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Disruptions in International Trade: A Perspective on Ports of Entry and Supply Chain Resilience

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DISRUPTIONS IN INTERNATIONAL TRADE:

A PERSPECTIVE ON PORTS OF ENTRY

AND SUPPLY CHAIN RESILIENCE

A Thesis

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ABSTRACT

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United States (U.S.) ports of entry (POEs) and supply chains (SCs) have a prominent trade relationship with a growing desire to improve their operational capabilities. Though trade deals like the U.S.-Mexico-Canada (USMCA) agreement have facilitated trade between these countries, U.S. Customs and Border Protection (CBP) at POEs have also increased security inspections, following the September 11th incident, which have impacted international and global SCs. More recently, the COVID-19 pandemic has caused labor shortages at both sea and land POEs, increasing vessel and commercial vehicle congestion. These POE disruptions have also propagated into the third-party logistics (3PL) of SC networks, which has increased transportation costs. In this thesis, we explored operational improvement strategies from the perspectives of the public sector (i.e., U.S.-Mexico POEs) and the private sector (i.e., 3PL SC networks). The goal of this study was to understand the relationship between transportation disruptions and international trade.

DEDICATION

I dedicate this thesis work to my loving family and friends, which would not have been possible to complete without their continued support. Un sentimiento especial de gratitud a mis padres, José y Rosalinda, cuyas palabras de aliento y sabiduría me guiaron a perseverar a través de los obstáculos de la vida para lograr mis sueños, que también son sus sueños.

I want to thank my siblings – Venice, Ingrid, and Luis – for always believing in me and helping me to not give up on my endeavors. I also want to thank one of my best friends, Daniel, for the hours of proofreading and constant motivation. I am grateful to my dog, Cici, for helping me to understand how to be more patient.

I dedicate this thesis work to my best friend and beautiful fiancé, Sophia, for always encouraging me to overcome my most challenging obstacles throughout graduate school. I am truly thankful for you inspiring me to become a better individual, and for taking care of me.

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I cannot express enough thanks to Dr. Hiram Moya, chair of my thesis committee, for all his mentoring and advice throughout my graduate career. From research design and investigation, to professional career advice, he encouraged me to always ask questions, seek knowledge of my own, and helped me to become resilient through my personal struggles. My thanks also go to the rest of my thesis committee: Dr. Douglas H. Timmer and Dr. Satya Aditya Akundi. Their support, advice, insight, and knowledge helped to ensure the quality of my thesis work.

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CHAPTER I

INTRODUCTION

In recent decades, supply chains (SCs) have adopted substantial changes into their business practices in response to increasing modernization and globalization (Hosseini, Ivanov, & Dolgui 2019; Kleindorfer & Saad 2005; Tang 2006). For example, to remain competitive, SCs have continually outsourced logistic activities to third-party logistics (3PL) providers. This practice has allowed SCs to eliminate assets, enhance customer service, and become more flexible, while focusing on their core business. However, any risks and uncertainties that SCs experience are also transferred to 3PLs, so under such disruptive conditions, 3PL SCs cannot freely transport goods and maintain their operational performance.

Past disruptions such as the 2010 Iceland volcano eruption, the 2011 Japanese tsunami, and 2017's hurricane Harvey in Houston caused serious financial losses to the computer and automotive industries among many others (Chen, Xu, & Zhou, 2020; Dolgui, Ivanov, and Sokolov, 2018). More recently, the COVID-19 outbreak caused an estimated 6 million Twenty-foot Equivalent Units (TEU) global volume reduction in Q1 2020 (Wacket, 2020). This volume reduction led to an estimated $6 billion loss of revenue, raising concern for 3PL SCs' ability to execute shipments and the survival of shipping lines (Wacket, 2020). Additionally, U.S. Customs and Border Protection (CBP) at ports of entry (POEs) have continued to increase security inspections, following the September 11th incident, which have impacted international and global SCs. U.S. POEs (i.e., land and seaports) also experienced a 20% decrease in SC trade

volume from April through June when comparing data between FY2019 and FY2020 (Department of Homeland Security (DHS), 2021). Companies around the world continue to be impacted by the COVID-19 pandemic, since many of them have SCs present in China where the pandemic originated, as well as U.S. CBP security inspections. With many SCs being globalized in structure, unexpected disruptive events have challenged their ability to trade freely, adapt quickly, and become more resilient, but what strategies they use, their general applicability, and to what extent those strategies might translate to better lead times and cost savings are less clear.

To understand we will study two models, each with their own resilient strategy. We will first observe the Laredo POE under staffing changes since that change can be easily controlled to facilitate trade for U.S.-Mexican SCs. What is special about the Laredo POE is that it is the largest land POE in the U.S. by trade value (WorldCity, Inc., 2022). Since high volumes of trade go through the Laredo POE, modifying the number of staff available to process commercial vehicles can show us a more significant improvement in trade for SCs than at other U.S.-Mexican land POEs. By using queueing theory techniques, we will model the border crossing process and approximate the change in wait time from adding or subtracting a staff member. We expect to find that having additional staff at the Laredo POE will lead to reduced wait times and therefore lower transportation expenses for U.S.-Mexican SCs. Secondly, we will observe an anonymous company's 3PL SC network under a flexible logistics strategy. What is special about this network is that consists of different routes from which the company receives overseas goods through U.S. sea POEs, all prone to transportation disruptions. Whenever a route is faced with a disruption, such as the COVID-19 pandemic, alternate routes can be used to ship goods to avoid and manage disruptions. By using operations research techniques, we will model the 3PL SC network and report its expected SC cost and lead time delivery. We expect to find that choosing

alternate routes will provide a smooth logistics flow for the company's SC but at the cost of increasing its transportation expenses. The ability of SCs to overcome trade disruptions is closely linked to their ability to remain competitive, so using a staffing strategy at POEs and a flexible logistics strategy for companies can help SCs to trade freely and improve their resilience.

The rest of the chapter is broken down into two sections. We first discuss the U.S.-Mexico border trade relationship and the trade disruptions that SCs see at U.S.-Mexico land POEs. The second section focuses on disruptions SCs see at U.S. sea POEs and the significance of the sea POEs to global trade. The second chapter is a literature review covering different improvement strategies for POEs and SCs. The third chapter explores the staffing strategy used to reduce disruptions and facilitate trade at the Laredo POE. The fourth chapter discusses the flexible logistics strategy used to improve the resilience of a company's 3PL SC network under disruptions. The fifth chapter discusses the analyses and results of the two presented strategies. Finally, the sixth chapter concludes our study with a discussion of limitations and future research.

1.1 U.S.-Mexico Trade

The U.S.-Mexico joint economic relationship has grown extensively since the inception of the North American Free Trade Agreement (NAFTA), now replaced by the USMCA trade agreement. The USMCA has enabled the continued facilitation of North American trade, which is now more important as the global economy has grown more competitive. In fact, Mexico was the second largest trading partner for the U.S. in 2020, second only to China (Villareal, 2021). In terms of U.S. imports and exports, Mexico ranked second in both after China and Canada, respectively. Moreover, U.S.-bound Mexican exports destined made up about 80% of all merchandise trade, mostly from motor vehicle parts. Most importantly, continued trade relations

between the U.S. and Mexico have prominently improved the U.S.-Mexico border region as a production site for manufacturing industries, especially for automotive SCs (Villareal, 2021). This improvement has led to an increase in SC travel demand across the U.S.-Mexico border. Despite the benefits that the USMCA has provided for the U.S.-Mexican trade relationship, SCs continue to experience daily border crossing delays that impact the facilitation of trade.

1.2 Disruptions at U.S.-Mexico Land POEs

After the September 11th incident, tighter security and inspection procedures arose for all modes of transport (e.g., passenger vehicle, air cargo, rail, etc.) at U.S. POEs. New regulations designed to enhance border security also increased paperwork burdens for cross-border SCs, which indirectly increased transportation expenses (Brooks, 2003). Presently, commercial vehicles entering the U.S. from Canada and Mexico are subject to inspections conducted by U.S. Customs and Border Protection (CBP) officers. Though the inspection process has become a necessity for national security and contraband screening, the process has disrupted North American trade by increasing commercial vehicle (i.e., truck) delays and congestion at U.S.-Mexico land POEs. For instance, a study conducted by Taylor, Robideaux, & Jackson (2003), reported that border crossing delays cost Canada and the U.S. over $13.2 billion every year. Other reports estimate the cost of truck delays at U.S.-Mexico POEs to range from $5.8 to $7.5 billion annually (Del Castillo Vera, 2009; Accenture, 2008). More recently, the COVID-19 pandemic impacted U.S.-Mexico SCs, resulting in a 9.2% decrease in merchandise trade from $358B in 2019 to $325B in 2020, as seen in Figure 1.1. Figure 1.1 also shows how before the COVID-19 pandemic, U.S.-Mexico trade had been increasing over a span of 17 years, from 2002 to 2019 (Villareal, 2021).

Figure 1.1: U.S.-Mexico Merchandise Trade: 2002 – 2020 (U.S. $ in billions).

Note. This graph was obtained from the U.S. International Trade Commission's DataWeb, which summarizes the trade balance in exports and imports between the U.S. and Mexico from 2002 to 2020. From U.S.-Mexico Trade Relations, by M. V., 2021. Congressional Research Service. Copyright 2022 by United States International Trade Commission.

The Laredo POE is relevant to truck delays and congestion because it has been particularly key in supporting the dramatic growth of U.S.-Mexico border trade. In 2021, the leading U.S. merchandise import from Mexico were motor vehicle parts, most of which crossed through the Laredo POE (WorldCity, Inc., 2022). Figure 1.2 shows that the land POE accounted for about $243B in total trade with Mexico in 2021, which was approximately 98% of the total world trade, making it the No. 1 land POE in the U.S. by trade value (WorldCity, Inc., 2022).

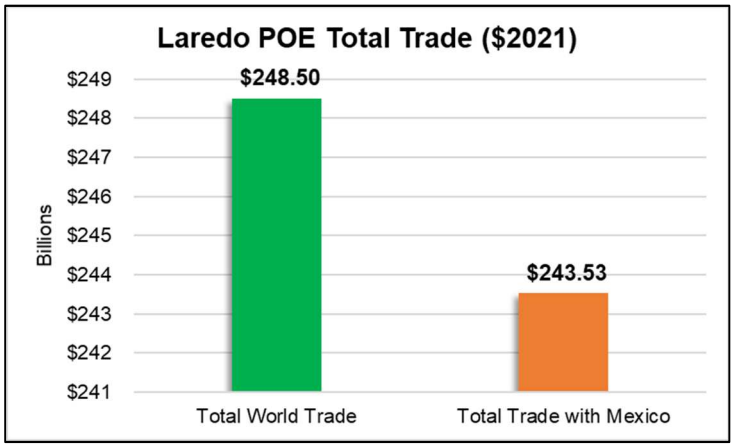

Figure 1.2: Total trade of the Laredo POE ($2021).

With how crucial the Laredo POE is to U.S.-Mexico trade, it is important that truck congestion is reduced to avoid further shipment delays and increased transportation expenses for cross-border SCs.

Figure 1.3 and 1.4 shows an aerial view of the Columbia Solidarity and World Trade Bridge crossings, respectively.

Figure 1.3: Top view of the Laredo Columbia Solidarity crossing.

Note. From *Laredo Columbia Solidarity, 27° 42'04"N, 99°44'31"W, 141 m* by Google Earth V 9.159.0.0, 2022. (www.earth.google.com). Copyright 2022 by Google Earth.

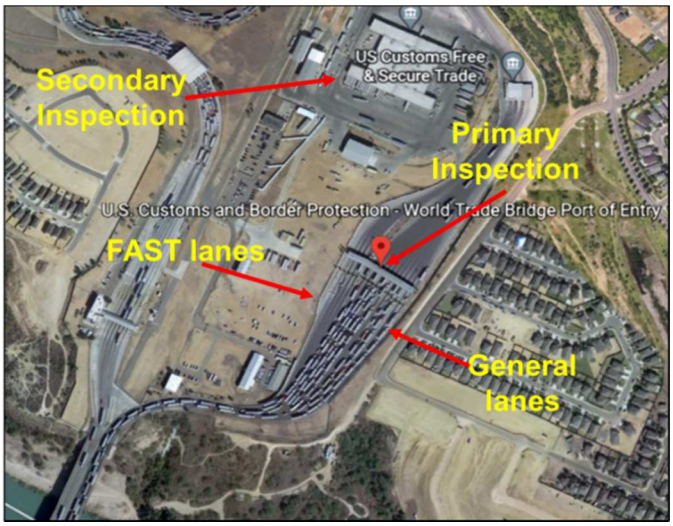

Figure 1.4: Top view of Laredo World Trade Bridge crossing.

Note. From *Laredo World Trade Bridge. 27° 35'53"N, 99°31'53"W, 142 m* by Google Earth V 9.159.0.0, 2022. (www.earth.google.com). Copyright 2022 by Google Earth.

Together, these border crossings make up the Laredo POE. where trucks are subject to CBP inspections through either FAST (Free and Secure Trade) lanes or General lanes. FAST lanes are a part of a trusted-shipper program for known low-risk shipments coming from Mexico, which essentially allows expedited inspection processing for trucks who meet certain eligibility requirements and have been certified under the Customs-Trade Partnership Against Terrorism (C-TPAT) program. Trucks not enrolled in the FAST program must be processed through General lanes and go through regular screenings and checks. These screenings involve a primary inspection and a secondary inspection for trucks deemed suspicious. Due to the nature of this inspection process, most truck congestion builds up at General lanes, as shown in Figure 1.5.

Figure 1.5: Truck congestion at the Laredo World Trade Bridge.

Note. From *World Trade Bridge Mexico-USA Border Operations* by Scarbrough, 2017. (https://thescarbroughgroup.com/world-trade-bridge-mexico-usa-border). Copyright 2017 by Luis Espinosa.

1.3 Sea POE Process

Due to the high lead times associated with sea-bound merchandise, disruptions at U.S. sea POEs are different to the ones seen at U.S. land POEs. Moreover, the trade entry process through sea POEs is also different, as it involves container vessels. Figure 1.6 shows the entry process of trade through U.S. sea POEs.

Figure 1.6: U.S. sea POE trade entry process.

Note. From *Importing in the United States: An Introduction.* by Lambert, 2016. (https://traderiskguaranty.com/trgpeak/importing-in-the-united-states-introduction). Copyright 2016 by Trade Risk Guaranty.

When a carrier with container vessels is seeking entrance into a sea POE, they must coordinate with CBP to declare entry and to ensure correct documentation and duties are filed. The container merchandise may be entered for warehousing at the POE, consumption, or transport to another POE (Lambert, 2016). The performance of the entry process depends on several factors: the throughput capacity of the terminal, accessibility to the port, available terminal space, and available labor. When any of these factors are disrupted, sea POE operations suffer.

1.4 Disruptions at U.S. Sea POEs

For more than 20 years, the Port of Los Angeles (LA) has been the busiest container sea POE in the U.S. (Port of LA, 2021a). This POE alone is responsible for 17% of the U.S.'s market share, supporting about 1,585,000 jobs throughout the country. Naturally, the LA POE and sea POEs were not exempt from the impacts of the COVID-19 outbreak. According to a report by Wackett (2020), the pandemic increased the variability of cargo volumes for global SCs and caused a 6 million Twenty-foot Equivalent Units (TEUs) global volume reduction, leading to an estimated $6 billion loss of revenue in Q1 2020. Figure 1.7 shows the initial drop in merchandise demand at the LA and Long Beach (LB) terminals that led to many sea carriers cancelling

sailings into the POE, which caused a buildup of empty containers set to export from the sea POE (Mongelluzzo, 2020).

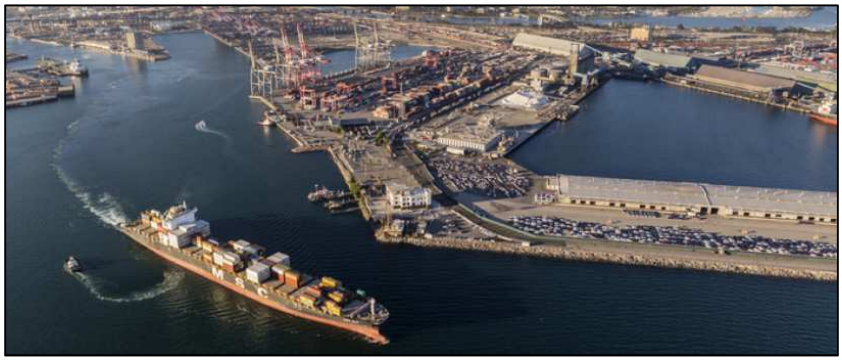

Figure 1.7: Empty containers buildup at Port of LA and Long Beach terminals.

Note. From *LA–LB ports warn Asia volume plunge could deepen,* by B. M., 2020. (https://www.joc.com/port-news/us-ports/impact-coronavirus-cargo-volumes-being-felt-la-lb_20200226.html). Copyright 2020 by Shutterstock/JOC Group Inc.

Figure 1.8 shows the growth in world merchandise trade from Q1 2015 to Q1 2019, and a quick reduction in trade from Q1 to Q2 2020 during the pandemic. This scarce demand in trade then quickly shifted into uncertain high demand related to large-scale restocking in H2 2020, as well as fiscal stimulus measures primarily from the U.S. (Cullinane & Haralambides, 2021).

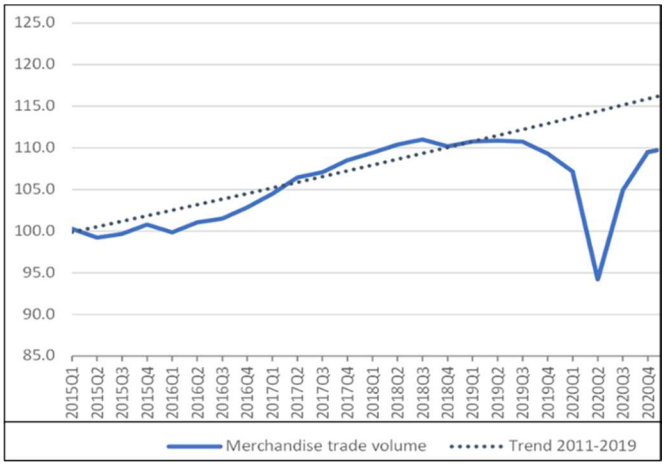

Figure 1.8: World merchandise trade volume, Q1 2015 – Q4 2020 (Index, 2015 = 100).

Note. From *World trade primed for strong but uneven recovery after COVID-19 pandemic shock,* by WTO & UNCTAD, 2021. (https://www.wto.org/english/news_e/pres21_e/pr876_e.htm#). Copyright 2022 by World Trade Organization.

In H2 2020, the LA POE registered a nearly 50% surge in container throughput, and in the week prior to Christmas the seaport handled 94% more throughput than in the same week for the previous year (Port of LA, 2021b). Sea POE services were caught unprepared from a sudden increase in demand, which strained terminal loading/unloading operations and shipping schedules. Additionally, a shortage in dock labor followed from the COVID-19 measures set in place (e.g., limited personal mobility and restrictive lockdowns). Figure 1.9 shows how the effects of COVID-19 caused long turnaround times and congestion for containers and vessels.

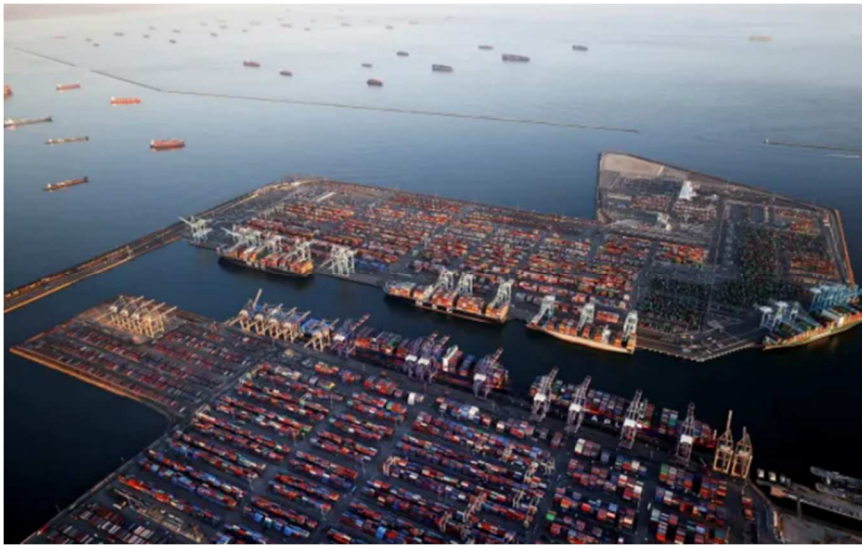

Figure 1.9: Congestion of anchored vessels and containers at Port of LA and LB.

Note. From *The supply chain crisis and US ports: 'Disruption on top of disruption',* by Christopher Grimes & Andrew Edgecliffe-Johnson, 2021. (https://www.ft.com/content/aa24d82e-16c7-4e3e-868e-42bd32f593be). Copyright by Mario Tama/Getty Images.

As of September 19, 2021, there were a record 73 anchored container vessels waiting to berth at the LA and Long Beach (LB) port terminals (Grimes & Edgecliffe-Johnson, 2021). Due to geographical, infrastructural, and capacity constraints at the LA and LB ports, vessels continue to offload past their expected date and increased merchandise demand continues to cripple terminal performance. The disruptions brought by the COVID-19 pandemic have made the LA and LB ports the largest port bottlenecks in the U.S. SC (Grimes & Edgecliffe-Johnson, 2021).

1.5 Impacts of Transportation Disruptions to U.S. POEs and SCs

The COVID-19 pandemic and other transportation disruptions continue to challenge the operations of U.S. land and sea POEs, as well as international and global SCs. On one hand, labor shortages and constrained terminal capabilities (e.g., limited berthing space, lack of cranes) at sea POEs have caused long turnaround times, congestion for container vessels, and have impacted terminal throughput. On the other hand, increased security measures and labor shortages at the U.S.-Mexico POEs have caused increased truck wait times, truck congestion, and has impacted border crossing throughput. The disruptive conditions present at POE types have also propagated into 3PL SC networks. This disruption propagation (i.e., ripple effect) has resulted in shortages of truck drivers, limited chassis availability at rails, and increasing transportation costs and time, which has significantly disrupted the facilitation of trade. Thus, the pandemic has presented an opportunity for POE operations to improve and for 3PL SCs to improve their resilience.

CHAPTER II

LITERATURE REVIEW

There is prevalent research on how to improve the operational capabilities of POEs to manage the congestion of container vessels and/or trucks (Bassan, 2007; Fan et al., 2012; Ansu & Anjaneyulu, 2013; Lin et al., 2014; Chen & Jiang, 2016; Moniruzzaman, Maoh, & Anderson, 2016; Miltiadou et al., 2016; Topcu et al., 2020). These studies usually focus on analyzing performance measures such as vessel/truck wait time, queue length and cost, average container and/or truck processing time and port throughput by using a queueing model. Such models help stakeholders evaluate port expansions (e.g., construction of terminals/inspection booths, more berths or cranes, additional labor, etc.) needed to facilitate trade.

However, each stakeholder involved has differing objectives towards improving port efficiency. For example, at land POEs, whose operations mostly involve truckers and CBP, truckers are concerned with reducing transportation time and cost, while CBP focuses on increasing security measures and enhancing legitimate trade (DHS, 2021). Interestingly, the development of short-term predictors for POE performance measures (e.g., wait times, volume level, and crossing times) have incentivized CBP to make resource or staffing decisions that mitigate truck congestion and for truckers to make routing decisions to avoid POE delays (Sharma et al., 2021). However, most studies that explore this method are conducted on the U.S.-Canada border. We will change this by conducting a study on the U.S.-Mexico border instead.

Competing interests also exist at sea POEs. Sea POE operations involve terminal operators, labor, carriers, stevedores, railways, port authorities, shippers/truckers, and the government (Dowd & Leschine, 1990). While the port authority is concerned with increasing the yearly cargo throughput, the terminal operator is interested in reducing the cost per container, and the carrier/3PL SC may be concerned with minimizing the time a vessel spends in the port. Each stakeholder contributes to the cost reduction and operational efficiency of the sea POE in their own way. However, the objectives of each stakeholder are conflicting in achieving system efficiency. A collaborative policy between all stakeholders that seeks to facilitate maritime trade would help improve sea POE efficiency but can be difficult to implement. Additionally, improving port capacity by increasing port infrastructure is usually a costly last resort alternative but was recently considered by the Biden administration, which allocated $17 billion to ports including the high demand LA and LB ports (Grimes & Edgecliffe-Johnson, 2021).

Rather than wait for port conditions to improve, 3PL SC networks have sought to instead become more resilient. Resilience is the ability of a disturbed system to recover to its original state or to evolve to an improved state. Recent literature on SC resilience mostly addresses the use of proactive strategies (e.g., optimizing the advance allocation of inventory) before disruptive events occur. However, there are few studies that focus on building resilience into 3PL SC networks through reactive and flexible strategies (e.g., adopting alternate routes in transportation systems).

To address the gaps in the literature, the objectives of this thesis are to:

1. Evaluate the impact to cross-border SC trade by using a staffing model that can reduce truck wait times at the Laredo POE.

2. Evaluate the impact of using a flexible logistics strategy for the 3PL SC network of an anonymous company during transportation disruptions.

The first objective aims to address how U.S.-Mexico border trade delays impact cross-border SCs, while the second objective aims to address how the resilience of a 3PL SC network is impacted by transportation disruptions. We conducted an extensive literature review that considers several questions that will address the presented objectives.

2.1 U.S.-Mexico Border Trade Delays

2.1.1 What strategies alleviate truck congestion at land POEs?

Past border studies have noted various strategies on modifying POEs to mitigate truck wait times. Queuing theory can be used to detect delay points in a system, which can be addressed through cycle time, throughput, and/or capacity changes. For example, Avetisyan et al. (2015) developed a theoretical model of a stationary deterministic queueing system that captures the truck congestion at the U.S-Mexico POEs. They shock the queue (i.e., congestion or volume level) by adding CBP officers over the most congested hours of the border inspection process, which provides an estimated truck wait time. The change in wait time, together with cross-border expenses, make up logistics cost data that is fed into the Global Trade Analysis Project (GTAP) computable general equilibrium (CGE) model. The results of using the GTAP CGE model show that adding CBP officers at each crossing decreased the truck wait time and increased U.S. Gross Domestic Product (GDP) by $350k. Similarly, Gu, Cassidy, & Li (2012) presented three different capacity models – branch, staggered, and tandem layouts that estimated the vehicle-processing capacities of border crossing inspection booths in a highway network. These layouts served as alternatives to improving checkpoint capacities, in place of expanding the road to accommodate more booths in a parallel manner.

The authors found that placing a set of booths in tandem with separate passenger vehicle and truck buffers results in the highest capacities, which can help to reduce truck wait times at the border.

Other studies have used qualitative and quantitative approaches, as in Burns (2019), who provides policy recommendations aimed at improving the efficiency of cross-border management of SCs at the Laredo and Eagle Pass POEs. According to Burns, suboptimal border security operations and minimal enrollment in homeland security programs (e.g., C-TPAT'S FAST trusted traveler program) cause border inspection delays for SCs. Harmonizing paperwork and joint inspections between the U.S. and Mexican authorities can save up to 50% of document preparation time and 60 minutes off the truck inspection process. In another study, Topcu et al. (2020) prioritized a set of action plans with a multi-attribute decision making method that can improve the efficiency of export and import flows at the Kapikule border crossing. The action plans were evaluated by using six attributes: (1) Operations cost, (2) Daily average number of trucks waiting, (3) Sustainability, (4) Border security, (5) Investment cost, and (6) Satisfaction of beneficiaries. The weights of these attributes were determined with the help of nineteen managers of customs and logistics consultancy organizations. The findings of this study revealed that implementing action plans such as (1) using combined stations for registration, scaling and passport operations of export and import processes, (2) having registration officers working 24/7, and (3) increasing the border crossing capacity would lead to the reduction of truck waiting time, facilitating legitimate trade (Topcu et al., 2020). Lastly, Moniruzzaman, Maoh, & Anderson (2016) designed, trained, and validated two separate Artificial Neural Network (ANN) models to predict the crossing time and the volume of trucks at the U.S.-Canada Ambassador Bridge. The models were trained with a multilayer feedforward ANN with a backpropagation approach, fed

with yearlong GPS data for crossing time and a month's worth of volume data from Remote Traffic Microwave Sensors (RTMS). The authors found that the ANN models can support the operations of Intelligent Transportation Systems (ITS) technologies, allowing for efficient management of traffic through reduced truck crossing time at the international bridge.

2.1.2 What models represent the border crossing process?

Analytical models (e.g., queueing, linear programming) are also widely used in improving inspection and security screening processes. In fact, several studies offer solutions to improve border crossing processes by adopting performance measures (e.g., average waiting time, queue length) into an objective function that can be optimized. Zhang, Luh, & Wang (2011) used a two-stage queueing model to achieve an optimal balance between system congestion and security screenings at U.S.-Canadian border crossings. The authors found that by minimizing vehicle waiting cost subject to a minimum probability of True Alarm (i.e., system indicates alarm and a threat is identified), they could determine the optimal proportion of vehicles that are selected for further inspection, which balances the expected vehicle waiting time and security level.

In a separate study, Zhang (2009) developed a congestion-based staffing (CBS) queueing model that aimed to effectively control the number of servers and the average queue length of the border-crossing process between Canada and the U.S. The model acts as a flexible staffing policy that switches between high and low staffing levels subject to a certain average queue length range. This study is important because it provides an approximate framework for U.S. and Canada government authorities to design CBS policies that fit their needs. Similarly, Lin, Wang, & Sadek (2014) used a multi-server queueing model to predict the waiting time experienced at the Peace Bridge border crossing. The authors used forecasted passenger traffic volume from a

microscopic traffic simulation model of the bridge to estimate delays under two queueing models: an exponential inter-arrival times and Erlang service times model (i.e., $M/E_k/n$), and a Batch Markovian Arrival Process (BMAP) and phase type (PH) services model. Results showed that the $M/E_k/n$ model more accurately predicted the border crossing wait times. In addition to its accuracy, the $M/E_k/n$ model was applied within a border management optimization framework and revealed that a reduced waiting time cost is possible when the cost of operating many inspection lanes is on the low end.

Yet another study simulated a border checkpoint system with a non-linear programming model that considered the marginal costs of staffing and wait time, vehicle queue, and average queue length to optimize staffing at inspection lanes (Wander & Pierce, 2011). The authors posit that a trade-off between minimizing operating costs and minimizing vehicle wait time is necessary. They found that having fewer lanes available to inspect vehicles resulted in higher checkpoint operating costs and vehicle queues. Lastly, Haughton & Isotupa (2013) considered a flow-control policy that can be used to study capacity constraints in queueing systems that experience non-stationary customer arrival rates. Specifically, this policy involved aligning commercial vehicle arrival rates to the capacity constraints of an international border crossing. The authors found that shifting some truck arrivals at the border from peak queue periods to periods with less demand helped to reduce waiting times/truck congestion.

2.2 Supply Chain Resilience

2.2.1 How have SCs been impacted by transportation disruptions?

Resilience is the ability of a disturbed system to recover to its original state or to evolve to an improved state. In the literature, 3PLs for SC networks can survive and become resilient towards transportation disruptions by quickly identifying and mitigating the most significant

disruptors. Motivated mostly by the COVID-19 pandemic, recent literature on SC resilience has provided insights into predicting and analyzing epidemic impacts. Fartaj et al. (2020) adopted the best-worst method and rough strength relation (RSR) framework to determine the weights of decision makers and rank disruption factors' interrelationships for a parts manufacturing SC network. The authors used the analytic hierarchy process (AHP) method and the Decision-making trail and evaluation laboratory (DEMATEL) method to validate the efficiency of the presented framework. Results showed that variable product delivery time, inadequately skilled labor, and infrastructural bottlenecks are the most significant transportation disruption factors for the automotive industry SC.

Another study by Vadali et al. (2015) used a dynamic traffic assignment (DTA) model to simulate disruptions (i.e., truck delays and volumes) to international trade at the Bridge of the Americas POE. Their simulation revealed that the simulated disruption costs for carriers and shippers could be $191 million on a given day. Similarly, Bueno-Solano & Cedillo-Campos (2014) used a system dynamics model to assess the effects of disruptions caused by increased border-crossing times at U.S.-Mexico border SCs. Their simulation analyses consisted of three disruptive periods of border closures for a company's inventory costs. Results for a 5-day safety stock and 10-day disruption showed an approximate additional inventory cost of $25 million for northbound trips to the U.S. The increased border-crossing time resulted in a 472% increase in costs for the SC.

In addition, a research study developed a discrete-event simulation model to evaluate the performance of a SC network during the COVID-19 pandemic (Ivanov, 2020). The author explores the ability of a SC to react towards and simultaneously manage disruption propagation regarding location, duration, and supply-demand.

Ivanov finds that the performance of a SC is impacted the most when facilities and demand disruption durations downstream the SC are very long, rather than the disruption duration present upstream.

2.2.2 What strategies can be used to improve SC resilience?

Proactive and redundant strategies are recognized as suitable methods for SCs to become resilient and overcome disruptive events before they occur (Jüttner & Maklan 2011; Azadeh et al., 2014). Examples of redundancy in a SC includes optimizing the advance allocation of inventory, having multiple tier-1 and tier-2 suppliers, overcapacity, and safety stock (Kamalahmadi & Parast 2017). Ratick, Meacham, & Aoyama (2008) constructed a set cover model to minimize the distance between redundant resources for a SC that depends on storage facilities and emergency backup. Their results showed that the minimization tool helped instill SC responsiveness into companies.

Although proactive strategies are well-documented, reactive, and flexible strategies focused on building resilience into SCs are less studied (Datta, Christopher, & Allen 2007; Ishfaq 2012). Flexibility is the ability to quickly respond to unplanned situations and adapt to major changes in a SC network. Adding volume flexibility based on suppliers' production capacities or adopting alternate routes in transportation systems are examples of flexible strategies (Shekarian, Nooraie, & Parast 2020). Ishfaq (2012) presented a logistics strategy that involves two minimum cost network flow (MCNF) models which incorporated multiple transportation modes and origin-destination pairs, modal transfer costs, and service and transit time requirements. This study found that maintaining a multi-mode transport capability provides operational flexibility for SCs to manage transportation disruptions, which enables them to enhance the resilience of their logistics operations. In fact, the methods we use in our study is

based on Ishfaq (2012) with some changes to the model that make it more suitable to our considered SC network. In another study, Shekarian, Nooraie, & Parast (2020) developed a multi-objective mixed-integer programming model to study the impact of SC agility and flexibility under supply and demand disruptions. The model aims to minimize cost, minimize risk, and maximize responsiveness for a SC system by considering multiple transportation channels and sites, and multiple periods and product planning. They found that firms can minimize the negative effect of SC disruptions and are more profitable when investing in flexibility rather than agility.

There are also studies that examine and incorporate both proactive and reactive strategies (Zsidisin & Wagner, 2010; Kamalahmadi, Shekarian, & Parast, 2021). For example, a two-stage mixed-integer programming model was developed to maximize expected service delivery and minimize expected SC cost to assess the impact of a SC exposed to environmental and supplier disruptions (Kamalahmadi, Shekarian, & Parast, 2021). The model serves as a SC responsiveness and risk management strategy that considers capabilities based on flexibility and redundancy, demand allocation, and supplier selection. Results showed that combining capabilities from the backup-suppliers and flexible-suppliers practices significantly reduced the expected total cost and improved the responsiveness of a SC, than when either of these practices were used alone.

2.3 Theory Model

Based on the extensive literature review presented, this thesis explores methodologies on U.S.-Mexico Border Trade Delays and SC Resilience. Our first topic on the Laredo POE uses a method based on Avetisyan et al. (2015). We captured the flow of trucks at the Laredo POE to understand the border crossing process. We used truck wait time data collected by CBP and a stationary deterministic queueing (SDQ) model to approximate change in wait time caused by

adding a CBP officer. We converted wait time change into border-related transportation costs with a logistical model. We also considered the GTAP CGE models used by Avetisyan et al. (2015). These models can differentiate between intermediate and final consumption goods and help in evaluating the impact that reduced border-related transportation costs have on the Mexican and U.S. economies. Lastly, we reported on the benefits of using the SDQ model as a staffing model.

Our second topic focuses on building resilience for the SC of a pandemic-disrupted company, and uses methods based on Ishfaq (2012). In the context of our study, we define resilience as the ability of a SC to quickly respond to unplanned disruptions in their transportation network by redirecting shipments to undisrupted routes. First, we identified and mapped the 3PL SC network flow of procuring overseas containers. We developed a mixed integer linear programming (MILP) model that incorporates an origin-destination pair, several modes of transportation, the costs of each mode, and lead time and service time needs. Next, we used a flexible logistics strategy in the form of a MCNF and shortest route analysis to evaluate the resilience of the 3PL SC network when faced with a transportation disruption. Finally, we determined the costs and benefits of using the resilient and flexible logistics strategy.

CHAPTER III

A PERSPECTIVE ON THE PUBLIC SECTOR: THE LAREDO POE

3.1 Methodology

3.1.1 Effects on primary inspection wait times by adding a CBP officer

The U.S.-Mexico border trade process at any given border crossing involves trucks going through Mexican Customs inspection, paying the toll booth at the Mexican side, getting inspected by U.S. CBP, and finally exiting the border crossing. This path is represented in the flow diagram shown in Figure 3.1.

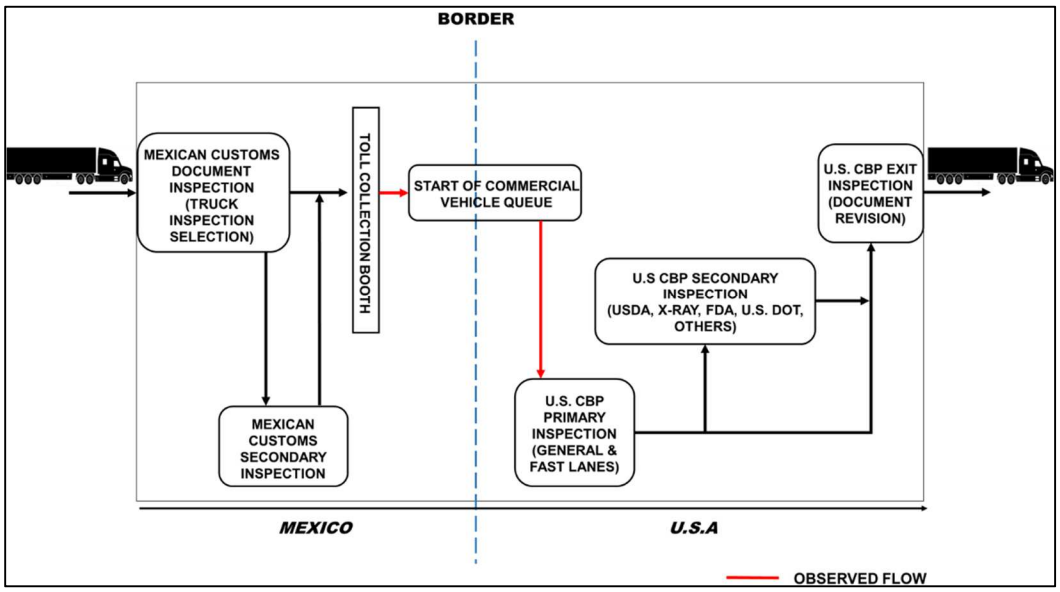

Figure 3.1: U.S.-Mexico border trade process.

We focus on the General inspection lanes because it is the process that is most affected by truck congestion. The congestion at the Laredo POE starts from the exit of the Mexican toll booth and extends to the U.S. primary inspections. Though a secondary inspection is used for any trucks

deemed suspicious, the queue for this process is independent from that of primary inspection, so we do not consider it in our study. The buildup of trucks at the General inspection lanes represents a queueing process, which creates wait times. Wait time outcomes are affected by the following: changes in traffic levels, the number of available inspection stations and the average inspection time. We consider the first two factors to model the truck congestion with a stationary deterministic queueing (SDQ) system. Staffing is the easiest, most-effective variable to change in this system as opposed to training staff, designing a new system, and/or constructing a new inspection station. Hence, we mainly focus on the impact of adding CBP officers on General inspection stations and not FAST stations.

We use CBP data, an algebraic approach, and economic methods to analyze the Laredo POE. The goal is to quantify how wait times for commercial vehicles change when one CBP officer is added to each crossing. This is challenging to carry out since some reactionary behavior takes place at the POE, such as the fluctuation of CBP officer numbers as traffic varies with the rush hour cycle. In our case, a simple regression analysis would not be a feasible estimation of the relationship between CBP officer additions and wait time. In contrast, the SDQ model is effective in evaluating how wait time changes with the addition of CBP officers to General inspection stations because it is not sensitive to the dynamic staffing behavior (Avetisyan et al., 2015).

Every CBP officer added to the POE produces 8 extra hours that can be used for the primary inspection process. This is evident for only 153 days in a year, which is the time that an individual CBP officer is responsible for enforcement activities. Identifying the 8 most-congested hours of each day of a given week allows our SDQ model to evaluate wait time changes during each of those 8 hours. Additionally, we assume that an additional CBP officer is

added to inspect trucks in a General inspection station during these hours. Staff are not added to FAST inspection stations since the trucks that are processed in these stations are subjected to different inspection conditions.

3.1.2 Mathematical model of stationary deterministic queueing system

The SDQ model is based on an algebraic approach from Avetisyan et al. (2015). The formulas that are used in this approach help to approximate and quantify how changes in wait time are affected when a CBP officer is added to the 8-most congested hours. To leave out variability from the SDQ model, the parameters used in the estimation of the wait time are made deterministic.

Parameters:

T = total number of trucks processed,

C = average number of CBP officers available, where one officer is manning a General inspection booth,

W = average wait time spent in the queue in minutes,

Q = average queue length in a given hour expressed as number of trucks waiting in the General inspection lane queues,

t $= \frac{T}{C}$ = number of trucks processed by a CBP officer,

m $= \frac{60}{t}$ = number of minutes needed to process a truck by a CBP officer,

n $= \frac{Q}{C}$ = number of time periods that are m minutes long needed to eliminate a queue of size Q. Also note that $n = \frac{W}{m}$.

SDQ model equations:

$$Q = nC = \frac{W}{m} * C \tag{3.1}$$

$$\Delta Q = (A - D) = (C - C) = 0 \tag{3.2}$$

$$\Delta Q = (A - D) = (C - \{C + 1\}) = -1 \tag{3.3}$$

$$\Delta Q = -t \tag{3.4}$$

$$\Delta Q = -\frac{t}{2} \tag{3.5}$$

$$Q_M = Q_0 - \frac{t}{2} \tag{3.6}$$

$$W_M = \frac{mQ_M}{(C+1)} = \frac{m\left(Q_0 - \frac{t}{2}\right)}{(C+1)} \tag{3.7}$$

CBP collects data on T, C, and W, and subsequently t, m, and n, for the Columbia Solidarity and World Trade bridges at the Laredo POE. Although Q is not collected by CBP, it can be estimated by Equation (3.1). Let's now consider a queueing system that is balanced. This means that every m minutes, arrivals A to the queue equal departures D from the queue, while Q remains the same over time. Since $C = D$, then also $C = A$, with a change in the balanced queue length represented by Equation (3.2). When one CBP officer is added at the start of a congested hour, truck arrivals remain fixed at C every m minutes, and D now becomes $C + 1$. The change in queue length from the addition of the officer is now represented as in Equation (3.3). After an entire hour has passed, Q diminishes by t trucks, as shown in Equation (3.4), and Equation (3.5) shows Q at the mid-point of the hour. The queue length at the beginning of the hour can be represented as Q_0. When a CBP officer is added, the new queue length at the mid-point of the hour can now be represented as in Equation (3.6). By using Equation (3.1), the new wait time at the mid-point of the hour when one CBP officer is added can be determined with Equation (3.7).

3.1.3 Effects of reduced wait times on border-related transportation costs

When truck wait times are reduced at the General lanes queue, border-related transportation costs associated with importing goods into the U.S. also decrease. To compute the

border-related transportation costs, we determine cross-border expenses associated with the Laredo POE and combine them with the reduced wait time. The percent difference between the initial and reduced wait time costs can be used to evaluate the economic impact on U.S.-Mexico border trade.

The number of trucks that traveled through the Laredo POE during 2021 is given in Table 3.1 (U.S. Bureau of Transportation Statistics, 2021).

Table 3.1: Truck volumes at Laredo POE for 2021.

Ports of Entry	Crossing	# of trucks processed				
		Total	8 Most congested hours	All other hours	Average per block of 8 most congested hours	Average per block of 8 most congested hours * 153 days
Laredo	Columbia Solidarity	262,148	176,651	85,497	862	131,886
	World Trade Bridge	1,648,500	1,023,175	625,325	2,818	431,307
Total		1,910,648	1,199,826	710,822	N/A	563,193

The 8 most-congested hours of each day contained ~60% to 70% of all truck crossings, totaling about 1.2 million. When this value is multiplied by one additional CBP officer's 153 on-duty days, we see how many trucks would benefit from reduced wait time thanks to the addition of that CBP officer to a General inspection station. This benefit could be extended to the rest of the work hours if the additional CBP officers were to be available at any time. This possibility will not be explored in this research but may be of interest in future research.

The SDQ model that we use does not include the actual processing time of the primary inspection process, nor is the secondary inspection accounted for. Instead, we only consider the estimated wait times starting from the exit of the toll booth in Mexico and the change in wait

time due to the addition of the CBP officer. The average wait times associated with the General primary inspection are listed in Table 3.2.

Table 3.2: Average wait times and transport costs with additional CBP officers to POEs.

Ports of Entry	Crossing	# of trucks with wait time reductions	Average wait time for 8 most congested hours (min)			New wait time and percent change during 8 most congested hours, +1 officer		Change in truck transport costs (all trucks)
			Weekdays	Weekends	All days	New (min)	Percent	Total (million 2021$)
Laredo	Columbia Solidarity	131,886	9.5	4.3	8.0	3.0	-63%	-$0.57
	World Trade Bridge	431,307	16.4	11.6	15.0	13.00	-13%	-$8.06
Total								-$8.63

We aggregated historical wait time data for both the Columbia Solidarity and World Trade bridges in 2021 and averaged the 8 most-congested hours of each day. Note that Table 3.2 shows average wait times for weekdays, weekends, and all days. For this study, we only considered the average wait time of all days, since weekends and weekdays are included in the 153 days that the additional CBP officer is on duty. In a future study, it would be worth exploring the effect that the additional CBP officer has on truck wait times on weekends vs. weekdays separately. All data was obtained from CBP (U.S. CBP, 2021).

3.1.4 Data collection of border-related transportation costs

For all trucks crossing the Laredo POE, we assume that they are registered in either the U.S. or Mexico. The average numbers we present are based on the for-hire carrier industry for both truckload (TL) and less-than-truckload (LTL) fleets. All costs are based on a per truck trip basis for 2021. An average truck speed of 39.4 miles/hr is assumed for both U.S. and Mexican trucks. This speed is applicable for all roadways in which trucks travel (American Transportation

Research Institute, 2019). The cost of diesel fuel was approximated to $4.10/gallon in the U.S. and $4.74/gallon in Mexico according to GlobalPetrolPrices.com (2021).

All truck operating cost data that is in the "$/mile" form is converted into hourly costs by using 39.4 miles/hr. This is necessary for the data to be linked to reduced wait times at the General inspection lanes. The American Transportation Research Institute reports an average driver wage (including benefits) of $29.18/hr and an average truck operating cost of $26.00/hr for U.S. trucks. Additionally, the International Council on Clean Transportation (ICCT) gives an average driver wage (excluding benefits) of $3.23/hr and an average truck operating cost of $12.20/hr for Mexican trucks (Rogers, Kaenzig, & Rogers, 2017). Both the U.S. and Mexican operating costs consider maintenance, insurance, licenses, tires, and tolls. These costs have been inflated to 2021 dollars.

Based on an interview conducted with a trucking carrier, a truck trip through the border takes ~2.5 hours to complete. We were not able to obtain a more objective estimate, since there are no scanners (e.g., license plate readers) throughout the Laredo POE that can record the time required by a truck to cross the border. We assume a truck trip starts at the Mexican toll booth and ends at the primary inspection exit. Each truck trip consumes an average 4.62 gallons of diesel or an estimated 1.85 gallons of diesel/hr. We also account for a $50 - $150 customs broker fee and a $90 drayage fee per truck trip. Drayage is the process in which the goods of a truck that transports them within Mexico are unloaded, then loaded back into another truck that crosses the Laredo POE, and moved into a truck that transports them within the U.S. Since these costs are fixed, we assume that they do not depend on wait times. Consequently, the driver wage, truck operating cost, fuel cost, and diesel consumption per truck trip all depend on wait times. These

variables are considered in the border-related transportation cost per truck, as shown in the logistical cost model in Equation (3.8):

Logistical Cost Model:

$$\Delta TC = \Delta TC_b = Avg.WT * \left[(UC_w + UC_o) + \left(UC_f * UV_d\right)\right] \quad (3.8)$$

The unit costs for driver wages ($/h), the truck operating costs ($/h), and fuel cost ($/gallon) are denoted as UC_w, UC_o, and UC_f, respectively. UV_d represents the unit volume of diesel consumption per truck trip. Border-related transport costs (TC_b) are affected by the wait time changes at the POE. Equation (3.9) shows that ΔTC has a linear relationship with *Avg. WT*. The percent difference in ΔTC (100% * TC_b) divided by the change in border-related transport costs for the initial wait time (TC) can used as an input for the GTAP CGE model. Border-related transport costs, with the addition of the CBP officer, are listed in Table 3.2.

CHAPTER IV

A PERSPECTIVE ON THE PRIVATE SECTOR: SC RESILIENCE

4.1 Methodology

4.1.1 Mathematical model of minimum cost network flow and shortest route

In this thesis, we developed a model to study the impact of a flexible logistics strategy for the 3PL SC network of an anonymous company. Our model used a minimum cost network flow (MCNF) and a shortest route approach, while considering one origin–destination pair, several modes of transport, their respective costs, and service and lead time needs. Our model considered three shipment routes for the single o–d pair in the transportation network, but the company wished to limit their transportation network to two paths, modeled as follows: The first identified path is the optimum network route with the best minimized cost or lead time (i.e., the company's preferred route), while the second identified path is the company's chosen path when the first path is experiencing disruptions. The third path is ignored since it would be shown to be the least favorable among considered paths. All paths are independent from each other.

This above transportation strategy ensures continued service against link disruptions by incorporating flow conservation constraints into the model within the origin and destination locations. The nature of the model is to have no arcs or nodes – except for the supplier and demand node – that share a connection between the three routes, which ensures that the model only responds to one path if another is experiencing a disruption. This strategy highlights a tradeoff between the flexibility and resilience of a 3PL SC network (Ishfaq, 2012). Resilience is

incorporated through path redundancy by modeling in loss/gain-in-efficiency, while flexibility is introduced through a three-connected network topology. The change in cost or lead time between the primary and secondary routes identified act as a quantifiable loss/gain-in-efficiency in the model.

Consider an undirected graph $G = (\mathbb{N}, \mathbb{A})$, with node set $\mathbb{N}$ and arc set $\mathbb{A}$. For o-d nodes n_0 and n_l, a route consists of the order $\mathbb{R} = (n_0, a_1, n_1, \dots, a_l, n_l)$, where $n_1, \dots, n_{l-1}$ are unique nodes and a_i is an arc (or link) connecting nodes n_{i-1} and n_i $(i = 1, \dots, l)$. A group of $R_1, R_2, \dots, R_q$ of routes is considered disjoint if any node except for n_0 and n_l (and respectively, any arc) appears in at most one route. The model developed in this study uses a graph representation of the company's SC network in which several modes of transportation are used. Figure 4.1 shows the network flow graph considered for the logistics strategy.

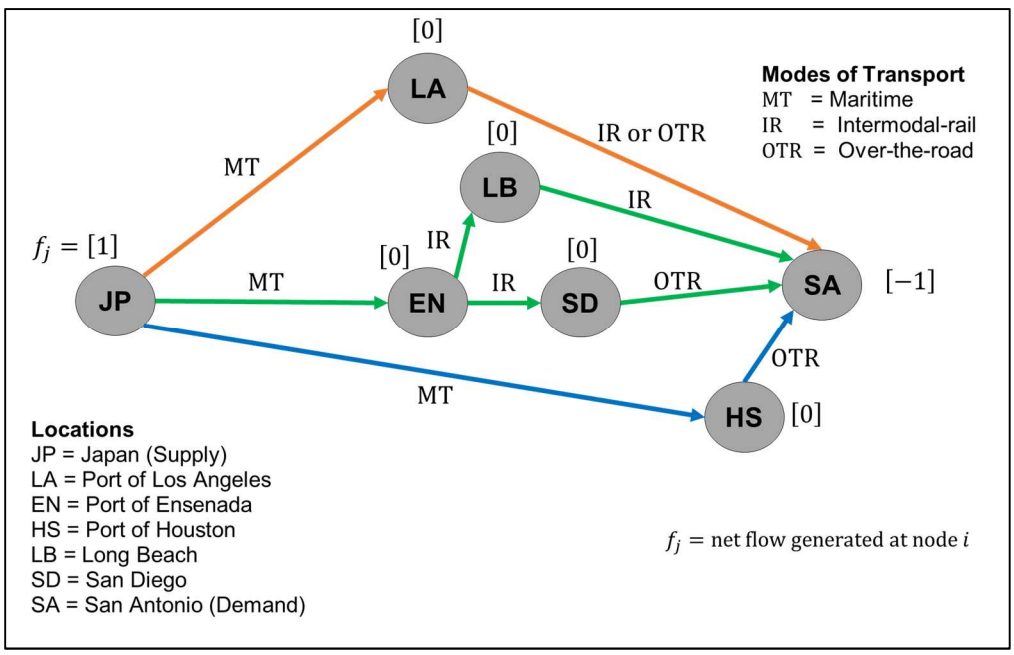

Figure 4.1: Network flow graph of flexible logistics strategy.

This graph shows cities represented by nodes which are connected through transportation arcs. Each arc represents either a maritime (MT), intermodal-rail (IR), and/or road (OTR) modes of transport. Between the origin and destination nodes, represented by $O(i)$ and $D(j)$, respectively,

we consider a demand flow of shipping containers, f. The unit transportation cost to send a container on an arc (i, j) is represented by c_{ij}, while a container's lead time between nodes i and j is given by t_{ij}. All containers for the given origin-destination (o-d) pair, $D(j)$ are subject to a service time constraint T.

Sets:

$\mathbb{N}$ = set of nodes,

$\mathbb{A}$ = set of arcs or links,

$\mathbb{M}$ = $\{\mathrm{MT}, \mathrm{IR}, \mathrm{OTR}\}$; set of transportation modes,

$\mathbb{R}$ = set of arcs contained in the shortest route

$\mathbb{D}$ = $(i, j) \in \mathbb{A} \mid (i, j) \notin \mathbb{R}$.

Parameters:

c_{ij} = shipping container transportation cost on arc (i, j),

t_{ij} = lead time of a container on arc (i, j),

T = service time requirements for o-d pair, $D(j)$.

Decision variables:

X_{ij} = 1, if any arc (i, j) is used for the first path; 0 otherwise,

Y_{ij} = 1, if any arc (i, j) is used for the second path; 0 otherwise,

Z_{ij} = 1, if any arc (i, j) is used for the third path; 0 otherwise,

Model formulations:

$$\min \sum_{(i,j)\in\mathbb{A}} f * c_{ij}\left(X_{ij} + Y_{ij} + Z_{ij}\right) \wedge \min \sum_{(i,j)\in\mathbb{A}} f * t_{ij}\left(X_{ij} + Y_{ij} + Z_{ij}\right) \tag{4.1}$$

s.t.

$$\sum_{(i,j)\in\mathbb{A}} X_{ij} - \sum_{(j,i)\in\mathbb{A}} X_{ij} = \begin{cases} 1 & \text{if } i = O(i) \\ -1 & \text{if } j = D(j) \\ 0 & \text{otherwise} \end{cases} \quad \forall i \in \mathbb{N} \tag{4.2}$$

$$\sum_{(i,j)\in\mathbb{A}} Y_{ij} - \sum_{(j,i)\in\mathbb{A}} Y_{ij} = \begin{cases} 1 & \text{if } i = O(i) \\ -1 & \text{if } j = D(j) \\ 0 & \text{otherwise} \end{cases} \quad \forall i \in \mathbb{N} \tag{4.3}$$

$$\sum_{(i,j)\in\mathbb{A}} Z_{ij} - \sum_{(j,i)\in\mathbb{A}} Z_{ij} = \begin{cases} 1 & \text{if } i = O(i) \\ -1 & \text{if } j = D(j) \\ 0 & \text{otherwise} \end{cases} \quad \forall i \in \mathbb{N} \tag{4.4}$$

$$\sum X_{ij} + \sum Y_{ij} + \sum Z_{ij} \leq 2 \quad \forall (i,j) \in \mathbb{A} \tag{4.5}$$

$$\sum_{(i,j)\in\mathbb{A}} X_{ij} t_{ij} \leq T \tag{4.6}$$

$$\sum_{(i,j)\in\mathbb{A}} Y_{ij} t_{ij} \leq T \tag{4.7}$$

$$\sum_{(i,j)\in\mathbb{A}} Z_{ij} t_{ij} \leq T \tag{4.8}$$

$$X_{ij} \in \{0,1\} \quad \forall (i,j) \in \mathbb{A} \tag{4.9}$$

$$Y_{ij} \in \{0,1\} \quad \forall (i,j) \in \mathbb{A} \tag{4.10}$$

$$Z_{ij} \in \{0,1\} \quad \forall (i,j) \in \mathbb{A} \tag{4.11}$$

The above model calculates the optimal routes in a three-connected network for o-d pair $D(j)$. In this study, the primary route is the route with the lowest cost or lead time and is therefore the default option for shipping container travel. Whenever the primary route is faced with disruptions, the secondary route, which is the route with the 2nd lowest cost or lead time, is used instead. For o-d pair, $D(j)$, the first, second, and third routes are defined by arcs (i,j) represented by the decision variables X_{ij}, Y_{ij}, and Z_{ij} respectively. A shipping container at node j for one of the routes chosen can incur a diversion cost by using another mode of transportation. We will elaborate on the nature of this cost in the Results section.

The goal of objective function (4.1) is to either minimize the total transportation costs or minimize the total service time in the 3PL SC network. The flow conservation restrictions for each route are represented by constraints (4.2), (4.3), and (4.4), respectively. Constraint (4.5) considers the disjoint restriction on the routes. All routes must also satisfy a service time

restriction, which is represented by constraints (4.6), (4.7), and (4.8). It is assumed that intermodal shipping containers are used for shipments in each route, as they can be readily transferred from one transportation mode to another. The three distinct routes for o–d pair [$O(i)$, $D(j)$] presented in the model are not restricted to use different transportation modes. Essentially, the routes are distinct in their transportation arcs. For example, it is possible that all routes are MT, IR, OTR or a combination of the three transportation modes. Such an arrangement offers a high level of flexibility across a diverse range of transportation disruptions which can increase the resilience of the SC network.

4.1.2 Algorithm procedure

The model presented is a mixed integer linear programming (MILP) formulation based on the MCNF problem and the classical shortest route problem. The following iterative approach borrowed from Ishfaq (2012) is used to solve the models:

Step 1: FOR $\forall(i,j) \in \mathbb{A}$

Step 2: Solve for lowest cost/shortest lead time route over $\mathbb{A}$. Record first route $\mathbb{R}$.

Step 3: Remove first route $\mathbb{R}$

Step 4: Solve for second route $\mathbb{R} + 1$

Step 5: END FOR

These steps are used to solve the model by iteratively searching for three edge-disjoint routes. In other words, this procedure begins by looking for the minimum cost or shortest lead time route $\mathbb{R}$ for o–d pair, $D(j)$ over the set of arcs $\mathbb{A}$. The consequent path from origin $O(i)$ to destination $D(j)$ is stored by noting the list of arcs (i,j) which create the minimum cost or shortest lead time route $\mathbb{R}$ in step 2. For step 3, a new set of arcs $\mathbb{D}$ is produced for o–d pair, $D(j)$, from $\mathbb{A}$ by removing the arcs included in the first minimum cost or shortest lead time route $\mathbb{R}$ (i.e., $\mathbb{D} = \frac{\mathbb{A}}{\mathbb{R}}$).

Solving another problem over $\mathbb{D}$ results in the second minimum cost or shortest lead time route $\mathbb{R} + 1$ between origin $O(i)$ and destination $D(j)$ which is edge-disjoint of $\mathbb{R}$. Repeating this procedure until two routes out of three are chosen yields the optimal solution.

4.1.3 Data collection for case study

We use a MILP model to assess the feasibility of a flexible logistics strategy based on using multiple routes and modes of transportation. Specifically, our model is based on a transportation network that the company opted to use during the COVID-19 pandemic. The network consists of routes that include the Port of Los Angeles and the Port of Houston in the U.S., and the Port of Ensenada in Mexico from which the company receives overseas merchandise. Our study identifies the key cities used in each of the routes. Using an overseas company database with historical container data for each route, we aggregated freight flows for each route from January 2021 to January 2022 to compute their total average flow volume. The o-d demand was defined as container flows through each identified sea POE. Shipping container freight rates were based on Forty-foot Equivalent Units (FEUs) and include the cost of warehousing, taxes and duties, U.S. Customs and carrier fees, etc. for each route.

The cost of transportation for each mode of transport for each arc is also included in the container cost. We also considered the average transit times between each arc for each route in the transportation network. All data was provided by the anonymous company.

CHAPTER V

RESULTS AND DISCUSSION

5.1 Wait Time and Cost Analysis for the Laredo POE

This study was initially conducted in 2019 but after the COVID-19 pandemic and security measures increased, we decided to recalculate the average wait times and border-related transportation costs with additional 2021 data. Figure 5.1 shows estimations of the truck wait times from the stationary deterministic queueing (SDQ) model for the Columbia Solidarity and World Trade Bridge crossings. The values are represented for a given hour during the 8-most congested hours. Figure 5.2 shows the effect that an additional CBP officer had on the wait times for the Laredo POE.

Laredo POE Wait Time Analysis (General Inspection Lane)		
SDQ Model Parameters and Equations	Columbia Solidarity	World Trade Bridge
T = Total trucks processed	108	352
C = Avg. number of CBP officers	5	10
W = Avg. wait time in queue (in minutes)	8	15
Q = (W/m)*C = Avg. queue length (in trucks)	14	88
t = T/C = Trucks processed by one CBP officer	22	35
m = 60/t = minutes to process a truck by one CBP officer	2.8	1.7
Qm = Q0 - (t/2) = queue length at mid-point of the hr with +1 CBP officer	4	70
Wm = (m*Qm)/(C+1) = new wait time with +1 CBP officer (in minutes)	3.00	13.00

Figure 5.1: SDQ model wait times estimation for the Laredo POE.

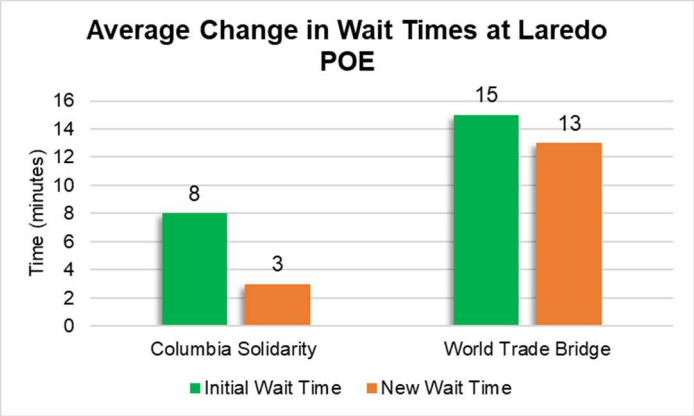

Figure 5.2: Average change in wait times with +1 CBP officer at the Laredo POE.

We found that adding one CBP officer at the Columbia Solidarity bridge reduced truck wait time during the 8 most-congested hours by an average 63%, from 8 minutes to 3 minutes. Similarly, adding one CBP officer at the World Trade Bridge reduced the truck wait time by an average 13%, from 15 minutes to 13 minutes. These results show that opening another General lane at the primary inspection stations would help to reduce the truck congestion at the Laredo POE. By using the SDQ model to estimate truck wait times and incorporating time into the logistical cost model, we determined the total border-related transportation costs at the Laredo POE for the initial and new wait times, about $10.8M and $8.63M, respectively. Table 3.3 shows truck wait time costs determined using the logistical cost model for the Laredo POE.

Table 5.1: Logistical model cost and sensitivity analysis for Laredo POE.

Laredo POE Cost Analysis

Country	Columbia Solidarity						World Trade Bridge					
	Wait time with +1 officer (hrs) = 0.05			Initial wait time (hrs) = 0.13			Wait time with +1 officer (hrs) = 0.22			Initial wait time (hrs) = 0.25		
	New wait time cost (per truck)			Initial wait time cost (per truck)			New wait time cost (per truck)			Initial wait time cost (per truck)		
	Avg.	10%	-10%	Avg.	10%	-10%	Avg.	10%	-10%	Avg.	10%	-10%
United States	$ 13.86	$ 15.45	$ 12.30	$ 15.99	$ 17.83	$ 14.19	$ 3.20	$ 3.57	$ 2.84	$ 8.53	$ 9.51	$ 7.57
Mexico	$ 4.80	$ 5.46	$ 4.17	$ 5.54	$ 6.30	$ 4.81	$ 1.11	$ 1.26	$ 0.96	$ 2.95	$ 3.36	$ 2.57
Total wait time cost	$ 18.65	$ 20.91	$ 16.47	$ 21.52	$ 24.13	$ 19.00	$ 4.30	$ 4.83	$ 3.80	$ 11.48	$ 12.87	$ 10.14
Total border-related transport cost (all trucks)	$8,045,471	$9,018,129	$ 7,103,379	$ 9,283,236	$10,405,534	$8,196,207	$567,730	$636,365	$501,251	$1,513,946	$1,696,974	$1,336,669
Avg. total border-related transport cost (all trucks)	$8,045,471	$ 8,060,754		$ 9,283,236	$ 9,300,870		$567,730	$ 568,808		$1,513,946	$ 1,516,822	

Total Laredo POE Cost

New wait time (+1 officer)		Initial wait time	
Avg.	±10%	Avg.	±10%
$8,613,201	$8,629,562	$10,797,182	$ 10,817,692

In Table 5.1, we also performed a sensitivity analysis. Specifically, we estimated a low and high border-related transportation cost by varying the following parameters by 10%:

- Unit wage, Unit operating, and Unit fuel costs per country
- Unit volume diesel consumption per truck trip

As an example, our sensitivity analysis found an aggregate change in the border-related transportation costs of $7.61M for the low value and $9.65M for the high value. Getting the average of these values resulted in a change of $8.63M, as shown in the total new wait time cost for the Laredo POE in Table 3.3. This value represents a 10% change in magnitude and indicates that the changes in costs are linear with respect to the changes in wait times. Figure 5.3 shows a graphical representation of the total border-related transportation costs associated with the initial and new wait times.

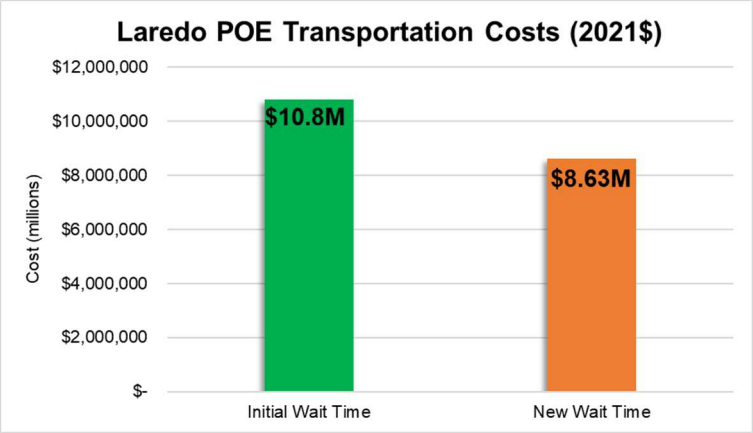

Figure 5.3: Total costs before and after an additional CBP officer.

We found that adding a CBP officer led to an estimated 20% reduction in the total border-related transportation costs between the initial and new wait times. In other words, our data showed that adding a CBP officer to the Laredo POE translated to lower transportation costs for cross-border SCs.

5.2 Global Trade Analysis Project Analysis

The General inspection lane wait time reductions turn into border-related transport cost reductions and then into changes in the competitiveness of U.S. trade (i.e., imports and exports). Since CBP officers are a cost that the U.S must incur, Mexico would initially reap the benefits of this change. This is because the wait time for goods entering the U.S. would be reduced, which, in turn, would make those goods cheaper. Although, it is important to note that most goods entering the U.S. from Mexico are intermediate goods and not of final consumption. This means that the cost of production in the U.S. would decrease and would essentially make U.S. exports more competitive around the world. A consequence of the U.S. having competitive exports is that the country's income, employment, and GDP would increase. The offset between the negative and positive economic impacts that the U.S. might incur can be estimated with the use of the Global Trade Analysis Project (GTAP) computable general equilibrium CGE model (Avetisyan et al., 2015).

The GTAP CGE model is a multi-market model that can show behavioral responses of individual consumers and producers to price signals based on the limits of available natural resources, capital, and labor. It provides a clear role for markets and prices, allows for input substitution, contains behavioral content, and can tell the difference between intermediate and final consumption goods. The model considers the import and export trade linkages between 129 country economies and each of their 57 industry commodities. Since the analysis of this paper incorporates the economies of the U.S. and Mexico, we find the GTAP CGE model suitable to determine to what degree of economic competitiveness U.S.-Mexican trade benefits (Global Trade Analysis Project, 2017). The application of the GTAP CGE model towards issues regarding transportation and trade is not new, and so this paper adapts an approach used from

prior research (Avetisyan et al., 2015). Now that we determined a percentage value in the change in border-related transport costs, we could also estimate the economic impact on U.S.-Mexican trade. However, the economic impact analysis has a few shortcomings, which we highlight further.

The following are the data contained in the GTAP CGE model: consumption, production, transport, and trade. The consumption, production, and trade factors are left unchanged in the model. The transport factor consists of three industries: Other Transport, Water Transport, and Air Transport. The Other Transport industry includes truck transport, pipelines, rail transport, travel agencies, and auxiliary transport activities. For our study, we would only consider the truck transport variable, which means that the GTAP CGE model would have to be heavily adjusted to maintain equilibrium. This makes using the GTAP CGE model to analyze the economic impact that the border-related transport costs bring to the U.S. and Mexico complex and tedious, since equilibrium adjustments, perfect competition, and perfect information would be needed to obtain an accurate outcome. Despite the model's shortcomings, another study reports that the GTAP CGE model can show a change in the economic impact when modifications are made (Avetisyan et al., 2015). We further discuss what the economic analysis consists of when the transport variable is modified.

Since we assume the addition of a CBP officer and consequently a reduction of wait times, we simulate a decrease in transportation costs by changing the transportation technology through the increase in staff, which allows to determine the economic impact on the U.S. Trade data for the Laredo POE is not available in the GTAP CGE model, so we also consider truck import data. It is important to note, in the GTAP CGE model, Avetisyan et al. (2015) consider both shares of intermediate and final consumption goods in the total import trade demand. Trade

demand is represented by intermediate import intensities. In other words, these intensities signify what percentage of imports cross through the Laredo POE, which is about 60%. Though adding a CBP officer results in higher trade volumes in the number of truck transport imports from Mexico, the GTAP CGE model is not readily available to conduct a sufficiently accurate economic impact analysis of U.S.-Mexican commercial trade. However, based on the results of Avetisyan et al. (2015), intermediate goods coming from Mexico into the U.S. would increase, as well as exports of final consumption goods from the U.S. Ultimately, lowering border-related transport costs through the addition of CBP staff led to an overall positive economic impact for the U.S. and Mexico.

5.3 MCNF and Shortest Route Analysis for 3PL SC Network

We sought to build resilience into the 3PL SC network of the anonymous company by exploring two separate goals: minimizing total transportation costs and minimizing total service time. To model these outcomes, we designed MILP models in Microsoft Excel and solved using the Solver tool. We first report on the results of the cost-focused analysis, with a total of two runs conducted. Next, the results of the time-focused analysis are reported by conducting a total of six runs. Lastly, we combined the results of both analyses. For all analyses, we assumed that an average total of 14 containers were allocated among the routes chosen. The company required for containers to arrive at the demand point within 45 days, with or without a disruption in the 3PL SC network.

5.3.1 MCNF analysis

The presented cost-focused analysis results revealed that including different transportation routes allowed for a variety of options when determining the primary and secondary routes. This helped in minimizing the total transportation network costs in a flexible

three-connected network. The flow conservation constraints in the model ensured that for each node, any containers coming into a node would come out of that node. Figure 5.4 shows the base model of the MCNF analysis.

From-To Destination	Arcs (*i,j*)		Standard Arc Cost	Diversion Cost	Arcs Chosen
Japan to Los Angeles	1	2	$ 4,900.00	N/A	1
Japan to Ensenada	1	3	$ 12,430.00	N/A	0
Japan to Houston	1	4	$ 6,850.00	N/A	0
Los Angeles to San Antonio	2	7	$ 1,920.00	$ 4,950.00	1
Ensenada to Long Beach	3	5	$ 4,915.00	N/A	0
Ensenada to San Diego	3	6	$ 5,950.00	N/A	0
Houston to San Antonio	4	7	$ 349.00	N/A	0
Long Beach to San Antonio	5	7	$ 4,155.00	N/A	0
San Diego to San Antonio	6	7	$ 1,620.00	N/A	0

Nodes	Flow Conservation Constraints		
1	1	=	1
2	0	=	0
3	0	=	0
4	0	=	0
5	0	=	0
6	0	=	0
7	-1	=	-1

Objective Function ($)	
Min:	$ 95,480.00

Figure 5.4: Base model of the MCNF analysis (considering all routes).

The first route chosen by the model consisted of starting from the supplier in Japan (JP), shipping containers to the Port of LA via maritime (MT), and finally transporting them to the demand point in San Antonio (SA) via intermodal-rail (IR). Containers traveling from LA to SA have the option to travel via truck (OTR), but this option was not favored by the model due to it being more expensive. The route chosen served as the primary route and was removed for the second run of the model.

The secondary route chosen by the model consisted of the JP start point, shipping containers via MT to the Port of Houston (HS), and then traveling via OTR to the SA demand point. Table 5.2 shows a summary of the cost-focused analysis.

Table 5.2: Routes selected for the MCNF analysis.

Route	Chosen route	Total transportation cost	Loss-in-Efficiency
Primary Route	JP-LA(IR)-SA	$95,480.00	-5.6%
Secondary Route	JP-HS-SA	$100,786.00	

The cost-focused analysis revealed an important insight in the form of loss-in-efficiency. This was measured as the increase in total transportation costs by using the secondary route when the primary route was faced with a COVID-19 disruption. Figure 5.5 shows an estimated 5.56% higher total transportation cost for the secondary route when compared to the primary route. The low-cost differential between these routes means that the different sea POEs offered a cost-effective and feasible solution to lower the vulnerability of the 3PL SC network.

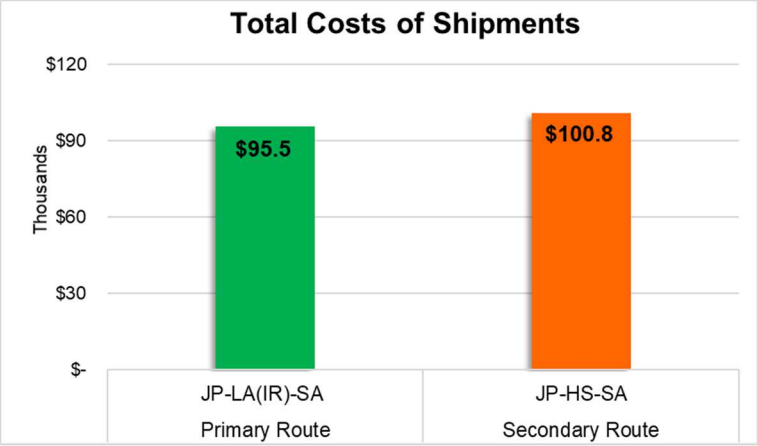

Figure 5.5: Total shipment costs associated with choosing the LA and HS routes.

5.3.2 Shortest route analysis

In the following time-focused analysis, results showed that considering different modes of transportation in the three routes considered allowed for flexible options for the company. This flexibility helped to minimize the total network service time. Figure 5.6 shows the 1st base model, which considered all routes in the company's transportation network free of disruptions caused by the COVID-19 pandemic.

From-To Destination	Arcs (*i,j*)		Standard Lead Time (Days)	Diversion Lead Time (Days)	Arcs Chosen
Japan to Los Angeles	1	2	23	N/A	1
Japan to Ensenada	1	3	23	N/A	0
Japan to Houston	1	4	39	N/A	0
Los Angeles to San Antonio	2	7	9	6	1
Ensenada to Long Beach	3	5	10	N/A	0
Ensenada to San Diego	3	6	11	N/A	0
Houston to San Antonio	4	7	2	N/A	0
Long Beach to San Antonio	5	7	2	N/A	0
San Diego to San Antonio	6	7	3	N/A	0

Objective Function (Days)	
Min (No COVID):	32

Nodes	Flow Conservation Constraints		
1	1	=	1
2	0	=	0
3	0	=	0
4	0	=	0
5	0	=	0
6	0	=	0
7	-1	=	-1

	Service Time Constraints		
LA Route	32	≤	45
HS Route	0	≤	45
EN Route	0	≤	45

Figure 5.6: 1st base model of the shortest route analysis (w/o COVID).

This model also considered a service time constraint of 45 days for any route selected. The primary route chosen in the 1st base model consisted of JP-LA(IR)-SA, with a total service time of 32 days.

In the event of a COVID-19 disruption, two other scenarios may have occurred. The OTR option from LA to SA can be chosen when a diversion request is made to the company's carrier, having containers travel by road, rather than rail. This request can only be done within 10 days of arrival at the Port of LA. Making a diversion requires that the merchandise from the FEU containers be transloaded into a 53' container that can travel by road. Figure 5.7 shows the diversion option selected, which can only be useful during a COVID-disrupted Port of LA.

From-To Destination	Arcs (*i,j*)		COVID Lead Time (Days)	Diversion Lead Time (Days)	Arcs Chosen
Japan to Los Angeles	1	2	39	N/A	1
Japan to Ensenada	1	3	23	N/A	0
Japan to Houston	1	4	53	N/A	0
Los Angeles to San Antonio	2	7	13	6	1
Ensenada to Long Beach	3	5	10	N/A	0
Ensenada to San Diego	3	6	11	N/A	0
Houston to San Antonio	4	7	3	N/A	0
Long Beach to San Antonio	5	7	2	N/A	0
San Diego to San Antonio	6	7	3	N/A	0

Objective Function (Days)	
Min (COVID):	45

Nodes	Flow Conservation Constraints		
1	1	=	1
2	0	=	0
3	0	=	0
4	0	=	0
5	0	=	0
6	0	=	0
7	-1	=	-1

	Service Time Constraints		
LA Route	45	≤	45
HS Route	0	≤	45
EN Route	0	≤	45

Figure 5.7: 2nd base model (w/COVID and Diversion made).

A successful diversion results in a total service time of 45 days for the primary route. However, if the diversion request time window is missed, the OTR option would not be considered in the model, as shown in Figure 5.8.

From-To Destination	Arcs (*i,j*)		COVID Lead Time (Days)	Arcs Chosen
Japan to Los Angeles	1	2	39	0
Japan to Ensenada	1	3	23	1
Japan to Houston	1	4	53	0
Los Angeles to San Antonio	2	7	13	0
Ensenada to Long Beach	3	5	10	1
Ensenada to San Diego	3	6	11	0
Houston to San Antonio	4	7	3	0
Long Beach to San Antonio	5	7	2	1
San Diego to San Antonio	6	7	3	0

Objective Function (Days)	
Min (COVID):	35

Nodes	Flow Conservation Constraints		
1	1	=	1
2	0	=	0
3	0	=	0
4	0	=	0
5	0	=	0
6	0	=	0
7	-1	=	-1

	Service Time Constraints		
LA Route	0	≤	45
HS Route	0	≤	45
EN Route	35	≤	45

Figure 5.8: 3rd base model (w/COVID and Diversion missed).

The new primary route chosen consisted of shipping containers via MT from JP to the Port of Ensenada (EN), transporting them via IR to Long Beach (LB), and finally traveling via IR to SA. This resulted in a total service time of 35 days. It is important to note that containers coming out the Port of EN can also travel via IR to the city of San Diego (SD). However, this option involved transloading merchandise from an FEU container to a 53' container resulting in a longer service time.

5.3.3 Selection of secondary routes for shortest route model

Since the base models resulted in three different primary routes being chosen depending on the scenario, we also considered three separate scenarios when choosing the secondary routes. For the 1st and 2nd base models, the LA primary route was removed. This resulted in the secondary route chosen consisting of JP-EN-LB-SA, with a total service time of 35 days, with or without a COVID-19 transportation disruption.

For the 3rd base model, the EN primary route was removed. Previously, the diversion request time window would have been missed, so the OTR option from LA was not considered. Also, this scenario considered a COVID-19 disruption. Results showed that the routes of JP-LA(IR)-SA and JP-HS-SA were chosen. Since the JP-LA(IR)-SA route had a shorter service time than the JP-HS-SA route, the model allocated a greater weight towards the shorter route. However, this resulted in a total service time of 52 days, 7 days past the given company due date. This means that when the company's 3PL SC network was faced with a COVID-19 disruption and had missed the diversion, the LA route served as the secondary route where there was a risk of a longer service time. Table 5.3. provides a summary of the results for selecting the primary and secondary routes for the shortest route analysis.

Table 5.3: Routes selected for the shortest route analysis.

Route	Scenario			Scenario Service Time (days)		
	No COVID	COVID	COVID (Diversion missed)	No COVID	COVID	COVID (Diversion missed)
Primary	JP-LA(IR)-SA	JP-LA(OTR)-SA	JP-EN-LB-SA	32	45	35
Secondary	JP-EN-LB-SA	JP-EN-LB-SA	JP-LA(IR)-SA	35	35	53
Loss/Gain-in-Efficiency	N/A	N/A	N/A	-9.4%	+22%	-51%

Figure 5.9 shows each primary and secondary route chosen for each scenario and the service times associated with them.

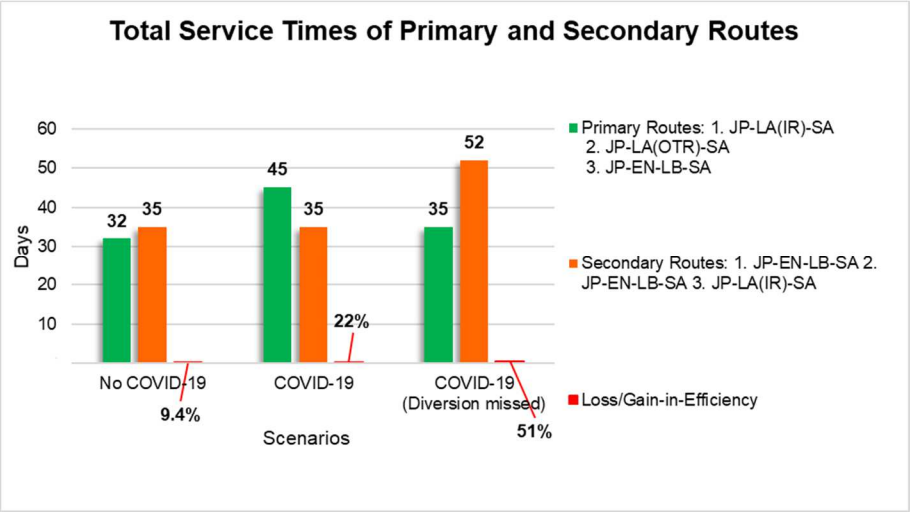

Figure 5.9: Total service times of routes associated with each scenario.

For the "No COVID-19" scenario, there was an estimated 9.4% loss-in-efficiency when the Ensenada route was chosen over the LA route. Since there was no transportation disruption in this scenario, the LA route was the best option. For the "COVID-19" scenario, there was an estimated 22% gain-in-efficiency when the Ensenada route was chosen over the LA route. In the case of a transportation disruption, the Ensenada route was the best option. Lastly for the "COVID-19, Diversion missed" scenario, there was an estimated 51% loss-in-efficiency when

the LA route was chosen over the Ensenada route. In this case, the Ensenada route was the most beneficial option again.

5.3.4 Combination of MCNF and shortest route analyses

Figure 5.10 combines the results of the MCNF and the shortest route analyses, revealing that the LA route was chosen four times, the Ensenada route was chosen three times, and the Houston route was chosen once.

Route	Number of Times Selected	Percentage Selected
Port of Los Angeles	4	50%
Port of Ensenada	3	37.5%
Port of Houston	1	12.5%
Total	8	100%

Figure 5.10: MILP model selection and percentage associated with each route.

Essentially, the model favored the LA route by 50%, the Ensenada route by 37.5%, and the Houston route by 12.5%. Based on these percentages and the company's requirements, the LA route and Ensenada routes served as the primary and secondary routes, respectively. The LA route offered a cost advantage, whereas the Ensenada route offered a time advantage. Specifically, during a transportation disruption, such as the one caused by the COVID-19 pandemic, the LA route was not be feasible due to the high lead time associated and the potential risk of failing to divert containers to travel via OTR rather than IR. On the other hand, the Ensenada route's lead time remained the same before and during the COVID-19 pandemic. This means that the Ensenada route was more feasible during a transportation disruption since containers arrived on time, whether traveling by IR or OTR.

5.3.5 Cost and time analysis of MCNF and shortest route combination

We also considered a cost and time analysis using the Ensenada and LA routes. We assumed that an average total of 14 containers were allocated among the two routes. The company prioritized on-time delivery over the cost of containers. The company's carrier limited

the number of containers that can travel through the Ensenada route to 10 containers due to contractual reasons. Also, from January 2021 to January 2022, an average of 5 containers per vessel were sent through the LA route. Combining this data, we allocated 9 containers to the Ensenada route and 5 containers to the LA route. We assumed that the LA-bound containers were diverted to meet the service time requirement and the Ensenada-bound containers traveled via IR. Figure 5.11 shows the results of our cost analysis, with a total cost of $49,250 of sending 5 containers through the LA route, and a total cost of $180,000 of sending 9 containers through the Ensenada route.

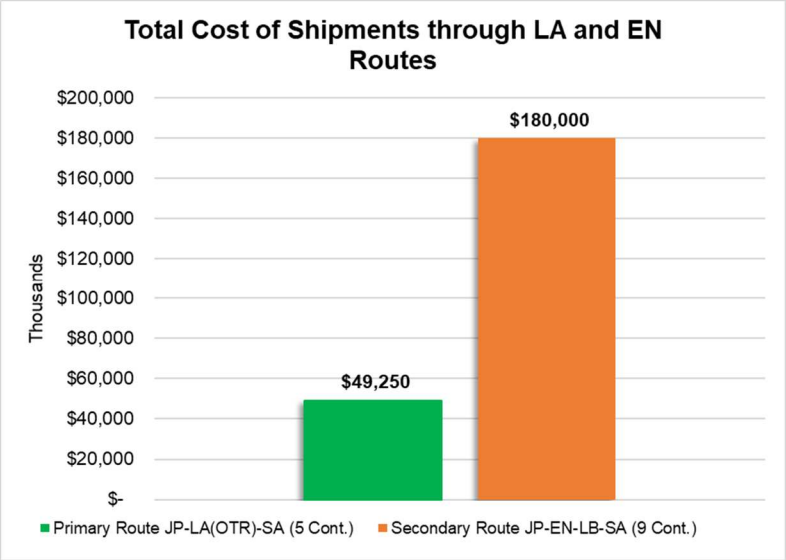

Figure 5.11: Cost of shipments through LA and EN routes during COVID-19.

The total cost of using both the LA and Ensenada routes during a transportation disruption was $229,250. Due to the low cost associated with the LA route, it was considered as the primary route, whereas the Ensenada route was the secondary route. The cost-focused loss-in-efficiency resulted in an estimated 408% higher total transportation cost for the secondary route when compared to the primary route.

Figure 5.12 shows the results of our time analysis, with a service time of 45 days attributed to the LA route and a service time of 35 days attributed to the Ensenada route.

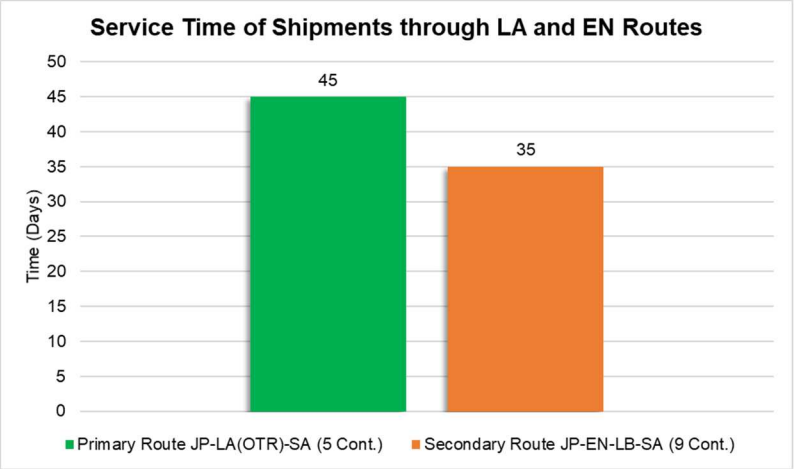

Figure 5.12: Service time of shipments through LA and EN routes during COVID-19.

The time-focused gain-in-efficiency resulted in an estimated 22% lower total service time. The high-cost and low-time differential between these routes showed that the Port of Ensenada did not offer a cost advantage but offered a feasible and resilient time-focused solution to lower the vulnerability of the 3PL SC network during a transportation disruption.

5.4 Comparison of the Public and Private Sector Results

Previously on the public sector approach, we reported an annual Reduced Wait Time Transportation Cost of $8.63M, while the private sector approach reported the Resilient Transportation Network Cost of $229,250 per vessels sent through the chosen routes. We determined the private sector annual cost to compare the results of both approaches based on their annual cost. From January 2021 to January 2022, a total of 124 vessels shipped containers among all routes. Since an average ratio of 5/14 containers were allocated to the LA route, 44 vessels were considered for this route. The remaining 80 vessels were considered for the Ensenada route. We multiplied the number of vessels associated with each route in a year by the cost of sending containers through each route. This resulted in an annual total average cost of $16.6M. Figure 5.13 shows that when compared to the Staffing Model Strategy, using the Flexible Logistics Strategy to overcome transportation disruptions was 92% more expensive.

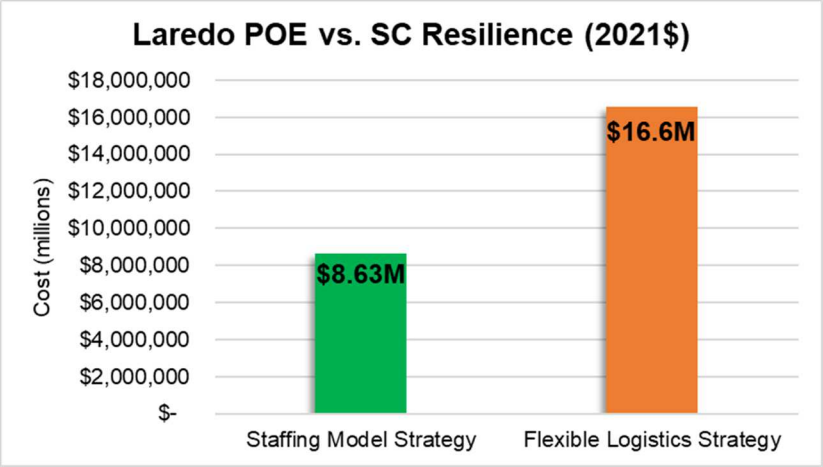

Figure 5.13: Total annual cost of using the public and private sector strategies.

The high cost from the private sector strategy was attributed to the long lead time associated in processing and receiving overseas goods through the U.S. sea POEs, in addition to the costs involved from each stakeholder in the 3PL SC network. On the other hand, the relative low cost of the public sector strategy was attributed to the shorter lead time associated in processing and crossing Mexican imports at U.S. land POEs.

5.5 Contributions of Both Perspectives

The method used in the public sector perspective provides a way to estimate the economic impact caused by the reduction of the General lane wait times at the Laredo POE. These results are useful to the U.S. government, as well as importing firms, exporting firms, and other governments, for making operational decisions that can benefit cross-border SCs. However, since September 11th , U.S. CBP mostly bases their decisions on tighter security, rather than trade facilitation. Regardless, the addition of a CBP officer at the Laredo POE provides a framework of a reduced wait time strategy that can be incorporated at other U.S.-Mexico POEs. Additionally, the SDQ model was able to represent a point in time (i.e., 8 most-congested hours) of the border crossing process. Our research on the public sector perspective contributes to the existing body of knowledge because it highlights the significance of CBP inspection disruptions

and the importance of facilitating cross-border trade to positively impact the U.S.-Mexico economies.

The method used in the private sector perspective provides a way to evaluate the resilience of a 3PL SC network for an anonymous company through an operations-research-based flexible logistics strategy. Specifically, we estimated the loss/gain-in-efficiency by considering the increase/decrease of transportation costs and lead time when alternate routes were selected during pandemic-induced disruptions. The results of our study provide a framework for other companies to manage their 3PL SC networks when faced with disruptions and insufficient time to implement a long-term plan. This is important because having a flexible, yet reactive strategy can be the difference between a competitive and non-competitive SC. Furthermore, we had the privilege of accessing reliable and accurate data from a private company. This is important because this kind of data is normally difficult to get ahold of in a competitive global market. Finally, our study contributes to the body of knowledge towards understanding the relationship between transportation flexibility in 3PL SCs and resilience.

CHAPTER VI

CONCLUSIONS AND FUTURE RESEARCH

6.1 Conclusions of the Public and Private Sector Perspectives

This thesis sought to understand and evaluate the impact of transportation disruptions to SCs from a public and private sector point of view. In the public sector perspective, U.S. CBP's mission is to adopt an increased security level approach to manage land POEs, which facilitates legitimate trade and ensures the protection of U.S. borders. However, this border management approach fails to support cross-border SCs' ability to trade freely and become more economically competitive. To better support U.S.-Mexico trade at the Laredo POE, staffing levels could be an effective variable to change. For example, Zhang (2009) used a congestion-based staffing policy, changing between low and high staffing levels based on the queue length of trucks, and it helped to better control the time spent waiting at the border. Similarly, Wander & Pierce (2011) used a non-linear programming model to optimize staffing levels and found that having more staff available to inspect vehicles resulted in lower waiting times and border operating costs. To assess these ideas, we used a staffing model to reduce truck wait times at the Laredo POE and evaluated the economic impact to U.S.-Mexico border SCs. For instance, our results showed that adding a CBP officer to the Columbia Solidarity Bridge reduced wait times by 63%, from 8 to 3 minutes. For the whole Laredo POE, the reduced wait time led to a 20% reduction in the total truck transportation cost, from $10.8M and $8.63M. This means that cross-border SCs could save $2.17M in border-related transportation costs from adding a CBP officer.

However, this also shows that the lack of an additional officer could affect U.S.-Mexico trade by indirectly increasing transportation costs. In summary, we found that additional staffing decreased the cost of imports from Mexico into the U.S., decreasing the cost of production in the U.S. and making exports more competitive worldwide.

For the private sector perspective, 3PL SCs and other organizations, including port authorities and U.S. CBP, are involved with the management of sea POE operations. However, each of the stakeholders contribute to sea POE operations from different angles that are conflicting in achieving port efficiency, failing to support the facilitation of maritime trade for SCs. Alongside lackluster port operations, pandemic disruptions also interfere with the operations of 3PL SCs. To better support their maritime trade at sea POEs, 3PL SCs could adopt a flexible logistics strategy to become resilient. For example, Shekarian, Nooraie, & Parast (2020) used a mixed-integer linear programming (MILP) model to minimize cost and risk through transportation flexibility, and it helped a SC to become more profitable. Likewise, Ishfaq (2012) used a flexible MILP model to minimize costs and transit times for a logistics network through multiple transportation modes, and it showed that it could help companies better manage disruptions and enhance their SC network resilience. Learning from these studies, we used a flexible logistics strategy for a COVID-19 pandemic-disrupted company to evaluate the impact of building resilience into its 3PL SC network. For the MCNF and shortest route model combination, the cost analysis revealed that shipping goods through the Port of Ensenada route cost approximately 103% more per container than through the default Port of LA route. In contrast, the time analysis showed that shipping goods through the Port of Ensenada route resulted in a 22% shorter service time than through the Port of LA route. Compared to the default Port of LA route, the alternate Port of Ensenada route offered a service time advantage,

highlighting the effectiveness of flexible logistics, especially important during a worldwide pandemic. In summary, we found that using a flexible three-connected network, with multiple modes of transport, allowed for competitive and resilient alternate routes under cost and service time constraints.

Finally, we compared the results of both perspectives. Adopting a staffing model strategy for the public sector perspective resulted in an annual total transportation cost of approximately $8.63M. Conversely, adopting a flexible logistics strategy resulted in an annual total transportation cost of approximately $16.6M. Compared to the staffing model strategy, the flexible logistics strategy was 92% more expensive for SCs. Nevertheless, each strategy provided their own advantages to SCs, with the staffing approach being useful at managing trade congestion at land POEs and the flexible logistics approach being useful at managing unplanned disruptions at sea POEs.

Disruptions caused by the COVID-19 pandemic and the increasing CBP inspection measures at the U.S. POEs have continued to affect U.S. international trade, despite the existence of the USMCA trade agreement. Growing consumer demand at both sea and land POEs has led to increased levels of truck and vessel congestion, which have indirectly increased import and transportation costs for SCs. As the level of globalization and modernization continues to grow, transportation disruptions will continue to challenge U.S. CBP and SCs. Ultimately, this research highlights the importance of understanding how U.S. POEs and SCs can overcome disruptions in trade and become resilient through specific adaptive strategies, such as increased staffing and flexible logistics.

6.2 Limitations and Future Research

6.2.1 Laredo POE

For the public sector perspective, we collected historical CBP wait time data and the number of trucks crossed at the Laredo POE crossings to develop a SDQ model. This model was used to estimate the reduction in truck wait time caused by the addition of a CBP officer. Since this model was based on an algebraic approach, it was limited in that it only considered one static point in time (i.e., the 8-most congested hours) to analyze the wait time effects during the operation of the border crossings. In the future, we wish to analyze the effect that the addition of a CBP officer would have during the hours before the congestion starts. Additionally, we limited our analysis of the additional CBP officer to the effect it had on the average wait times of all days of the week. However, Table 3.2 shows that average wait times for the 8 most-congested hours varied between weekdays and weekends. In a future study, we would like to separately consider weekdays and weekends, and analyze how wait times would change if a CBP officer were added.

Furthermore, the wait time data we used was easily accessible online but the prediction method for wait times that CBP currently uses did not make the most accurate or reliable data. In the future, we could design and train a set of Artificial Neural Network (ANN) models to predict the volume of trucks and their crossing times, as explored by Moniruzzaman, Maoh, & Anderson (2016). The model would be fed with year-long crossing time GPS data and truck volume data for a more accurate prediction of the U.S.-Mexico border trade process. Based on the ANN model predictions, a non-linear programming model could be formulated to optimize the staffing level – when subject to costs, wait time, and truck volume constraints – as investigated by Wander & Pierce (2011). This approach would allow for efficient border management of truck

congestion, which could help CBP to make better decisions to either mitigate or facilitate international trade. Lastly, we would also consider investigating the effect that recent increases of Texas Department of Public Safety (DPS) inspections – which were ordered by the governor of Texas – would have on U.S.-Mexico trade (Aguirre, Ferman, & Garcia, 2021).

6.2.2 SC resilience

For the private sector perspective, we built resilience into the 3PL SC network of an anonymous company by using a three-connected network that contained several modes of transportation. A primary and secondary route were considered, where the secondary route served as the alternate option whenever the primary route was affected by a transportation disruption. This capability provided operational flexibility through path redundancy within the network considered. However, our research was limited to managing disruptions seen at the U.S. sea POEs. In the future, we suggest using the flexible logistics strategy to manage disruptions at the U.S. land POEs of the Mexican border, while also considering capabilities based on supplier selection as explored by Kamalahmadi, Shekarian, & Parast (2021). For the considered strategy, the company prioritized selecting routes that provided a lead time advantage over a cost advantage. This choice led to high operational costs associated with the 3PL SC network. In the future, we suggest exploring the same strategy but prioritizing cost advantageous routes in our selection to avoid high costs. Also, we only considered the Port of Los Angeles, Houston, and Ensenada for our flexible logistics strategy because the company procures overseas containers only through these sea POEs. In the future, we suggest analyzing the effect of the strategy when considering the Port of Corpus Christi.

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APPENDIX A

APPENDIX A

WAIT TIME DATA FOR LAREDO POE

World Trade Bridge Historical Wait Time Data (CY 2021)

Table A.1: World Trade Bridge average wait times (Jan. 2021).

Average Wait Times for January							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM	0	4	5	4	5	6	0
8:00 AM	4	3	5	5	5	5	5
9:00 AM	5	4	5	6	6	6	7
10:00 AM	8	5	6	7	6	6	9
11:00 AM	17	6	9	12	10	6	13
Noon	31	13	17	21	18	9	28
1:00 PM	28	10	13	12	10	8	30
2:00 PM	15	7	9	10	7	8	19
3:00 PM	5	9	9	11	7	9	13
4:00 PM	0	11	14	13	10	12	2
5:00 PM	0	7	14	8	7	10	0
6:00 PM	0	7	14	6	7	11	0
7:00 PM	0	7	13	7	8	12	0
8:00 PM	0	11	18	14	16	13	0
9:00 PM	0	11	12	9	11	7	0
10:00 PM	0	7	5	7	6	6	0
11:00 PM							

8-most congested hours in January							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	31	13	18	21	18	13	30
2	28	11	17	14	16	12	28
3	17	11	14	13	11	12	19
4	15	11	14	12	10	11	13
5	8	10	14	12	10	10	13
6	5	9	13	11	10	9	9
7	5	7	13	10	8	9	7
8	4	7	12	9	7	8	5
Average	14.1	9.9	14.4	12.8	11.3	10.5	15.5

Table A.2: World Trade Bridge average wait times (Feb. 2021).

Average Wait Times for February							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM	0	4	4	5	6	4	0
8:00 AM	4	5	5	5	8	5	5
9:00 AM	5	6	5	5	6	6	6
10:00 AM	9	6	5	6	8	6	9
11:00 AM	10	6	8	7	10	7	10
Noon	26	9	14	14	13	10	28
1:00 PM	26	6	10	17	10	10	38
2:00 PM	7	9	11	13	8	12	19
3:00 PM	1	6	9	10	8	9	15
4:00 PM	0	9	12	12	13	14	3
5:00 PM	0	7	11	9	14	15	0
6:00 PM	0	6	7	8	15	14	0
7:00 PM	0	8	7	19	18	16	0
8:00 PM	0	8	14	15	24	22	0
9:00 PM	0	6	6	10	12	11	0
10:00 PM	0	5	7	5	8	6	0
11:00 PM							

8-most congested hours in February							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	26	9	14	19	24	22	38
2	26	9	14	17	18	16	28
3	10	9	12	15	15	15	19
4	9	8	11	14	14	14	15
5	7	8	11	13	13	14	10
6	5	7	10	12	13	12	9
7	4	6	9	10	12	11	6
8	1	6	8	10	10	10	5
Average	11.0	7.8	11.1	13.8	14.9	14.3	16.3

Table A.3: World Trade Bridge average wait times (Mar. 2021).

Average Wait Times for March							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM	0	4	4	5	5	4	0
8:00 AM	4	5	5	5	6	5	4
9:00 AM	5	6	5	6	5	6	6
10:00 AM	9	6	7	5	7	5	10
11:00 AM	11	7	9	9	6	7	13
Noon	22	9	16	19	8	13	29
1:00 PM	21	6	10	16	7	12	29
2:00 PM	6	7	9	12	7	10	16
3:00 PM	3	8	9	10	8	9	12
4:00 PM	0	11	16	11	11	8	2
5:00 PM	0	12	10	7	7	9	0
6:00 PM	0	12	7	8	8	11	0
7:00 PM	0	14	7	11	11	13	0
8:00 PM	0	13	12	18	13	11	0
9:00 PM	0	7	9	14	6	6	0
10:00 PM	0	6	6	6	6	7	0
11:00 PM							

8-most congested hours in March							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	22	14	16	19	13	13	29
2	21	13	16	18	11	13	29
3	11	12	12	16	11	12	16
4	9	12	10	14	8	11	13
5	6	11	10	12	8	11	12
6	5	9	9	11	8	10	10
7	4	8	9	11	7	9	6
8	3	7	9	10	7	9	4
Average	10.1	10.8	11.4	13.9	9.1	11.0	14.9

Table A.4: World Trade Bridge average wait times (Apr. 2021).

Average Wait Times for April							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM	0	4	4	4	4	4	0
8:00 AM	4	5	5	5	5	5	5
9:00 AM	5	7	7	6	6	6	6
10:00 AM	7	6	11	6	11	6	10
11:00 AM	8	7	15	10	13	7	11
Noon	24	11	14	14	18	13	43
1:00 PM	21	8	6	10	12	12	31
2:00 PM	11	6	8	7	8	8	23
3:00 PM	1	7	10	7	8	6	15
4:00 PM	0	8	12	13	6	8	2
5:00 PM	0	7	9	11	6	6	0
6:00 PM	0	8	12	7	6	6	0
7:00 PM	0	10	8	6	7	6	0
8:00 PM	0	13	8	8	7	8	0
9:00 PM	0	11	7	8	5	5	0
10:00 PM	0	6	6	7	6	5	0
11:00 PM							

8-most congested hours in April							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	24	13	15	14	18	13	43
2	21	11	14	13	13	12	31
3	11	11	12	11	12	8	23
4	8	10	12	10	11	8	15
5	7	8	11	10	8	8	11
6	5	8	10	8	8	7	10
7	4	8	9	8	7	6	6
8	1	7	8	7	7	6	5
Average	10.1	9.5	11.4	10.1	10.5	8.5	18.0

Table A.5: World Trade Bridge average wait times (May 2021).

Average Wait Times for May							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM	0	4	4	4	5	5	0
8:00 AM	2	5	5	6	5	5	4
9:00 AM	3	5	6	6	6	6	5
10:00 AM	4	7	6	6	6	9	6
11:00 AM	6	6	5	7	8	9	8
Noon	13	7	6	12	12	10	13
1:00 PM	11	6	6	12	9	7	13
2:00 PM	6	5	6	12	11	7	10
3:00 PM	1	5	7	11	10	6	6
4:00 PM	0	8	7	6	9	7	2
5:00 PM	0	11	6	9	7	6	0
6:00 PM	0	8	6	9	7	6	0
7:00 PM	0	7	7	10	13	5	0
8:00 PM	0	6	7	6	9	7	0
9:00 PM	0	7	6	6	6	6	0
10:00 PM	0	6	6	6	5	6	0
11:00 PM							

8-most congested hours in May							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	13	11	7	12	13	10	13
2	11	8	7	12	12	9	13
3	6	8	7	12	11	9	10
4	6	7	7	11	10	7	8
5	4	7	6	10	9	7	6
6	3	7	6	9	9	7	6
7	2	7	6	9	9	7	5
8	1	6	6	7	8	6	4
Average	5.8	7.6	6.5	10.3	10.1	7.8	8.1

Table A.6: World Trade Bridge average wait times (Jun. 2021).

Average Wait Times for June							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM		2	4	4	2	4	0
8:00 AM	5	3	4	4	5	4	2
9:00 AM	5	3	4	3	4	4	4
10:00 AM	5	3	10	4	4	4	5
11:00 AM	5	5	7	6	6	6	4
Noon	20	4	5	18	16	11	19
1:00 PM	28	1	4	18	13	10	20
2:00 PM	5	3	6	14	11	5	11
3:00 PM	0	3	4	14	3	4	4
4:00 PM		4	7	13	8	4	2
5:00 PM		3	5	11	6	10	
6:00 PM		4	5	9	6	5	
7:00 PM		4	5	12	4	6	
8:00 PM		10	7	8	5	4	
9:00 PM		5	5	8	4	4	
10:00 PM		4	4	5	1	4	
11:00 PM		2	3	0	0	2	

8-most congested hours in June							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	28	10	10	18	16	11	20
2	20	5	7	18	13	10	19
3	5	5	7	14	11	10	11
4	5	4	7	14	8	6	5
5	5	4	6	13	6	6	4
6	5	4	5	12	6	5	4
7	5	4	5	11	6	5	4
8	0	4	5	9	5	4	2
Average	9.1	5.0	6.5	13.6	8.9	7.1	8.6

Table A.7: World Trade Bridge average wait times (Jul. 2021).

Average Wait Times for July							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM		0	0	0	0	0	0
8:00 AM	4	3	1	6	4	4	4
9:00 AM	3	1	8	10	4	2	5
10:00 AM	4	3	11	18	5	5	5
11:00 AM	4	5	9	16	5	5	8
Noon	11	9	13	25	8	24	15
1:00 PM	23	21	30	28	18	28	31
2:00 PM	13	5	19	26	9	22	26
3:00 PM	1	6	20	29	6	13	17
4:00 PM		4	23	14	5	4	
5:00 PM		4	11	21	5	4	
6:00 PM		4	11	8	4	4	
7:00 PM		6	11	6	3	4	
8:00 PM		6	10	9	7	6	
9:00 PM		5	6	6	4	4	
10:00 PM		14	2	4	2	1	
11:00 PM		11	0	0	1	0	

8-most congested hours in July							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	23	21	30	29	18	28	31
2	13	14	23	28	9	24	26
3	11	11	20	26	8	22	17
4	4	9	19	25	7	13	15
5	4	6	13	21	6	6	8
6	4	6	11	18	5	5	5
7	3	6	11	16	5	5	5
8	1	5	11	14	5	4	4
Average	7.9	9.8	17.3	22.1	7.9	13.4	13.9

Table A.8: World Trade Bridge average wait times (Aug. 2021).

Average Wait Times for August							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM	0	2	4	2	2	2	0
8:00 AM	0	5	5	4	3	4	3
9:00 AM	1	3	2	4	4	4	4
10:00 AM	5	5	2	4	4	4	5
11:00 AM	5	5	5	5	5	4	5
Noon	19	3	4	14	11	5	14
1:00 PM	23	5	18	10	10	13	18
2:00 PM	12	4	20	4	3	5	16
3:00 PM	2	4	8	3	4	5	5
4:00 PM		6	14	10	6	6	2
5:00 PM		13	11	9	5	4	0
6:00 PM		12	10	14	6	4	0
7:00 PM		11	11	28	11	15	0
8:00 PM		15	13	35	8	20	0
9:00 PM		19	3	10	8	8	0
10:00 PM		15	2	3	3	4	0
11:00 PM		4	0	0	0	0	

8-most congested hours in August							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	23	19	20	35	11	20	18
2	19	15	18	28	11	15	16
3	12	15	14	14	10	13	14
4	5	13	13	14	8	8	5
5	5	12	11	10	8	6	5
6	2	11	11	10	6	5	5
7	1	6	10	10	6	5	4
8	0	5	8	9	5	5	3
Average	8.4	12.0	13.1	16.3	8.1	9.6	8.8

Table A.9: World Trade Bridge average wait times (Sep. 2021).

Average Wait Times for September							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM		0	0	0	0	2	
8:00 AM	0	3	3	3	2	3	0
9:00 AM	3	3	4	4	5	9	3
10:00 AM	4	3	10	3	8	6	4
11:00 AM	5	5	13	16	5	9	10
Noon	19	11	15	21	11	18	30
1:00 PM	24	6	15	46	24	26	29
2:00 PM	9	8	15	38	19	8	16
3:00 PM	0	4	16	35	21	11	13
4:00 PM		8	40	30	33	31	
5:00 PM		5	25	24	25	26	
6:00 PM		5	19	18	6	18	
7:00 PM		5	31	16	9	8	
8:00 PM		16	43	34	13	16	
9:00 PM		16	43	9	9	13	
10:00 PM		5	25	1	0	1	
11:00 PM		0	6	0	0	0	

8-most congested hours in September							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	24	16	43	46	33	31	30
2	19	16	43	38	25	26	29
3	9	11	40	35	24	26	16
4	5	8	31	34	21	18	13
5	4	8	25	30	19	18	10
6	3	6	25	24	13	16	4
7	0	5	19	21	11	13	3
8	0	5	16	18	9	11	0
Average	8.0	9.4	30.3	30.8	19.4	19.9	13.1

Table A.10: World Trade Bridge average wait times (Oct. 2021).

Average Wait Times for October							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM		2	0	0	0	0	
8:00 AM	1	13	5	8	5	6	0
9:00 AM	4	5	1	5	5	6	5
10:00 AM	4	10	18	8	5	10	5
11:00 AM	6	14	40	8	25	12	7
Noon	26	43	50	40	35	28	25
1:00 PM	34	43	46	49	38	25	33
2:00 PM	26	30	45	40	38	27	29
3:00 PM	6	35	50	40	38	20	15
4:00 PM		34	30	55	43	36	
5:00 PM		35	36	51	41	34	
6:00 PM		35	43	53	40	19	
7:00 PM		35	44	55	49	24	
8:00 PM		38	44	55	53	28	
9:00 PM		29	45	31	39	18	
10:00 PM		15	16	10	5	3	
11:00 PM		0	14	2	0	0	

8-most congested hours in October							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	34	43	50	55	53	36	33
2	26	43	50	55	49	34	29
3	26	38	46	55	43	28	25
4	6	35	45	53	41	28	15
5	6	35	45	51	40	27	7
6	4	35	44	49	39	25	5
7	4	35	44	40	38	24	5
8	1	34	43	40	38	20	0
Average	13.4	37.3	45.9	49.8	42.6	27.8	14.9

Table A.11: World Trade Bridge average wait times (Nov. 2021).

Average Wait Times for November							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM		0	0	0	0	0	
8:00 AM	1	5	9	5	8	6	1
9:00 AM	3	5	13	4	5	4	3
10:00 AM	3	4	14	8	3	3	3
11:00 AM	6	3	24	14	13	15	6
Noon	24	26	34	18	30	49	35
1:00 PM	28	24	43	43	29	38	43
2:00 PM	11	21	22	38	39	40	29
3:00 PM	5	24	25	35	26	43	20
4:00 PM		16	23	31	16	20	0
5:00 PM		16	20	31	15	19	
6:00 PM		23	24	29	15	18	
7:00 PM		31	20	33	16	18	
8:00 PM		28	26	31	14	16	
9:00 PM		25	4	33	1	6	
10:00 PM		14	1	16	0	1	
11:00 PM		0	1	0	0	0	

8-most congested hours in November							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	28	31	43	43	39	49	43
2	24	28	34	38	30	43	35
3	11	26	26	35	29	40	29
4	6	25	25	33	26	38	20
5	5	24	24	33	16	20	6
6	3	24	24	31	16	19	3
7	3	23	23	31	15	18	3
8	1	21	22	31	15	18	1
Average	10.1	25.3	27.6	34.4	23.3	30.6	17.5

Table A.12: World Trade Bridge average wait times (Dec. 2021).

Average Wait Times for December							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight						0	
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM		0	0	0	0	0	0
8:00 AM	0	8	8	4	6	4	3
9:00 AM	0	4	3	7	5	3	2
10:00 AM	3	3	5	8	6	4	3
11:00 AM	3	5	5	11	14	6	3
Noon	14	4	14	17	24	14	27
1:00 PM	33	18	9	19	31	17	35
2:00 PM	16	10	14	19	27	23	15
3:00 PM	0	8	11	12	23	21	11
4:00 PM		8	5	17	24	28	0
5:00 PM		6	23	15	22	30	
6:00 PM		8	13	18	16	27	
7:00 PM		10	15	15	18	25	
8:00 PM		18	15	4	13	33	
9:00 PM		4	3	5	3	15	
10:00 PM		4	0	2	2	12	
11:00 PM		0	0	0	0	0	

8-most congested hours in December							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	33	18	23	19	31	33	35
2	16	18	15	19	27	30	27
3	14	10	15	18	24	28	15
4	3	10	14	17	24	27	11
5	3	8	14	17	23	25	3
6	0	8	13	15	22	23	3
7	0	8	11	15	18	21	3
8	0	8	9	12	16	17	2
Average	8.6	11.0	14.3	16.5	23.1	25.5	12.4

Columbia Solidarity Bridge Historical Wait Time Data (CY 2021)

Table A.13: Columbia Solidarity bridge average wait times (Jan. 2021).

Average Wait Times for January							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	0	5	6	4	6	7	4
9:00 AM	1	5	6	6	5	8	5
10:00 AM	9	4	6	7	5	9	5
11:00 AM	8	12	11	8	8	9	7
Noon	9	10	13	17	14	13	16
1:00 PM	11	7	13	17	10	10	13
2:00 PM	3	8	10	11	8	7	10
3:00 PM	0	10	11	7	6	9	5
4:00 PM	0	12	9	10	11	9	2
5:00 PM	0	11	7	7	8	13	0
6:00 PM	0	19	6	7	5	12	0
7:00 PM	0	9	21	6	8	8	0
8:00 PM	0	8	7	8	6	10	0
9:00 PM	0	7	8	6	7	5	0
10:00 PM	0	6	6	5	5	5	0
11:00 PM							

8-most congested hours in January							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	11	19	21	17	14	13	16
2	9	12	13	17	11	13	13
3	9	12	13	11	10	12	10
4	8	11	11	10	8	10	7
5	3	10	11	8	8	10	5
6	1	10	10	8	8	9	5
7	0	9	9	7	8	9	5
8	0	8	8	7	7	9	4
Average	5.1	11.4	12.0	10.6	9.3	10.6	8.1

Table A.14: Columbia Solidarity bridge average wait times (Feb. 2021).

Average Wait Times for February							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	0	5	5	7	5	7	5
9:00 AM	0	9	5	8	6	5	5
10:00 AM	9	6	5	9	6	5	6
11:00 AM	7	8	7	8	11	7	8
Noon	6	13	8	10	12	10	8
1:00 PM	6	6	8	17	8	9	7
2:00 PM	2	6	11	8	7	9	6
3:00 PM	0	9	10	6	6	8	7
4:00 PM	0	8	10	10	9	11	2
5:00 PM	0	5	6	11	5	6	0
6:00 PM	0	7	6	7	6	8	0
7:00 PM	0	6	7	5	5	7	0
8:00 PM	0	10	7	7	6	6	0
9:00 PM	0	7	5	5	5	5	0
10:00 PM	0	5	6	6	5	5	0
11:00 PM							

8-most congested hours in February							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	9	13	11	17	12	11	8
2	7	10	10	11	11	10	8
3	6	9	10	10	9	9	7
4	6	9	8	10	8	9	7
5	2	8	8	9	7	8	6
6	0	8	7	8	6	8	6
7	0	7	7	8	6	7	5
8	0	7	7	8	6	7	5
Average	3.8	8.9	8.5	10.1	8.1	8.6	6.5

Table A.15: Columbia Solidarity bridge average wait times (Mar. 2021).

Average Wait Times for March							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	0	5	6	7	6	6	6
9:00 AM	0	6	7	12	7	6	6
10:00 AM	4	6	7	6	7	10	6
11:00 AM	6	12	11	11	6	8	7
Noon	8	15	14	13	9	13	7
1:00 PM	5	10	13	10	11	12	6
2:00 PM	2	8	15	7	11	12	8
3:00 PM	0	7	8	11	8	17	5
4:00 PM	0	8	9	9	10	11	2
5:00 PM	0	9	6	10	10	8	0
6:00 PM	0	15	8	20	7	8	0
7:00 PM	0	13	15	11	6	7	0
8:00 PM	0	11	6	7	7	6	
9:00 PM	0	6	6	9	6	5	
10:00 PM	0	5	6	9	5	5	
11:00 PM							

8-most congested hours in March							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	8	15	15	20	11	17	8
2	6	15	15	13	11	13	7
3	5	13	14	12	10	12	7
4	4	12	13	11	10	12	6
5	2	11	11	11	9	11	6
6	0	10	9	11	8	10	6
7	0	9	8	10	7	8	6
8	0	8	8	10	7	8	5
Average	3.1	11.6	11.6	12.3	9.1	11.4	6.4

Table A.16: Columbia Solidarity bridge average wait times (Apr. 2021).

Average Wait Times for April							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	0	7	6	7	7	6	4
9:00 AM	0	6	11	9	6	9	6
10:00 AM	5	8	12	9	7	11	6
11:00 AM	6	13	16	9	11	9	9
Noon	11	18	21	8	14	19	23
1:00 PM	5	19	16	13	9	8	15
2:00 PM	2	15	10	8	28	8	6
3:00 PM	0	13	8	9	13	6	6
4:00 PM	0	9	8	10	8	8	2
5:00 PM	0	8	6	8	6	5	0
6:00 PM	0	9	7	7	6	9	0
7:00 PM	0	8	6	8	5	6	0
8:00 PM	0	8	6	7	6	6	0
9:00 PM	0	5	6	5	5	6	0
10:00 PM	0	6	5	5	5	5	0
11:00 PM							

8-most congested hours in April							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	11	19	21	13	28	19	23
2	6	18	16	10	14	11	15
3	5	15	16	9	13	9	9
4	5	13	12	9	11	9	6
5	2	13	11	9	9	9	6
6	0	9	10	9	8	8	6
7	0	9	8	8	7	8	6
8	0	8	8	8	7	8	4
Average	3.6	13.0	12.8	9.4	12.1	10.1	9.4

Table A.17: Columbia Solidarity bridge average wait times (May 2021).

Average Wait Times for May							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	0	4	7	6	6	5	6
9:00 AM	1	10	7	6	13	15	8
10:00 AM	7	8	11	9	12	13	7
11:00 AM	7	18	9	11	10	14	6
Noon	13	19	16	13	14	10	7
1:00 PM	7	16	7	9	15	8	25
2:00 PM	4	12	6	6	11	6	5
3:00 PM	0	9	9	11	20	11	11
4:00 PM	0	12	6	5	32	16	2
5:00 PM	0	14	6	18	5	7	0
6:00 PM	0	11	6	20	19	6	0
7:00 PM	0	10	6	22	16	7	0
8:00 PM	0	6	7	10	9	5	0
9:00 PM	0	9	6	13	5	5	0
10:00 PM	0	5	5	8	5	5	0
11:00 PM							

8-most congested hours in May							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	13	19	16	22	32	16	25
2	7	18	11	20	20	15	11
3	7	16	9	18	19	14	8
4	7	14	9	13	16	13	7
5	4	12	7	13	15	11	7
6	1	12	7	11	14	10	6
7	0	11	7	11	13	8	6
8	0	10	7	10	12	7	5
Average	4.9	14.0	9.1	14.8	17.6	11.8	9.4

Table A.18: Columbia Solidarity bridge average wait times (Jun. 2021).

Average Wait Times for June							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	0	4	4	4	4	4	5
9:00 AM	0	5	5	5	5	5	5
10:00 AM	4	5	5	5	5	5	5
11:00 AM	5	5	7	5	5	5	5
Noon	5	5	15	10	5	5	5
1:00 PM	5	5	5	5	5	5	5
2:00 PM	2	5	5	9	5	5	5
3:00 PM	0	5	5	36	5	5	5
4:00 PM	0	5	20	5	5	13	2
5:00 PM	0	5	13	5	5	15	0
6:00 PM	0	6	19	5	5	10	0
7:00 PM	0	5	6	5	5	5	0
8:00 PM	0	5	5	5	5	5	0
9:00 PM	0	5	5	5	5	5	0
10:00 PM	0	5	5	5	5	5	0
11:00 PM							

8-most congested hours in June							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	5	6	20	36	5	15	5
2	5	5	19	10	5	13	5
3	5	5	15	9	5	10	5
4	4	5	13	5	5	5	5
5	2	5	7	5	5	5	5
6	0	5	6	5	5	5	5
7	0	5	5	5	5	5	5
8	0	5	5	5	5	5	5
Average	2.6	5.1	11.3	10.0	5.0	7.9	5.0

Table A.19: Columbia Solidarity bridge average wait times (Jul. 2021).

Average Wait Times for July							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	0	4	4	4	4	4	4
9:00 AM	0	5	5	5	5	5	5
10:00 AM	4	5	8	5	5	5	5
11:00 AM	5	5	5	5	5	5	5
Noon	5	5	5	5	6	5	5
1:00 PM	5	17	6	16	5	5	5
2:00 PM	2	5	17	11	11	5	5
3:00 PM	0	5	5	5	5	5	5
4:00 PM	0	39	5	5	5	5	2
5:00 PM	0	5	5	5	5	5	0
6:00 PM	0	5	5	5	5	42	0
7:00 PM	0	5	5	5	5	14	0
8:00 PM	0	5	5	5	9	5	0
9:00 PM	0	5	5	5	12	5	0
10:00 PM	0	5	5	5	5	5	0
11:00 PM							

8-most congested hours in July							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	5	39	17	16	12	42	5
2	5	17	8	11	11	14	5
3	5	5	6	5	9	5	5
4	4	5	5	5	6	5	5
5	2	5	5	5	5	5	5
6	0	5	5	5	5	5	5
7	0	5	5	5	5	5	5
8	0	5	5	5	5	5	4
Average	2.6	10.8	7.0	7.1	7.3	10.8	4.9

Table A.20: Columbia Solidarity bridge average wait times (Aug. 2021).

Average Wait Times for August							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	0	7	4	3	4	3	2
9:00 AM	0	4	5	5	4	9	3
10:00 AM	1	5	8	4	4	9	3
11:00 AM	2	10	8	4	4	5	3
Noon	2	11	10	11	4	5	3
1:00 PM	2	8	3	4	4	6	3
2:00 PM	1	6	3	5	5	3	3
3:00 PM	0	6	3	4	6	17	3
4:00 PM		5	3	4	5	15	2
5:00 PM		5	3	4	4	5	
6:00 PM		4	28	4	4	3	
7:00 PM		4	3	4	4	3	
8:00 PM		4	3	4	3	3	
9:00 PM		4	3	4	3	3	
10:00 PM		4	3	4	3	3	
11:00 PM		0	0	0	0	0	

8-most congested hours in August							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	2	11	28	11	6	17	3
2	2	10	10	5	5	15	3
3	2	8	8	5	5	9	3
4	1	7	8	4	4	9	3
5	1	6	5	4	4	6	3
6	0	6	4	4	4	5	3
7	0	5	3	4	4	5	3
8	0	5	3	4	4	5	2
Average	1.0	7.3	8.6	5.1	4.5	8.9	2.9

Table A.21: Columbia Solidarity bridge average wait times (Sep. 2021).

Average Wait Times for September							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	0	5	5	6	5	4	4
9:00 AM	3	0	0	2	0	1	4
10:00 AM	1	0	0	3	1	3	3
11:00 AM	3	1	1	3	2	3	3
Noon	3	6	20	7	5	3	9
1:00 PM	3	1	26	3	12	3	13
2:00 PM	1	5	20	3	1	3	0
3:00 PM	0	5	13	3	1	3	0
4:00 PM		3	13	3	3	1	
5:00 PM		3	5	2	4	4	
6:00 PM		3	4	2	1	3	
7:00 PM		1	3	2	1	0	
8:00 PM		1	1	1	4	1	
9:00 PM		1	0	1	6	0	
10:00 PM		1	0	6	0	0	
11:00 PM		0	0	5	0	0	

8-most congested hours in September							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	3	6	26	7	12	4	13
2	3	5	20	6	6	4	9
3	3	5	20	6	5	3	4
4	3	5	13	5	5	3	4
5	1	3	13	3	4	3	3
6	1	3	5	3	4	3	3
7	0	3	5	3	3	3	0
8	0	1	4	3	2	3	0
Average	1.8	3.9	13.3	4.5	5.1	3.3	4.5

Table A.22: Columbia Solidarity bridge average wait times (Oct. 2021).

Average Wait Times for October							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	3	4	5	6	5	8	3
9:00 AM	0	3	1	3	3	2	2
10:00 AM	0	1	6	4	3	11	2
11:00 AM	0	10	23	4	3	28	4
Noon	2	28	19	4	18	34	12
1:00 PM	6	29	10	3	13	22	10
2:00 PM	1	20	11	8	5	10	8
3:00 PM	0	14	11	3	3	1	1
4:00 PM		24	8	8	18	1	
5:00 PM		26	9	1	10	1	
6:00 PM		19	9	1	3	2	
7:00 PM		14	4	0	1	1	
8:00 PM		3	0	3	1	1	
9:00 PM		1	0	0	1	0	
10:00 PM		1	0	0	0	0	
11:00 PM		0	0	0	0	0	

8-most congested hours in October							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	6	29	23	8	18	34	12
2	3	28	19	8	18	28	10
3	2	26	11	6	13	22	8
4	1	24	11	4	10	11	4
5	0	20	10	4	5	10	3
6	0	19	9	4	5	8	2
7	0	14	9	3	3	2	2
8	0	14	8	3	3	2	1
Average	1.5	21.8	12.5	5.0	9.4	14.6	5.3

Table A.23: Columbia Solidarity bridge average wait times (Nov. 2021).

Average Wait Times for November							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	0	7	5	9	9	4	1
9:00 AM	1	2	2	3	5	3	1
10:00 AM	1	6	1	14	8	3	0
11:00 AM	4	11	9	24	4	8	4
Noon	3	7	9	25	10	15	5
1:00 PM	3	7	6	14	9	16	8
2:00 PM	1	6	7	14	9	10	0
3:00 PM	1	4	2	5	3	3	0
4:00 PM		5	4	9	4	5	0
5:00 PM		1	3	3	3	5	
6:00 PM		0	1	0	1	1	
7:00 PM		0	1	0	0	6	
8:00 PM		0	1	4	0	1	
9:00 PM		0	0	0	0	0	
10:00 PM		0	0	0	0	0	
11:00 PM		0	0	0	0	0	

8-most congested hours in November							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	4	11	9	25	10	16	8
2	3	7	9	24	9	15	5
3	3	7	7	14	9	10	4
4	1	7	6	14	9	8	1
5	1	6	5	14	8	6	1
6	1	6	4	9	5	5	0
7	1	5	3	9	4	5	0
8	0	4	2	5	4	4	0
Average	1.8	6.6	5.6	14.3	7.3	8.6	2.4

Table A.24: Columbia Solidarity bridge average wait times (Dec. 2021).

Average Wait Times for December							
Time	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM	8	6	5	5	4	8	5
9:00 AM	1	4	0	2	2	5	3
10:00 AM	0	6	1	5	2	11	8
11:00 AM	4	13	3	14	15	13	3
Noon	1	14	3	12	11	8	10
1:00 PM	1	11	0	3	7	14	7
2:00 PM	1	6	0	9	14	6	3
3:00 PM	0	1	0	1	12	2	0
4:00 PM		4	4	4	6	4	0
5:00 PM		4	1	3	12	3	
6:00 PM		1	1	0	2	6	
7:00 PM		0	1	0	6	0	
8:00 PM		0	0	0	2	0	
9:00 PM		1	0	0	1	0	
10:00 PM		0	0	0	1	0	
11:00 PM		0	0	0	0	0	

8-most congested hours in December							
Rank	Sunday (min)	Monday (min)	Tuesday (min)	Wednesday (min)	Thursday (min)	Friday (min)	Saturday (min)
1	8	14	5	14	15	14	10
2	4	13	4	12	14	13	8
3	1	11	3	9	12	11	7
4	1	6	3	5	12	8	5
5	1	6	1	5	11	8	3
6	1	6	1	4	7	6	3
7	0	4	1	3	6	6	3
8	0	4	1	3	6	5	0
Average	2.0	8.0	2.4	6.9	10.4	8.9	4.9

APPENDIX B

APPENDIX B

CONTAINER, ROUTES, AND LEAD TIME DATA

Table B.1: Container data (Jan. 2021 – Jan. 2022).

CONTAINER NUMBER	CARRIER	ARRIVAL DATE	VESSEL NAME
SEGU4533394	ONE	1/3/2021	ONE HANNOVER 0083E
TEMU6641856	ONE	1/3/2021	ONE HANNOVER 0083E
SEGU5789185	ONE	1/3/2021	ONE HANNOVER 0083E
ONEU0342910	ONE	1/3/2021	ONE HANNOVER 0083E
TCLU6273973	ONE	1/3/2021	ONE HANNOVER 0083E
NYKU5132740	ONE	1/7/2021	NYK ORPHEUS 0060E
KKFU7957857	ONE	1/9/2021	NYK ORPHEUS 0060E
GLDU9340424	ONE	1/9/2021	NYK ORPHEUS 0060E
TCLU4862824	ONE	1/11/2021	NYK ORPHEUS 0060E
TCNU7623245	ONE	1/11/2021	NYK ORPHEUS 0060E
TCLU8475891	ONE	1/11/2021	NYK ORPHEUS 0060E
MOTU1430084	ONE	1/11/2021	NYK ORPHEUS 0060E
ONEU0114519	ONE	1/17/2021	NYK ORION 0065E
TCLU1657370	ONE	1/21/2021	NYK ORION 0065E
TCNU5631025	ONE	1/22/2021	NYK ORION 0065E
TCLU6649211	ONE	1/22/2021	NYK ORION 0065E
ONEU0235676	ONE	1/22/2021	NYK ORION 0065E
KKFU8092845	ONE	1/22/2021	NYK ORION 0065E
TCLU9421523	ONE	1/22/2021	ONE HAMBURG 0067E
MOTU0710270	ONE	1/22/2021	ONE HAMBURG 0067E
TCNU4105793	ONE	1/23/2021	NYK ORION 0065E
TCNU9634980	ONE	1/23/2021	ONE HAMBURG 0067E
TCNU6857568	ONE	1/23/2021	ONE HAMBURG 0067E
AXIU1615670	ONE	1/23/2021	ONE HAMBURG 0067E
TCLU7807857	ONE	1/23/2021	ONE HAMBURG 0067E
TCNU5628720	ONE	1/31/2021	ONE ALTAIR 0053E
TCLU6435713	ONE	1/31/2021	ONE ALTAIR 0053E
TCLU6479250	ONE	2/1/2021	ONE ALTAIR 0053E
TCLU6339875	ONE	2/3/2021	ONE ALTAIR 0053E
TCLU6648513	ONE	2/5/2021	ONE ALTAIR 0053E
NYKU0708072	ONE	2/13/2021	HENRY HUDSON BRIDGE 0073E
TCNU6988655	ONE	2/16/2021	HENRY HUDSON BRIDGE 0073E
KKFU7937296	ONE	2/16/2021	HENRY HUDSON BRIDGE 0073E

Table B.1, cont.

TCLU8485797	ONE	2/16/2021	HENRY HUDSON BRIDGE 0073E
TCLU8937599	ONE	2/16/2021	HENRY HUDSON BRIDGE 0073E
FSCU8544118	ONE	2/16/2021	HENRY HUDSON BRIDGE 0073E
KKFU7917941	ONE	2/17/2021	NYK VEGA 0070E
BMOU5267603	ONE	2/25/2021	NYK VEGA 0070E
TCNU5243170	ONE	2/25/2021	NYK VEGA 0070E
BMOU5272209	ONE	2/25/2021	NYK VEGA 0070E
KKFU7857565	ONE	3/5/2021	NYK VENUS 0067E
NYKU4874831	ONE	3/5/2021	NYK VENUS 0067E
NYKU5203530	ONE	3/8/2021	NYK VENUS 0067E (DIVERSION)
TCNU5973619	ONE	3/14/2021	NYK VENUS 0067E
NYKU5944949	ONE	3/14/2021	ONE HAMMERSMITH 0071E
TCLU8825310	ONE	3/14/2021	ONE HAMMERSMITH 0071E
TCLU9645170	ONE	3/15/2021	NYK VENUS 0067E
TCNU4115359	ONE	3/15/2021	NYK VENUS 0067E
NYKU4358603	ONE	3/15/2021	NYK VENUS 0067E
TCNU2719010	ONE	3/15/2021	ONE HONG KONG 0072E (DIVERSION)
FDCU0466935	ONE	3/15/2021	ONE HONG KONG 0072E (DIVERSION)
TCNU6602973	ONE	3/18/2021	NYK VENUS 0067E
NYKU4854985	ONE	3/19/2021	ONE HAMMERSMITH 0071E
NYKU5904479	ONE	3/19/2021	ONE HAMMERSMITH 0071E
TCNU5156012	ONE	3/19/2021	ONE HAMMERSMITH 0071E
TCLU8492857	ONE	3/19/2021	ONE HAMMERSMITH 0071E
TEMU6840328	ONE	3/19/2021	ONE HAMMERSMITH 0071E
TCNU7584149	ONE	3/22/2021	NYK OCEANUS 0065E (DIVERSION)
KKFU8104170	ONE	3/22/2021	NYK OCEANUS 0065E (DIVERSION)
TCLU1688175	ONE	3/31/2021	ONE HONG KONG 0072E
KKFU8150900	ONE	4/2/2021	NYK VESTA 0071E (DIVERSION)
NYKU5128272	ONE	4/2/2021	NYK VESTA 0071E (DIVERSION)
TCNU2454841	ONE	4/2/2021	ONE HONG KONG 0072E
MOTU1401173	ONE	4/16/2021	ONE HUMBER 0086E (DIVERSION)
BEAU4627146	ONE-MX	4/17/2021	VALOR 2111E (DIVERSION)
TCLU1601771	ONE-MX	4/17/2021	VALOR 2111E (DIVERSION)
NYKU5268572	ONE	4/19/2021	ONE HARBOUR 0087E (DIVERSION)
BEAU4601727	ONE-MX	4/20/2021	VALOR 2111E
TCLU4620693	ONE-MX	4/20/2021	VALOR 2111E
TCNU5557925	ONE-MX	4/20/2021	VALOR 2111E
TCLU7901457	ONE-MX	4/26/2021	CONTI CHIVALRY 2112E

Table B.1, cont.

TCLU6468300	ONE	4/30/2021	ONE HANNOVER 0084E (DIVERSION)
TGBU5148927	ONE	4/30/2021	ONE HANNOVER 0084E (DIVERSION)
BEAU5388236	ONE	5/1/2021	ONE HANNOVER 0084E (DIVERSION)
TCNU7086188	ONE	5/4/2021	ONE HANNOVER 0084E
TCLU6726180	ONE	5/4/2021	ONE HANNOVER 0084E
KKFU8157118	ONE	5/4/2021	ONE HANNOVER 0084E
TCNU4127750	ONE	5/4/2021	ONE HANNOVER 0084E
TCLU9301678	ONE-MX	5/4/2021	VALUE 2113E
ONEU0349318	ONE-MX	5/4/2021	VALUE 2113E
BSIU9814520	ONE-MX	5/4/2021	VALUE 2113E
TCLU1682198	ONE-MX	5/4/2021	VALUE 2113E
TCNU3021785	ONE	5/10/2021	NYK ORPHEUS 0061E (DIVERSION)
FDCU0442189	ONE	5/10/2021	NYK ORPHEUS 0061E (DIVERSION)
TCLU1533471	ONE-MX	5/11/2021	SEASPAN BELLWETHER 2114E
TCNU4961378	ONE-MX	5/11/2021	SEASPAN BELLWETHER 2114E
CAIU9353823	ONE	5/19/2021	ONE HARBOUR 0087E
BSIU9620273	ONE	5/24/2021	ONE HAMBURG 0068E (DIVERSION)
DRYU9431167	ONE-MX	5/24/2021	SEASPAN BEYOND 2115E
FCIU9764150	ONE-MX	5/24/2021	SEASPAN BEYOND 2115E
TCLU7819523	ONE-MX	5/24/2021	SEASPAN BEYOND 2115E
NYKU4331670	ONE-MX	5/24/2021	SEASPAN BEYOND 2115E
TCNU7128370	ONE-MX	5/24/2021	SEASPAN BEYOND 2115E
CRSU9308006	ONE	5/25/2021	ONE HAMBURG 0068E (DIVERSION)
BEAU4448011	ONE	5/26/2021	ONE HAMBURG 0068E (DIVERSION)
CAAU5178571	ONE-MX	5/27/2021	CROATIA 2116E
NYKU5125566	ONE	5/27/2021	ONE HANNOVER 0084E
TCLU5258568	ONE-MX	5/27/2021	SEASPAN BEYOND 2115E
SEGU4458372	ONE	5/28/2021	NYK ORPHEUS 0061E
ONEU0345755	ONE	5/28/2021	NYK ORPHEUS 0061E
BSIU9807351	ONE	5/28/2021	NYK ORPHEUS 0061E
KKFU7602693	ONE-MX	5/31/2021	CROATIA 2116E
TCNU7484520	ONE-MX	5/31/2021	CROATIA 2116E
TCNU9436623	ONE-MX	5/31/2021	CROATIA 2116E
TLLU5617706	ONE-MX	5/31/2021	CROATIA 2116E
TCNU6856279	ONE-MX	5/31/2021	VANTAGE 2117E
TCNU6850120	ONE-MX	5/31/2021	VANTAGE 2117E

Table B.1, cont.

TRLU7417098	ONE-MX	5/31/2021	VANTAGE 2117E
TCNU5687235	ONE-MX	5/31/2021	VANTAGE 2117E
KKFU7759424	ONE-MX	6/1/2021	VANTAGE 2117E
NYKU0820863	ONE-MX	6/1/2021	VANTAGE 2117E
TCLU1824179	ONE-MX	6/1/2021	VANTAGE 2117E
GCXU5255178	ONE-MX	6/2/2021	VANTAGE 2117E
DRYU6085836	ONE-MX	6/4/2021	VANTAGE 2117E
FDCU0375666	ONE	6/14/2021	NYK VIRGO 0070E (DIVERSION)
FFAU1857515	ONE	6/14/2021	NYK VIRGO 0070E (DIVERSION)
FDCU0347387	ONE	6/14/2021	NYK VIRGO 0070E (DIVERSION)
NYKU5200783	ONE	6/14/2021	NYK VIRGO 0070E (DIVERSION)
BEAU5392880	ONE	6/14/2021	NYK VIRGO 0070E (DIVERSION)
NYKU4383442	ONE	6/14/2021	NYK VIRGO 0070E (DIVERSION)
TCNU6097953	ONE	6/14/2021	NYK VIRGO 0070E (DIVERSION)
TCLU6249827	ONE-MX	6/18/2021	VALIANT 2119E
TCKU7942994	ONE-MX	6/18/2021	VALIANT 2119E
ONEU0304669	ONE-MX	6/18/2021	VALIANT 2119E
NYKU4326632	ONE-MX	6/18/2021	VALIANT 2119E
NYKU4916114	ONE-MX	6/25/2021	SEASPAN BREEZE 2121E (DIVERSION)
TCLU4873053	ONE-MX	6/25/2021	SEASPAN BREEZE 2121E (DIVERSION)
FFAU1416886	ONE-MX	6/30/2021	SEASPAN BREEZE 2121E
SEKU4419196	ONE-MX	6/30/2021	SEASPAN BREEZE 2121E
KKFU7839089	ONE-MX	6/30/2021	SEASPAN BREEZE 2121E
NYKU4931398	ONE-MX	6/30/2021	SEASPAN BREEZE 2121E
TRHU4159427	ONE-MX	6/30/2021	SEASPAN BREEZE 2121E
TCNU4876152	ONE-MX	6/30/2021	SEASPAN BREEZE 2121E
TEMU8629401	ONE-MX	7/7/2021	VALOR 2123E (DIVERSION)
TCKU7216414	ONE-HOUSTON	7/12/2021	ONE MATRIX 0061E
TGCU0207722	ONE-HOUSTON	7/12/2021	ONE MATRIX 0061E
TCLU9882280	ONE-MX	7/15/2021	VALOR 2123E (DIVERSION)
TLLU5470390	ONE-HOUSTON	7/16/2021	ONE MATRIX 0061E
TGBU9824697	ONE-HOUSTON	7/16/2021	ONE MATRIX 0061E
TCLU7898815	ONE-HOUSTON	7/16/2021	ONE MATRIX 0061E
NYKU4922570	ONE-HOUSTON	7/16/2021	ONE MATRIX 0061E

Table B.1, cont.

SEGU4635159	ONE-HOUSTON	7/16/2021	ONE MATRIX 0061E
KKFU8024590	ONE-MX	7/21/2021	MSC ANTONELLA 2124E
ONEU0099559	ONE-MX	7/21/2021	MSC ANTONELLA 2124E
KKFU7958365	ONE-HOUSTON	7/25/2021	EVER SMILE 0103E
NYKU5214811	ONE-HOUSTON	7/25/2021	EVER SMILE 0103E
TCNU5692479	ONE-HOUSTON	7/25/2021	EVER SMILE 0103E
NYKU4843785	ONE-HOUSTON	7/25/2021	EVER SMILE 0103E
GESU6356170	ONE-HOUSTON	7/25/2021	EVER SMILE 0103E
TLLU5686190	ONE-HOUSTON	7/25/2021	EVER SMILE 0103E
TCLU6644755	ONE-HOUSTON	7/25/2021	EVER SMILE 0103E
NYKU5106864	ONE-MX	7/26/2021	VALUE 2125E
ONEU0065712	ONE-MX	7/28/2021	SEASPAN BELLWETHER 2126E
BEAU4599234	ONE-MX	7/28/2021	SEASPAN BELLWETHER 2126E
TCLU1791835	ONE-MX	7/28/2021	VALUE 2125E
TCLU6755390	ONE-HOUSTON	7/29/2021	ONE MANEUVER 0056E
KKFU8046691	ONE-HOUSTON	7/29/2021	ONE MANEUVER 0056E
NYKU5112050	ONE-HOUSTON	7/29/2021	ONE MANEUVER 0056E
TCNU5562963	ONE-HOUSTON	7/29/2021	ONE MANEUVER 0056E
TCNU9485680	ONE-HOUSTON	7/29/2021	ONE MANEUVER 0056E
TCNU3022800	ONE-MX	7/30/2021	MSC ANTONELLA 2124E
FFAU3634634	ONE-HOUSTON	7/30/2021	ONE MANEUVER 0056E
FCIU9746074	ONE-HOUSTON	7/30/2021	ONE MANEUVER 0056E
DRYU9933611	ONE-HOUSTON	7/30/2021	ONE MANEUVER 0056E
TLLU4654942	ONE-HOUSTON	8/1/2021	ONE MOTIVATOR 0056E
TLLU5529837	ONE-MX	8/4/2021	MSC ANTONELLA 2124E
TCLU1783260	ONE-HOUSTON	8/8/2021	ONE MAXIM 0055E
CAIU9371241	ONE-HOUSTON	8/8/2021	ONE MAXIM 0055E

Table B.1, cont.

NYKU5239337	ONE-HOUSTON	8/8/2021	ONE MAXIM 0055E
TCLU9671559	ONE-HOUSTON	8/8/2021	ONE MAXIM 0055E
SEGU5298601	ONE-HOUSTON	8/8/2021	ONE MAXIM 0055E
ONEU0089360	ONE-MX	8/8/2021	SEASPAN BEYOND 2127E
FDCU0449162	ONE-MX	8/8/2021	SEASPAN BEYOND 2127E
FDCU0367887	ONE-MX	8/8/2021	SEASPAN BEYOND 2127E
TLLU5540292	ONE-MX	8/11/2021	SEASPAN BEYOND 2127E
CAAU5171263	ONE-MX	8/11/2021	SEASPAN BEYOND 2127E
TCLU1655274	ONE-MX	8/17/2021	CROATIA 2128E
TCLU7959926	ONE-MX	8/17/2021	CROATIA 2128E
MOTU1430320	ONE-MX	8/17/2021	CROATIA 2128E
KKFU7852943	ONE-HOUSTON	8/19/2021	ONE MISSION 0060E
BEAU5500114	ONE-HOUSTON	8/19/2021	ONE MISSION 0060E
GCXU5262198	ONE-HOUSTON	8/19/2021	ONE MISSION 0060E
TCLU4889065	ONE-HOUSTON	8/19/2021	ONE MISSION 0060E
CAIU8775146	ONE-HOUSTON	8/19/2021	ONE MISSION 0060E
BEAU5529191	ONE-MX	8/21/2021	CROATIA 2128E
KKFU7838415	ONE-MX	8/25/2021	VANTAGE 2129E
BEAU5535419	ONE-MX	8/25/2021	VANTAGE 2129E
DRYU6053588	ONE-MX	9/1/2021	HYUNDAI SATURN 0029E
FDCU0546985	ONE-HOUSTON	9/8/2021	ONE MODERN 0057E
FFAU1846763	ONE-HOUSTON	9/20/2021	ONE MAGNIFICENCE 0062E
SEGU4165158	ONE-HOUSTON	9/20/2021	ONE MAGNIFICENCE 0062E
ONEU0211421	ONE-HOUSTON	9/20/2021	ONE MAGNIFICENCE 0062E
SEGU5052618	ONE	10/5/2021	ONE OLYMPUS 0066E
KKFU8084285	ONE	10/15/2021	MOL SUCCESS 0129E
BEAU4601748	ONE	10/15/2021	MOL SUCCESS 0129E
GESU6731630	ONE	10/15/2021	MOL SUCCESS 0129E
TLLU5455483	ONE	10/24/2021	ONE OLYMPUS 0066E
TCLU8471324	ONE	10/24/2021	ONE OLYMPUS 0066E
ONEU0104608	ONE-HOUSTON	10/27/2021	ONE MOTIVATOR 0057E

Table B.1, cont.

TCLU7815024	ONE-HOUSTON	10/29/2021	ONE MOTIVATOR 0057E
TCLU7824880	ONE-HOUSTON	10/29/2021	ONE MOTIVATOR 0057E
TCLU6641519	ONE-HOUSTON	10/29/2021	ONE MOTIVATOR 0057E
NYKU0803697	ONE	11/1/2021	NYK ORION 0068E
NYKU0728084	ONE	11/1/2021	NYK ORION 0068E (DIVERSION)
TCLU1659813	ONE	11/3/2021	NYK ORION 0068E (DIVERSION)
FDCU0433253	ONE-HOUSTON	11/3/2021	ONE MAXIM 0056E
TLLU5678640	ONE-HOUSTON	11/3/2021	ONE MAXIM 0056E
TCNU5890617	ONE-HOUSTON	11/3/2021	ONE MAXIM 0056E
BEAU5256902	ONE	11/4/2021	NYK ORION 0068E
DRYU6028179	ONE-HOUSTON	11/4/2021	ONE MAXIM 0056E
BEAU5415326	ONE	11/9/2021	NYK ORION 0068E
TCNU3032162	ONE-HOUSTON	11/10/2021	ONE MISSION 0061E
GAOU6521080	ONE-HOUSTON	11/10/2021	ONE MISSION 0061E
FFAU1415426	ONE-HOUSTON	11/11/2021	ONE MISSION 0061E
NYKU4749172	ONE-HOUSTON	11/11/2021	ONE MISSION 0061E
CXDU1749611	ONE	11/14/2021	ONE HANOI 0041E
FDCU0459772	ONE-HOUSTON	11/15/2021	EVER SUPERB 0091E
KKFU7932611	ONE-HOUSTON	11/15/2021	EVER SUPERB 0091E
BEAU5512898	ONE-HOUSTON	11/15/2021	EVER SUPERB 0091E
NYKU5275864	ONE-HOUSTON	11/16/2021	EVER SUPERB 0091E
NYKU4978190	ONE-HOUSTON	11/16/2021	EVER SUPERB 0091E
ONEU0093632	ONE	11/16/2021	ONE HANOI 0041E
TGBU4447158	ONE	11/18/2021	ONE HANOI 0041E
BEAU5254833	ONE	11/19/2021	ONE HANOI 0041E
BEAU5329022	ONE	11/19/2021	ONE HANOI 0041E
KKFU7888252	ONE	11/20/2021	ONE HANOI 0041E
BSIU9677664	ONE	11/20/2021	ONE HANOI 0041E
TCLU8570796	ONE	11/24/2021	ONE HAMMERSMITH 0074E
TCNU6281528	ONE	11/24/2021	ONE HAMMERSMITH 0074E

Table B.1, cont.

DRYU6010122	ONE	12/1/2021	ONE HONG KONG 0074E
TRHU4993321	ONE	12/1/2021	ONE HONG KONG 0074E
NYKU4932814	ONE	12/1/2021	ONE HONG KONG 0074E
TCLU8526896	ONE	12/1/2021	ONE HONG KONG 0074E
FFAU3649470	ONE-HOUSTON	12/1/2021	ONE MODERN 0058E
GAOU6522488	ONE	12/4/2021	ONE HONG KONG 0074E
CXDU1120064	ONE	12/4/2021	ONE HONG KONG 0074E
DRYU6045725	ONE-HOUSTON	12/4/2021	ONE MODERN 0058E
TCLU5298405	ONE-HOUSTON	12/4/2021	ONE MODERN 0058E
FFAU1424285	ONE-HOUSTON	12/4/2021	ONE MODERN 0058E
CAIU9905326	ONE-HOUSTON	12/4/2021	ONE MODERN 0058E
TGCU5199717	ONE-HOUSTON	12/7/2021	ONE MAGNIFICENCE 0063E
TCLU1784348	ONE-HOUSTON	12/7/2021	ONE MAGNIFICENCE 0063E
BEAU5430737	ONE-HOUSTON	12/7/2021	ONE MAGNIFICENCE 0063E
FFAU1416762	ONE-HOUSTON	12/8/2021	ONE MAGNIFICENCE 0063E
TCLU9800701	ONE	12/15/2021	NYK OCEANUS 0067E
TCLU1638301	ONE	12/17/2021	NYK VESTA 0073E
CAIU8091020	ONE	12/21/2021	NYK OCEANUS 0067E
FFAU1432681	ONE	12/21/2021	NYK VESTA 0073E
BEAU5487769	ONE-HOUSTON	12/21/2021	ONE MATRIX 0063E
TCNU6639930	ONE-HOUSTON	12/21/2021	ONE MATRIX 0063E
TGBU4472206	ONE-HOUSTON	12/21/2021	ONE MATRIX 0063E
ONEU0107398	ONE-HOUSTON	12/22/2021	ONE MATRIX 0063E
TGBU9668784	ONE-HOUSTON	12/22/2021	ONE MATRIX 0063E
TEMU8824007	ONE-HOUSTON	12/29/2021	ONE MARVEL 0057E
NYKU4946248	ONE-HOUSTON	12/29/2021	ONE MARVEL 0057E
NYKU4957392	ONE-HOUSTON	12/29/2021	ONE MARVEL 0057E
TGBU5188154	ONE-HOUSTON	12/29/2021	ONE MARVEL 0057E

Table B.1, cont.

TCNU5969542	ONE-HOUSTON	12/29/2021	ONE MARVEL 0057E
TLLU4023660	ONE-HOUSTON	1/5/2022	EVER SMILE 0105E
GAOU6538247	ONE-HOUSTON	1/6/2022	EVER SMILE 0105E
TRHU5856128	ONE-HOUSTON	1/7/2022	EVER SMILE 0105E
TCLU9679930	ONE-HOUSTON	1/10/2022	EVER SMILE 0105E
TCLU1536969	ONE-HOUSTON	1/11/2022	EVER SMILE 0105E
FFAU1488124	ONE-HOUSTON	1/12/2022	ONE MANEUVER 0058E
TRHU4227964	ONE-HOUSTON	1/13/2022	ONE MANEUVER 0058E
GCXU5205433	ONE-HOUSTON	1/14/2022	ONE MANEUVER 0058E
TRHU4348288	ONE-HOUSTON	1/14/2022	ONE MANEUVER 0058E
TCLU7761083	ONE-HOUSTON	1/18/2022	ONE MOTIVATOR 0058E
BEAU5534135	ONE-HOUSTON	1/19/2022	ONE MOTIVATOR 0058E
NYKU4445225	ONE-HOUSTON	1/20/2022	ONE MOTIVATOR 0058E
OCGU8098322	ONE-HOUSTON	1/21/2022	ONE MOTIVATOR 0058E
TGBU4448370	ONE	1/24/2022	ONE HARBOUR 0089E
TRHU5174703	ONE	1/24/2022	ONE HARBOUR 0089E
BEAU5387950	ONE	1/24/2022	ONE HARBOUR 0089E
FDCU0354679	ONE	1/24/2022	ONE HARBOUR 0089E
NYKU4711773	ONE	1/24/2022	ONE HARBOUR 0089E
GCXU5257144	ONE	1/24/2022	ONE HARBOUR 0089E
TCNU4961378	ONE	1/24/2022	ONE HARBOUR 0089E
FDCU0382325	ONE	1/24/2022	ONE HARBOUR 0089E
TCLU9471714	ONE	1/24/2022	ONE HARBOUR 0089E
ONEU0112537	ONE	1/24/2022	ONE HARBOUR 0089E
TCNU3070239	ONE	1/24/2022	ONE HARBOUR 0089E
SEGU5859889	ONE-HOUSTON	1/24/2022	ONE MOTIVATOR 0058E
TLLU5646474	ONE-HOUSTON	1/25/2022	ONE MAXIM 0057E
BEAU5447051	ONE-HOUSTON	1/26/2022	ONE MAXIM 0057E
TCNU4004102	ONE-HOUSTON	1/27/2022	ONE MAXIM 0057E

Table B.1, cont.

TEMU8342432	ONE	1/28/2022	ONE HANOI 0042E
TRHU4893554	ONE	1/28/2022	ONE HANOI 0042E
TCLU6509272	ONE	1/28/2022	ONE HANOI 0042E
TGCU0154812	ONE-HOUSTON	1/28/2022	ONE MAXIM 0057E
SEGU5447367	ONE	1/30/2022	ONE ORPHEUS 0064E
KKFU7958745	ONE-HOUSTON	1/31/2022	ONE MAXIM 0057E

Transportation Routes: Container Costs and Lead Time Data (FY 2022)

Table B.2: LA route costs and lead times (based on condition).

JP --> LA --> SA (Los Angeles Route)		
Route Condition	Cost per Container	Lead Time (Days)
Standard: Rail	$ 6,820.00	32
Standard: OTR	$ 9,850.00	29
COVID-19-Disrupted: Rail	$ 6,820.00	52
COVID-19-Disrupted: OTR	$ 9,850.00	45

Table B.3: HS route costs and lead times (based on condition).

JP --> HS --> SA (Houston Route)		
Route Condition	Cost per Container	Lead Time (Days)
Standard: OTR	$ 7,199.00	41
COVID-19-Disrupted: OTR	$ 7,199.00	56

Table B.4: EN route costs and lead times (based on condition).

JP --> EN --> SA (Ensenada Route)		
Route Condition	Cost per Container	Lead Time (Days)
Standard: Rail (Long Beach)	$ 20,000.00	37
Standard: OTR (San Diego)	$ 21,500.00	35
COVID-19-Disrupted: Rail (Long Beach)	$ 20,000.00	37
COVID-19-Disrupted: OTR (San Diego)	$ 21,500.00	35

BIOGRAPHICAL SKETCH

Jose A. Jara Jr. Guerrero graduated with his Master's degree in Manufacturing Engineering from the University of Texas Rio Grande Valley (UTRGV) on August 2022. He resides in Laredo, Texas, and his email is josejarajr15@gmail.com. Mr. Jara previously graduated with his Bachelor's degree in Systems Engineering from Texas A&M International University (TAMIU) on May 2018, where he published a research paper under the *Chemical Physics Journal*. He was also an active member of the UTRGV Department of Manufacturing and Industrial Engineering by contributing as a student, teaching assistant, grader, and research assistant. In his research studies at UTRGV, he got the opportunity to publish his paper on the Proceedings of the 2020 Institute of Industrial and Systems Engineers Annual Conference. He was a member of the Rocket Launchers and the Society of Manufacturing Engineers, student organizations at UTRGV. Mr. Jara was also a guest speaker and recruiter for undergraduate students considering graduates studies. He has two years of professional experience in the logistics industry.