand could practically be fulfilled. For the second scenario of disruption, established in nine days, we could verify, once concluded the second phase that a breakdown of SS occurred and contrary to what was observed in the previous disruption scenario, the delivery of goods to the client was compromised by a lapse of 10
periods. In this case, the supply chain required 100 periods to achieve a desired operation state. In addition, as a result of failing to fully comply with the demand, an increase in IL of 125% versus the base scenario was observed. A large volume of OB was also created (Fig. 7), which led the supply system to increase the IL of 530%. This behavior in the IL was identified and studied by Sterman [30], who also shows that managers tend to pay more attention to pending orders than to the supply line, leading to place very large orders with the provider. A performance verified in the two disruptive scenarios under analysis.

The cost of the supply chain in the first scenario “MEX” reach to $8,015,205 while for the scenario two “BRA” the cost of the supply chain was increased to $19,780,320. It means than the total cost grew 21% and 121% for each case. This analysis help us to understand why some authors observe that SC prefer invest in Mexico even when the CEPAL considers it as an insecure destination for road cargo.

![Fig. 5. Criminal act Scenario 1 Buffer IL Behavior](image)

![Fig. 6. Criminal act Scenario 2 Buffer IL Behavior](image)

![Fig. 7. Zoom of Criminal act Scenario 2 Buffer IL Behavior](image)

V. CONCLUSION

As a result of the propagation effects studied here, we can affirm that although the world class companies have currently integrated fast and cost-efficient supply chains, they are also vulnerable to criminal acts, representing disruptions that can rapidly escalate from localized events into broader disruptions. On the other hand, our quantitative results checked what some authors [18, 30, 31] proposed qualitatively. These authors argued that the time during which the supply chain is under a disruption becomes a key factor to determine the impact of the deviations generated to the chain. As our research demonstrates, in both scenarios this time and the lead time can make the difference between an early recovery, or a catastrophic and unrecoveable losses. Finally, this research found that based on a better understanding of disruptions effects from a systemic perspective in ESC, managers would be most prepared to mitigate the impact of disruptive events and develop a proactive and resilient supply chain.

VI. REFERENCES

[1]. G. Perez, “Seguridad de la cadena Logistica terrestre en America Latina”. CEPAL, Division de Recursos Naturales e Infraestructura, Santiago, enero de 2013


