Supply chain dynamics and the “cross-border effect”: The U.S.–Mexican border’s case

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A system dynamics model is proposed for analyzing the uncertainty caused by delays and disruptions at the U.S.–Mexican border, and how their effects propagate through the cross-border supply chains. Since Mexico’s geographic proximity and low wages provide logistics advantages to North American Free Trade Agreement (NAFTA), it is becoming a favored manufacturing and logistics location. Nonetheless, crossing the border between U.S. and Mexico remains one of the most important challenges to the NAFTA supply chain competitiveness. Based on literature review and real-life information, the security policies at the U.S.–Mexican border and their cost implications to cross-border supply chains are identified. Information regarding the impact of variability on supply chain dynamics due to “cross-border effect” derived of security inspection policies is provided. Results are based on an auto-industry case study that was chosen due to its process standardization; however, results could be applied to other global supply chains. As conclusions, implications for the design of cross-border supply chains are exposed and future research is presented.

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1. Introduction

“Reverse globalization” is becoming a tendency as firms back off from China to other countries for sourcing and manufacturing requirements (Cedillo-Campos & Sánchez, 2013; Ghemawat & Altman, 2013; SCD, 2011, 2012). Indeed, different technical reports suggest that due to increased energy prices, near-sourcing will rise, which in turn will make global supply chains even more diverse, complex, risky and uncertain (Bueno & Cedillo-Campos, 2014; Hameri & Hintsa, 2009; Ping-Shun & Ming-Tsung, 2013; Sedarasan, 2013; The White House, 2012). Thus, concerning the U.S./Mexican region, “when you consider the amount of variability involved and the length of time it takes to get from origin to destination, it becomes apparent that companies need to increase their buffer stock. This has changed inventory policies. Consequently, the amount of growth in profits with China is not as great as the amount of profits crossing the U.S.-Mexico border” (White, 2010). In fact, “the stability and success of Mexican manufacturing sector is critically important for U.S. interest” (Haytko, Kent, & Hausman, 2007). From a global point of view, Mexican manufacturing sector provides low-cost goods to United States of America (U.S.) market, a revenue stream for U.S. businesses, a tax base for the U.S. government, economic growth along both sides of the border, and a platform to Latin American markets, which are the “major market opportunities” for U.S. products (Bowersox & Calantone, 1998).

In fact, since signing the North American Free Trade Agreement (NAFTA) in 1994, an increasing number of American companies have organized their production systems with material and component supply flows from their subsidiaries located in Mexico or Canada. As a result, supply chains interact more within the NAFTA area. Since there are more interfaces, supply chains are also more dispersed between the three countries. Under the North American Free Trade Agreement (NAFTA), the value of trade between the USA and Mexico by all modes of transportation increased from $97 billion in 1995, to $461 billion in 2011. Even though Mexico has 12 free trade agreements with 44 countries, its economy relies greatly on exports to the U.S., which represent almost a quarter of the country’s GDP (U.S. Department of State, 2010). Mexico is the third largest U.S. trade partner; in 2011, it bought more from...
the U.S. than any other country with the exception of Canada. In fact, for every dollar of trade between the Mexico and the U.S., Mexico imports almost 43% from the U.S. On the other hand, for instance, China only bought about 20% (RITA – Research, 2013). Nonetheless, crossing the border between these two countries remains one of the most important challenges to the competitiveness of the “NAFTA supply chains” (supply chains running operations under the North American Free Trade Agreement area) (Cedillo-Campos, 2012; NACC, 2008; Rodrigue, 2012).

The aim of this paper is to propose a system dynamics (SD) model to analyze the effects of delays as well as disruptions caused by processes at the U.S.–Mexican border and the variability transmitted along the cross-border supply chains. Given the large quantity of variables involved in this analysis, our research was limited to study border crossing times at the most important land port-of-entry in the NAFTA region, the U.S./Mexico border: Laredo, Texas/New Laredo, Tamaulipas. A research challenge identified by several authors (Kneemeyer, Zinn, & Eroglu, 2009; Wu, Blackhurst, & O’Grady, 2007; and Pföhl, Köhler, & Thomas, 2010) who proposed to analyze the local effects of the variability, and at the same time, its propagation effects over other supply chain members, underlining the highly complexity of the task. Actually, the study of large nonlinear systems of this type is a key challenge to even the most skilled control systems researcher.

This paper is organized as follows. Section 2 exposes a general background about the variability on the U.S.–Mexico cross-border flows. In Section 3, we expose a quantitative model based on the SD methodology to measure variability of cross-border process and its impacts on safety stocks. Section 4 presents the results obtained from applying the suggested model to a Tier 1 automotive company. Finally, Section 5 provides conclusions and suggestions for future research work.

2. Background

Before the attacks of September 11, 2001, a range of efforts was in place to organize a “seamless border” in order to improve regional economic performance on both sides of the U.S.–Mexican border. In that context, the Federal Reserve Bank of Dallas recognized that: “in short, maquiladoras help the Texas border region move up the economic ladder” (Vargas, 2001). However, after the 9/11 attacks, U.S.’ highest priority became the prevention of another terrorist act. The significant cross-border cooperation started under NAFTA, and reinforced by the signature of the Security and Prosperity Partnership of North America (called NAFTA Plus) has since stalled (Baughman & Francois, 2009).

In fact, in 2009 a total of 9.8 million maritime containers entered the U.S. while the total number of commercial trucks was 9.2 million (BTS, 2011). Despite a similar importance to U.S. trade, considerably analysis has been given to the inspection of maritime containers while less importance has been dedicated to design more efficient inspection process focus on the commercial trucks entering the U.S. from Mexico and Canada. A strategic issue since in the future; increased growth of the regional integration is foreseen, based on logistics flows boosted by the automotive industry as well as by the electronic and aerospace industry. The opportunity to organize one of the largest regional manufacturing zones in the world exists (Black & Rodriguez, 2010; Manners-Bell, 2010); however, if the main reason of the expansion of truck crossings has been the intensification of trade, improving cross-border process is a key issue for NAFTA. In fact, one of the key success factors for the region is to increase cross-border throughput, which is “the speed and volume with which products move through manufacturing processes, transportation, and customs at the border” (Lawrence & Leon, 2010). Clearly, Bakir and Pakdaman (2006) argue that: “Mexican cross-border trucking appears to be in the future of (North American) free trade.”

Ojah, Villa, Stockton, Luskin, and Harrison (2002) identify that the lack of coordination between the U.S. and Mexican authorities is the result of the absence of an overarching forum helping to coordinate planning and border operations. From a cost analysis approach, Villa (2007) exposes as a cause of increasing transaction costs, the large number of non-coordinated public and private stakeholders. As Villa (2007) states, delays are the main problem: “In 2000, the Mexican Department of Transportation (MDT) estimated the total delay costs along the U.S.–Mexico border at US $77.4 million”. The waiting time can reach several hours (CBP – U.S. Customs, 2012). In 2007, a study developed by specialists from the U.S. and Mexico estimated the cost per year at US$ 246.75 million, only at the Laredo port-of-entry (Colegio de la Frontera Norte and Peschard-Sverdrup & Associates, 2007). It is not easy to distinguish costs due to border security regulations from those caused by insufficient infrastructure or lack of coordination identified by GAO (2000), Ojah et al. (2002), Villa (2007) and Frittelli (2010). Certainly, non-coordinated and non-harmonized security policies on the border have an impact on trade facilitations and consequently, competitiveness performance of cross-border supply chains.

Thus, two basic assumptions appeared in designing an original SD model with uncertain effects caused by delays in a cross-border supply chain: (a) the lack of standardized security processes and safety inspections on the border, and (b) the differences in transport infrastructures at both countries. These elements create variability in crossing times (Haralambides & Londono-Kent, 2004). The disturbance and occasionally, disruptive influence of variability seem to be a key element degrading the performance of the cross-border system.

Essentially, the variability of the processes involved in border crossing is transmitted all along the NAFTA supply chains which not only generates direct costs associated with running vehicles but also imposes costs to shippers via inventory and safety stocks that companies have to maintain for responding to the demands of the market (Ojah et al., 2002; Rajbhandari, Saman, Vadali, Kang, & Samant, 2012). Consequently, variability in the process of border crossing is added to the variability of the market, increasing the consequences of a created (by inefficiencies) propagation of variability across U.S.–Mexican supply chains. In addition, while proximity is a plus for the Mexican manufacturing system compared to other global suppliers, the time to cross the US/Mexican border is often a concern for both the northbound and southbound direction shipments (Haytko et al., 2007). Actually, a portion of this problem is caused by efforts of both governments to stop the flow of drugs, illegal immigrants, weapons, and money. However, even though a minor fraction of the total flow of trucks crossing the border every day could carry illicit goods, it is imperative to design and organize an efficient inspection process to recognize and eliminate threats to the U.S./Mexican national security (Xue & Villalobos, 2012). In this sense, Koh (2007) argues that global supply chains running operations under a just in time environments, widely practiced today, highly depend on the efficiency of the border crossing. He states that the introduction of strict controls at international borders, product of greater attention to terrorism, is increasing global trade cost and consequently, decreasing global economic growth. Nevertheless, his research is descriptive and does not propose any methodology to help assess the quantitative impact of the border as a disruptive source.

1 The Colegio de la Frontera Norte (Northern Border College) is a research center that belongs to the National Council of Science and Technology (CONACYT) in Mexico.
3. Methodology

In accordance with Jankowicz (2000), the most pertinent research methods and techniques depend on the research problems and the fixed objectives. In this paper, based on three sources of information, variables of interest were identified, multiple relationships between the different processes were recognized, and an analytical model was build. Thus, first an exploratory study in which carriers were interviewed to obtain real-life information, second, a large literature research process, and finally original data from a detailed case study of the ABC Company presented and analyzed by Cedillo-Campos et al. (2012) and Bueno and Cedillo-Campos (2014), allowed us to design a first complex SD model. Therefore, we took the decision to set a basic supply chain structure in order to enable the dynamic analysis of propagation of the effects of delays as well as disruptions caused by processes at the U.S.–Mexican border. The proposed supply chain structure was valid due to three crucial issues:

(i) No pre-existing quantitative works considering cross-border supply chains were identified.
(ii) No pre-existing basic model capable of performing dynamic analysis scenarios to measure the impact on cost and level of service of the variability transmitted along the NAFTA supply chains was found.
(iii) To take into account the “National Strategy for Global Supply Chain Security” goals announced by The White House in 2012 (promoting the safe goods movement and building resilient supply chains) as a crucial paradigm of our work.

SD was selected because it offers a half way position between pure formal modeling and empirical observations in supply chain research areas; and it is an appropriate approach to analyze those complex processes with multiple variables evolving over time (Größler & Schieritz, 2005), Sterman (2000), Duggan (2008), Cedillo-Campos and Sánchez (2008), Sánchez, Cedillo-Campos, Perez, and Martinez (2011), Bueno and Cedillo-Campos (2014), as well as Das and Dutta (2013), have developed analysis of complex problems from a dynamic approach using SD as a tool to assess the impact of different policies in supply chains. In fact, Wilson (2007) suggests the use of SD to analyze and simulate disruptive events in transport chains.

This method is used when the structure of a system counts with multiple variables interacting dynamically, making the understanding of its performance very complex (Sterman, 2000). In fact, since the variability analysis is not caused by a simple cause-effect relationship, the use of SD to assess the propagation of its disruptive effects derived relevant. Its flexibility to analyze multiple interactions over time through the causal-loop diagrams (structure of relations of influence between variables, parameters and data) of the addressed problem, allows obtaining an ordered representation of the studied system (Cedillo-Campos & Sánchez, 2013; Chin-Huang, Chiu-Mei, & Chih-Tai, 2006; Ford, 1999).

Causal-loop 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) (Sterman, 2000).

Furthermore, from this approach, it is also possible to identify the polarity of a causal-loop. A causal-loop has a cyclical structure, which contributes to expose in an organized way the causal relationships of the variables that describe the behavior of a subsystem. In fact Forrester (1968) and Sterman (2000), argue that it is the training and understanding of causal-loops, which allow establishing 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. As argued by Georgiadis, Vlachos, and Iakovou (2005): “A negative feedback loop exhibits a goal-seeking behavior: after disturbance, the system seeks to return to an equilibrium situation. In a positive feedback loop, an initial disturbance leads to further change, suggesting the presence of an unstable equilibrium.”

Actually, the structural SD framework comprises sources of amplification, time lags, and information feedback, similar to complex uncertainties caused by the secondary inspections, and supply lead-time variability throughout the cross-border supply chains. At a the same time, SD considers entities in terms of their common fundamental flows instead of separate functions (Roberts, 1978). As Chopra and Meindl (2013) argue, to fully understand and solve a supply chain issue, identifying and measuring the flows of people, money, materials, orders, and capital equipment, and information flows is necessary. Thus, uncertainties such as secondary inspections, and supply lead-time variability throughout the supply-chain network are pertinently taken into consideration. Additionally, SD facilitates the assessment of uncertainty for the combination of different scenarios of interest.

The proposed methodology is composed of three modules: (i) a bibliographic and field information gathering and analyzing process to develop a supply chain modeling process base on the SD; (ii) an empirical validation process; and (iii) a simulation and analysis of result process. All these three modules, implemented in STELLA®), are seamlessly integrated together in order to achieve the efficiency. Fig. 1 illustrates the flowchart of the proposed methodology.

3.1. Mapping process

Based on several studies (Bueno & Cedillo-Campos, 2014; Haralambides & Londono-Kent, 2004; Hitzfelder & Villa, 2011; Invite, 2008; Xue & Villalobos, 2012), the scheme proposed by Villa (2007) (see Fig. 2), and fieldwork, enabled us to carry out a
comprehensive mapping process. It considered the time spent on all the procedures involved (inspections, paperwork, transit time and others), from the moment a truck leaves a production facility located in Mexico, until it arrives to the warehouse located in the U.S.

From a more detailed approach (see Fig. 3), the process begins when a Mexican carrier picks up cargo from a facility located in Mexico, prepares the bill of lading, and hauls the shipment to a U.S. Port-of-Entry (POE) along the border. In our case, we considered the POE of Laredo, Texas because of its importance at the NAFTA level, (see Table 1 and Fig. 4). Thus, the trip between the Mexican facility and the Mexican POE depends on the Mexican city of origin and can take from 2 to 4 days (or from 2 to 3 h if the Mexican facility is located in the city of Monterrey, for instance).

Arriving near the Mexican POE, after inspecting the vehicle’s cargo, a Mexican broker prepares a Mexican export declaration (a paper form called “pedimento”). A validation into the Mexican Customs Broker Association database is done. The cargo manifest is electronically submitted to Mexican Customs and Mexican export duties are paid. Truck carriers have to submit their electronic manifest (e-manifest) to the Advanced Commercial Environment (ACE) platform 1 h prior to a truck’s arrival at the U.S. land border crossing in order to be prescreened by the Automated Targeting System (ATS) used by U.S. Customs officers. The ATS is a tool that assigns a risk score, determining if a physical inspection is needed. It runs an algorithm that uses information provided by Mexican brokers, the Customs-Trade Partnership Against Terrorism (C-TPAT) program and gathered from intelligence sources (Bakir and Packdaman, 2006). The time required to submit advanced electronic transmission of cargo manifest information for the Free and Secure Trade (FAST) program is 30 min before reaching the U.S.

In fact, the time can be reduced if the company is registered into the FAST, which works in conjunction with C-TPAT. The main advantage of this initiative is that FAST shipments have a dedicated lane on the international bridge, as well as dedicated inspection booths at the access of the U.S. Federal Compound. Since all actors involved in a FAST shipment are C-TPAT certified, U.S. Customs and Border Protection (CBP) consider FAST shipments as “low risk” cargo, which leads to the high probability that a FAST shipment
will not be sent to secondary inspection. These set of advantages significantly help decrease the crossing times of FAST shipments. However, a low percentage of truck border crossing are FAST recognized.

The paperwork can take from 20 min to 1 h depending on the workload of the Mexican broker and the complexity of the exportation processes imposed by the type of shipment. This phase contributes to added congestion. Because of the Mexican classification system, which tracks shipments by units that may be transported by many different trucks, Mexican customs brokers often release trucks in batches at a time, contributing to longer lines and waiting times on the American side, before the primary inspection. Once the paperwork process over, the long-haul carrier transfers cargo to a drayage vehicle (a short-haul truck used to transfer cargo trailers back and forth across the border). The drayage vehicle receives the shipment and transports it to the Mexican Customs facility and until the end of the border crossing, once the shipment has gone through

![Image of U.S. Land ports of entry location](https://example.com/land_ports.jpg)
A drayage vehicle picks up the cargo and hauls it to the Mexican customs facility where the export declaration is checked against the electronic form. Then, the driver has to push a button triggering a traffic light that runs a random selection algorithm (see Fig. 5). A red light notifies the driver that the cargo should go to the Mexican export primary cargo inspection that takes from 15 min. to 3 h. If the traffic light turns green, the vehicle crosses the border and continues on to the U.S. port of entry. Customs officials pull only about 2% of the trucks aside for closer inspection. However, once submitted to the primary inspection, the selected vehicle must push again the button triggering of the traffic light. 10% of the vehicles already inspected have to go through a secondary cargo inspection that takes again from 15 min. to 3 h. Once the trucks exit the gate, they cross the border, and continue on to the U.S. customs primary inspection booth (Invite, 2008). This phase represents the main bottleneck, with lines up to 5 km, from the international bridge to Mexico, making sometimes the Mexican compound stop operations (Mendoza, Rico, 2005). In 2006, this average waiting time of this phase was of 2.9 h (Colegio de la Frontera Norte and Peschard-Sverdrup & Associates, 2007). This phase involves a truck driver questioning regarding the nature of the goods they are carrying and submit documents (identification, a copy of the Inward Cargo Manifest, and the commercial invoice) to the U.S. Customs officials. The primary inspection can take 1 or 2 min. Based on the questioning process, canine truck inspection, and a crosscheck using the ATS’s results, officials decide if secondary cargo inspection is required.

When a secondary inspection is required, it is usually conducted by personnel from CBP, and the cargo is either unloaded or the truck is processed through non-intrusive inspection (NII) equipment. Typically, shipments of agricultural goods, medical equipment and hazardous materials, undergo secondary inspections (Frittelli, 2010). Inside the POE area, Food and Drug Administration (FDA), Federal Motor Carrier Safety Administration (FMCSA), and the U.S. Department of Transportation (USDOT) have staff to perform inspection when necessary (Villa, 2007). The secondary cargo inspection can take from 1 to 6 h. In fact, there are some overlaps in the inspections processes between the governmental agencies, resulting in congestions and delays (Bakir and Packdaman, 2006). Since the volume of truck crossing makes the physical inspection of each vehicle impractical, U.S. Customs and Border Patrol (CBP) has installed nonintrusive inspection equipment. After carrying out primary or secondary inspection as required, the truck continues on to the U.S. customs final check-point where all the paperwork is submitted and the truck leaves the compound. This phase takes around 1 min.

The U.S.–Mexican border is a critical pillar to NAFTA competitiveness. Actually, in 2008, the southwestern truck crossings reached 4.8 million, which represent 21% of the total containers entry into the United States (Frittelli, 2010). However, since freight transportation across the U.S.–Mexican border involves many points of transfer; it generates congestion and consequently, poses numerous security threats (Bakir, 2006). Our mapping work confirmed that the trade flow from Mexico to the United States is a complex process with many different stakeholders (see Fig. 5). The U.S.–Mexico border crossing process is a source of uncertainty for cross-border supply chains.
3.2. Causal-loop diagrams

Since key variables at each stage of the system were identified, two basic subsystems were defined. The first one performed on the Mexican side of the cross-border supply chain system and the second one performed on the American side of it.

3.2.1. Mexican subsystem

As a result of the analytical process of the Mexican side of the system, six main variables were recognized (see Fig. 6):

(i) Daily order from the client (Do): Represents the daily requirements from the client
(ii) Daily shipments (Ds): Determines the number of transport units that will be used, according to the client’s order and Transport Capacity (TC).
(iii) Arrival time of transport to the border (ATTB): This is the time the units take to get to the border. It is defined by the sum of the times of: Time of Documentation Process (DPT), Travel Time to the Border (TTB) and Transfer Time (TF).
(iv) Primary inspection probability (PIP): This is the probability a unit might be inspected, which represents 0.02%, whereas the probability of non-inspection represents 0.98%. The time used for this Primary Inspection is defined as PIT.
(v) Secondary inspection probability (SIP): If a unit is inspected, it will have to go through a secondary inspection, where the probability of another inspection represents 0.10%, whereas the probability of non-inspection represents 0.90%, according to the Security Protocol. The time used for this Secondary Inspection is defined as SIT.
(vi) Inspection process time (IPT): This is the sum of the times used for the primary and the secondary inspection.

3.2.2. American subsystem

At the same time, the analytical process allows us identifying eight variables for the American subsystem of the U.S.-Mexican Border (see Fig. 7):

(i) Client’s stock (Cs): This is the client’s raw material stock.
(ii) Transit Time to Client (TTC): This is the time required to get to the client’s facilities. It is the addition of the Transfer to the American Side Time (TAST) and of the Inspection Time (IT).
(iii) Primary Inspection Time on the American Side (PITAS): This is the time used to carry out the primary inspection process.
(iv) Secondary Inspection Time on the American Side (SITAS): This is the time used to carry out the secondary inspection process.
(v) Security Inspection (SI): This is the additional inspection process, once the unit went through the primary and the secondary inspections.
(vi) Inspection Time (IT): This is the sum of the times used for the primary and the secondary inspections.
(vii) Primary Inspection Probability on the American Side (PIPAS): This is the probability a unit might be inspected, which represents 0.02%, whereas the probability of non-inspection represents 0.98%.
(viii) Secondary Inspection Probability on the American Side (SIPAS): According to the border security protocol, if a unit went through a primary inspection, there would be a 0.10% probability it goes through a secondary inspection.

3.3. Dynamic hypothesis

After identifying the variables of interest, causal-loop diagrams were developed. They assisted us in visualizing how different variables in the cross-border system are interrelated. Thus, in the Mexican subsystem, an important reinforcing loop was established (see Fig. 6):

Reinforcing loop (R1). If the time taken by the units to get to the border increases, then the number of units in transit will also increase. This means that the queue for inspection will increase, congesting the inspection process at the border, and generating a global delay of the system.

On the other hand, in the American subsystem, a balancing loop was established (see Fig. 7):

Balancing loop (B1). This loop is generated when the raw material stock is used for the daily orders from the client. If the client’s order increases, the raw material stock decreases.

3.4. Model equations

Thus, the equations for the Mexican subsystem were defined as follows:
Daily shipments:
\[ D_s = D_o/TC \]  
(1)

where \( s = 1 \ldots 96 \) h (a defined lead time of 4 days) and \( s_{t-1} \) represents the previous period. To calculate the Arrival Time of Transport to the Border, (ATTB), the following equation can be used:
\[ ATTB = DPT + TTB + TF \]  
(2)

The Inspection Process Time (IPT) is the addition of the times used to the primary and secondary inspections. It can be calculated as follows:
\[ IPT = PIT + SIT \]  
(3)

In addition, the equations for the American subsystem were defined as follows:

Client’s stock:
\[ C_s(t) = C_s(0) + \int_0^t (TTC - D_o)dt \]  
(4)

Transit time to client (TTC):
\[ TTC = IT + TAST \]  
(5)

Inspection time (IT):
\[ IT = PITAS + SITAS + SI \]  
(6)

3.5. Empirical validation

Model validation is a significant phase of any model-based methodology. For SD models, validity mainly means validity of the internal structure of the model, and a right model’s behavior or sensitivity analysis (Barlas, 1996). Indeed, if the model is trustworthy, it can be used to forecast future scenarios or to verify policies.

When robustness in the model is required or when the risk in establishing these policies is to be analyzed, as in our case study, previous works (Forrester & Senge, 1980; Kleijnen, 1995) suggest conducting the sensitivity analysis. The sensitivity analysis focuses on analyzing the changes in the behavior of the system, when some parameters of the model are modified (Forrester & Senge, 1980).

Therefore, it was important to detect the main feedbacks right from the conceptualization of the model and the realization of the causal-loop diagrams (Kleijnen, 1992, 1995). Consequently, our validation process focused first on the internal structure of the system, then, we prove the empirical correlation of the results provided by the proposed model based on sensitivity analysis and policy scenarios (see Section 3.6).

In order to validate our results in a real case, our assumption was that when both the demand and order lead time of a product are unknown but can be specified by means of a normal distribution, safety stock must be held to cover the uncertainty in both demand and lead time (see Fig. 5). Thus, the safety stock would be higher than if there was variation in the demand or only lead time. To our analysis, it was assumed as a realistic goal of the whole system that the carmaker’s daily demand (ds) is synchronized with supplier’s deliveries. The demand for product A-168 and B-216 behaved as shown in Figs. 8 and 9, and Table 2.

In that sense, it was verified that for northbound trips from Mexico to the U.S., the time required for a shipment to make the complete trip from the yard in Mexico to the exit of the State Inspection Facility depends on the number of secondary inspections required on the U.S. side. It also depends on the number of inspection booths in service and traffic volume at that specific time.
of day—and if the shipment is eligible for FAST program. Another critical issue boosting variability on the border is the duplication of vehicle safety inspections, as U.S. Federal and State agencies perform them on every truck that crosses from Mexico into the U.S. It was validated that uncertainty in cross-border crossing times not only affects the desired level of service of the product availability, but also the required safety stock level and the speed in the transportation system (Chopra & Meindl, 2013). Actually, uncertainty due to process variability because of time in security inspections, whether at border crossings, maritime ports, or airport hubs, has not been measured enough (Hintsa et al., 2010). Only a few researchers have explicitly studied this question within a supply chain context.

Since there is no systematic and consistent way of measuring border crossing time at land ports of entry (Hitzfelder & Villa, 2011), the fieldwork as all of the empirical studies mentioned before were based on average crossing-times for trucks at a single POE. Six scenarios were recognized and empirical validated in the field (see Figs. 5 and 10).

3.6. Policy scenarios

Considering that both the primary and the secondary inspections on the Mexican side count with an established probability, which enables decision-makers to consider it within their shipment programing, it was decided to focus the analysis on the determination of the variability impacts on the secondary inspection on the American side. We considered the US-located ABC Distribution Center inventory behavior, which is related to the arrival delays of the supply shipments. Thus, six scenarios were defined as follows:

(i) Scenario 1: When the company is not part of the FAST program, and when 100% of its shipments must go through the secondary inspection process upon arrival at the border.

(ii) Scenario 2: When the company is not part of the FAST program, and when 90% of its shipments must go through the secondary inspection process upon arrival at the border.

(iii) Scenario 3: When the company is not part of the FAST program, and when 60% of its shipments must go through the secondary inspection process upon arrival at the border.

(iv) Scenario 4: When the company is part of the FAST program, and when 40% of its shipments must go through the secondary inspection process upon arrival at the border.

(v) Scenario 5: When the company is part of the FAST program, and when 10% of its shipments must go through the secondary inspection process upon arrival at the border.

(vi) Scenario 6: Hypothetical case, in which high security measures are implemented, certified by both governments to guarantee the legitimacy of the load, without any inspection at the border.

These scenarios were analyzed for two company types (FAST and non-FAST shipments). The scenario called “Best Case” (S6) implies the best average crossing times for large corporations with FAST shipments exporting from Mexico to the U.S. On the other hand, the scenario called “Worst Case” (S1) implies the longest average crossing times (see Tables 3 and 4).

4. Simulation results and managerial implications

By integrating simulation processes into cross-border supply chain operations, we argue that it is possible to identify items of concern and seek to resolve them as early in the process as possible.

<table>
<thead>
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<th>No.</th>
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<th>Normal</th>
<th>Scenarios</th>
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<td>Upper Limit</td>
<td>Mean</td>
</tr>
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<td>40</td>
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<tr>
<td>2</td>
<td>Mx Point of transfer</td>
<td>15</td>
<td>30</td>
<td>22.5</td>
</tr>
<tr>
<td>3</td>
<td>Mx Customs</td>
<td>0.5</td>
<td>1</td>
<td>0.75</td>
</tr>
<tr>
<td>4</td>
<td>Mx Primary cargo inspection</td>
<td>15</td>
<td>180</td>
<td>97.5</td>
</tr>
<tr>
<td>5</td>
<td>Mx Secondary cargo inspection</td>
<td>15</td>
<td>180</td>
<td>97.5</td>
</tr>
<tr>
<td>6</td>
<td>US-Mx Bridge</td>
<td>15</td>
<td>318</td>
<td>166.5</td>
</tr>
<tr>
<td>7</td>
<td>US Primary Inspection</td>
<td>1</td>
<td>2</td>
<td>1.5</td>
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<tr>
<td>8</td>
<td>US Secondary Inspection</td>
<td>60</td>
<td>360</td>
<td>216</td>
</tr>
<tr>
<td>9</td>
<td>US Customs</td>
<td>8.5</td>
<td>1</td>
<td>0.75</td>
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<tr>
<td>10</td>
<td>US DOD</td>
<td>3</td>
<td>30</td>
<td>11.5</td>
</tr>
<tr>
<td>11</td>
<td>US Point of transfer</td>
<td>15</td>
<td>30</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Fig. 10. Scenarios of analysis (crossing times at the U.S.–Mexican border).

Table 2

Data of the export operations of the ABC company.

| D= | Average daily demand (B-216) | 1296.00 Units/day |
| σD= | Standard deviation of daily demand | 50.00 Units |
| L= | Average replenishment lead time | 4.00 Days |
| σR= | Lead time standard deviation | 4.00 Days |
| S = | Average cost of the product | 208.00 Dollars |
| T= | Size of shipment | 216.00 Units |
| LSQ= | Logistic service quality | 95 % |

Fig. 9. Analysis scenarios based on the ATS.
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 real case was selected. The interest was to evaluate the disruptive effects of delays as well as disruptions caused by processes at the U.S.–Mexican border and the variability transmitted along the cross-border supply chains. The impacts were measured on the behavior of inventories, and total costs. Within the costs, we considered the costs of inventory management and of failing to comply with orders of the client, as well as, the ones generated by the loss of the goods as a result of disruption in the supply chain.

The simulation of the model was carried out under STELLA® 9.1.3, in a 96-h period of time, and the lead-time was determined by the company. Since they received daily orders, STEPTIME equals one, thus, to illustrate how uncertainty on crossing times affects the safety stocks in a cross-border supply chain, we considered different scenarios taking data from the ABC Company. This Tier 1 automotive company is located in the automotive cluster in the Mexican border state of Coahuila, and was widely analyzed by Bueno and Cedillo-Campos (2014). It supplies mono-blocks (ψ) to an automotive company part of the “Big Three” located in the suburbs of Detroit, Michigan. Each piece costs US$ 208 and must be delivered just in time since for each minute the client's production line is stopped, the penalization cost is of US$ 3000. In spite of being a particular case, because of the standard structure of the model, it can be generalized to other assembly companies with NAFTA supply chains.

The daily demand of this ψ product is usually delivered, with 1,296 units per day and a standard deviation of 50 units. The replenishment process takes 4 days. In fact, the assembly plant requires keeping at least 5-day safety stock in the ABC warehouse and a 4-day transit inventory. The goal of the client is to guarantee a logistics service quality (LSQ) of 95%. Therefore, to analyze the "cross-border effect" and its impact on the supplier's safety stock, a sensitive analysis was carried out, taking into account the set of data that characterize its export operations.

For the first scenario, both the behavior of the component B-216's stock in the Distribution Center (DC) of the ABC company located in the U.S., as well as the arrival rate of the supply shipments were considered. As a result, the inventory level in the DC of the company suffered a high reduction because the first trucks had to go through all the U.S.-Mexican border’s security procedures and arrived to their destination 72 h later. In this case, the safety stock went from 6500 units of component B-216 to 2600 units. This 60% reduction of the safety stock, due to the accumulated delays during the border-crossing process, represents the maintenance of an extra 60% of safety stock as a mean of protection against the delays at border-crossing (see Fig. 11).

For the second scenario, based on the case of a non C-TPAT certified company, not participating to the FAST program, and with 90% of its vehicles having to go through the secondary inspection process upon arrival at the border, the inventory behavior inside the DC was analyzed. As a result, although some vehicles did not suffer major delays while crossing the border, the reduction rate of the safety stock level inside the DC was important, getting to a 55% reduction (see Fig. 12).

Table 4
Crossing times for FAST and Non-FAST companies, scenarios of analysis.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>Time (Units)</th>
<th>Expected (mean) value of crossing time over all possible scenarios.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-FAST</td>
<td>Mean</td>
<td>671.00</td>
<td>461.00</td>
<td>573.50</td>
<td>365.50</td>
<td>476.00</td>
<td>266.00</td>
<td>352.15</td>
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<tr>
<td></td>
<td>Standard deviation</td>
<td>78.04</td>
<td>56.75</td>
<td>73.97</td>
<td>51.01</td>
<td>69.66</td>
<td>44.53</td>
<td>37.84</td>
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<tr>
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<td>Variance</td>
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<td>5,471.00</td>
<td>2,602.00</td>
<td>4,853.00</td>
<td>1,983.00</td>
<td>1,431.88</td>
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<tr>
<td></td>
<td>Lower limit</td>
<td>518.04</td>
<td>349.78</td>
<td>428.53</td>
<td>263.53</td>
<td>339.46</td>
<td>178.72</td>
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<td>Upper limit</td>
<td>823.95</td>
<td>572.22</td>
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<td>612.54</td>
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<td>Probability</td>
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<td>0.0018</td>
<td>0.0018</td>
<td>0.0162</td>
<td>0.0980</td>
<td>0.8820</td>
<td>0.0162</td>
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<tr>
<td>FAST</td>
<td>Mean</td>
<td>586.00</td>
<td>376.00</td>
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<td>278.50</td>
<td>391.00</td>
<td>181.00</td>
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<tr>
<td></td>
<td>Standard deviation</td>
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<td>55.23</td>
<td>72.81</td>
<td>49.31</td>
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<td>42.58</td>
<td>38.16</td>
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<td>Variance</td>
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<td>3,050.00</td>
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<td>2,432.00</td>
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<td>1,813.00</td>
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<tr>
<td></td>
<td>Lower limit</td>
<td>435.19</td>
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<td>256.88</td>
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<tr>
<td></td>
<td>Upper limit</td>
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<td>0.0018</td>
<td>0.0018</td>
<td>0.0162</td>
<td>0.0980</td>
<td>0.8820</td>
<td>0.0162</td>
</tr>
</tbody>
</table>

Fig. 11. Safety stock (NON-FAST 100% inspection).
For the third scenario, the same case of the previous company was considered, but this time estimating that only 60% of the vehicles should go through the exhaustive inspection at the border. As a result, although there were vehicles having to go through each and every inspection processes, the average reduction rate of the safety stock inside the DC improved. Indeed, in comparison with the previous case, a peak in delays at border crossing reduced up to 55% the safety stocks (see Fig. 13).

For the fourth scenario, the same case of a C-TPAT certified company was considered, participating to the FAST program and with only 40% of its vehicles having to go through an exhaustive inspection at the border. As a result, the safety stock did reduce, but only up to 33% (see Fig. 14).

For the fifth scenario, the same case of the previous company was considered, but estimating this time that only 10% of the vehicles would have to go through a secondary inspection process. As a result, the safety stock reduced up to 40% (see Fig. 15).

For the sixth scenario, the same case of the previous company was considered, but estimating this time that no vehicle would have to go through a secondary inspection process. As a result, the safety stock did reduce, but only up to 33% (see Fig. 16).

In short, the sensitivity analysis regarding the safety stock behavior showed that if the company is not C-TPAT certified, and as such, does not participate to the FAST program, its crossing time could vary up to 72% (see Table 4). Consequently, for the case here analyzed, the company had to maintain a 4150-unit safety stock of the component B-216 to guarantee fully its operation, which represents in the worst case, 60% more safety stock.

On the other hand, by participating to the C-TPAT certification process, and as such, having access to the advantages of the FAST program, the company could reduce up to 50% the need of safety stock, independently from the different probabilities to follow the secondary inspection.

According to Ochoa (2010), Program Manager of C-TPAT at U.S. Customs and Border Protection, in Mexico, C-TPAT had only 1,568 certified members, 709 of which are land carrier and 859 are manufacturers, thus, most of the Mexican export-oriented companies are still not part of the C-TPAT and, consequently, of the FAST program. As such, the economic costs of delays and variability reduce the advantages in wages and geographic proximity (only to mention these two) that a near-sourcing strategy based on Mexico could provide. In that sense, our findings are consistent with Haralambides and Londono-Kent (2004) who found that the significant time and cost inefficiencies in the border crossing process dissipate the economic advantages of free trade and defy the spirit of the NAFTA.

Fig. 12. Safety Stock (NON-FAST 90% inspection).

Fig. 13. Safety Stock (NON-FAST 60% inspection).

Fig. 14. Safety Stock (FAST 40% inspection).

Fig. 15. Safety Stock (FAST 10% inspection).

Fig. 16. Safety Stock (FAST 0% inspection).
5. Conclusions

This paper proposes a system dynamic model to analyze the effects of delays as well as disruptions caused by processes at the U.S.–Mexico border and the variability transmitted along the cross-border supply chains. The model allows analyzing the effects of the variability at a local level and its propagation to other supply chain members. Since the automotive supply chain is highly standardized, our results are susceptible of generalization to other industrial sectors. In that sense, we count three contributions of the paper to the body of knowledge.

First, from a security approach, our research quantitatively supports the qualitative arguments exposed by GAO – U.S. General Accounting Office (2000) who emphasizes that “congestion can be a security risk”, since it has negative impacts on the rate of selected vehicles to inspection, on the time dedicated to the inspection process and on the quality with which it is carried out. In that sense, Mendoza and Rico (2005) also recognize the important problems of the process of border crossing and highlight the loss of NAFTA competitiveness, underlining the importance of designing a joint regional security program that allows a better logistics interaction between the U.S. and Mexico. It is clear that variability degrades the performance of cross-border flows, and consequently, of supply chains as a competitive asset of the NAFTA.

Second, currently most suppliers on both sides of the U.S.–Mexico border consider that the “normal” time to cross the border is between 24 and 48 h (from a Mexican facility to a U.S. facility or vice versa). Actually, non-quantified inventory in transit is reducing NAFTA competitiveness. The SD model here proposed allows analyzing the behavior of safety stocks and logistics service level.

Our research proves the high correlation between variability across the supply chain and its impacts on the regional competitiveness. In fact, our research reveals the importance of the C-TPAT program for improving cross border supply chain efficiency, and at the same time, identifies opportunity areas to standardize cross border processes as well as to integrate more shippers and companies to this program.

Finally, since security and safety inspections processes on the borders are sources of variability, our research not only provides more information about the processes themselves, but also about the importance of accurately measuring them in order to control their variability and their disruptive influence in cross-border supply chains performance.

5.1. Future research

Because of the importance of a more detailed analysis of cross border processes from a NAFTA point of view, a future research should involve the analysis of this phenomenon expanding the perspective from a supply chain clustering approach. It was detected that companies could capitalize on existing low-cost, increased flexibility and reduced risk of disruptions advantages by increasing the number of suppliers clustered around certain processes, technologies and services along the most important NAFTA’s inter-modal corridors. Actually, analyzing every point of entry between the NAFTA countries from a supply chain clustering approach could be a prolific source of solutions to increase NAFTA supply chains competitiveness.

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