Economic Costs of Critical Infrastructure Failure in the El Paso-Ciudad Juarez Region

El Paso Metropolitan Planning Organization

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DISCLAIMER

This research was performed by the Texas A&M Transportation Institute (TTI). This project was conducted for research purposes only in the context of analyzing a new methodology for determining the economic impact of an extreme event in El Paso, Texas. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the El Paso Metropolitan Planning Organization. This report does not constitute a standard, specification, or regulation. It must be noted that the data presented in this report were prepared for internal use of the agency above. It is further noted that all charts and graphs are for illustrative purposes only.

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INTRODUCTION

Introduction and Background

Cross-border trade with Mexico forms the backbone of economic growth of the United States (US). As thousands of commercial vehicles cross the US–Mexico border on a daily basis, the cross-border freight volumes are expected to increase by more than 75 percent by 2035 to a value of $111 billion [*1*]. This will entail important and timely strategic planning at all existing ports-of-entry (POEs) located along the US–Mexico border to accommodate and facilitate the manifold increase and growth in the movements of commercial vehicles at present and in future. Of the several existing POEs along the border, the ones located in the El Paso–Juarez region are considered to be the most critical and important for the movement of people and freight within the region.

The El Paso–Juarez bi-national region's international border crossings are a system of regional, statewide, and national significance. This system provides a critical link between maquiladora factories, primarily located in Ciudad Juarez, and distribution centers and consumer markets located in metropolitan El Paso, Texas, southern New Mexico, and beyond. Some of that can be easily deduced from the truck trade taking place through El Paso POEs. In 2009, trucks were the predominant mode of trade through Texas' El Paso–Juarez region POEs. That year a total of 16 percent of US–Mexico trade took place by that mode. In 2010, more than $71 billion moved through El Paso POEs representing a 50 percent increase in total trade over 2009. The comparable figures for 2012 are $89.5 billion in truck trade value flowing through El Paso POEs [*2*].

The El-Paso–Juarez metropolitan area has more than 2.6 million people, making it the largest bi-national metropolitan area in the world. The area hosts several large freight generating companies. With significant growth in the population projected for the region, the El Paso–Juarez region POEs would experience a tremendous increase in cross-border movement of passengers and freight. Much of this cross-border movement is due to investments in transportation networks, which have increased global access and connectivity while increasing the role of the bi-national region as a trade outlet. This transportation connectivity has been a significant contributor to efficiencies and synergies in businesses and industries in the region and, over time, have led to the emergence of a shared economy for the border-city pair. Table 1 showcases the type of products moving through the POEs with highlighted sections reflecting the categories involved in intra-industry trade. Some of the intra-industry trade is also part of an in-bond manufacturing process allowing foreign ownership of maquiladora firms just south of the border to engage in international production sharing. Another indicator of this shared culture is also apparent in the number of trucks that cross the border. The latest statistics from the Texas Center for Border Economic and

Enterprise Development (TCBEED) point to 674,819 border crossings through the El Paso POE in 2012. This is common to most trade activity along the US–Mexico border. However, El Paso remains vital since it is the second most important port along the US–Mexico border in terms of trade [*3*]. This joint dependence is known to influence the economies of both nations through several economic channels, including employment, wages, and income in related sectors on both sides of the border.

The increasing realization about the interdependence of the national and global transportation supply chains, where one transportation network is an integral part of a "flat" global transportation network, brings up questions as to the effects of any kind of disruption in the context of global bi-national linkages, which are an integral part of NAFTA (North American Free Trade Agreement) trade. Cross-border freight volumes are expected to increase by 2035 to a total of 25.5 million tons with a value of $111 billion. Nearly all of this volume (78 percent by weight, 90 percent by value) will be transported by truck, increasing overall volumes at the region's 22 commercial crossings, on connections to warehousing and distribution facilities, and along the region's 23 major trade corridors (primarily I-10 and US 54) [*4*].

Table 1: Top Export and Import Trade Categories Through El Paso POEs (2012) [*2*].

Top Ten Import Categories by Value	Top Ten Export Categories by Value
Electrical machinery and equipment and parts; sound recorders and reproducers	Electrical machinery and equipment and parts; sound recorders and reproducers
Nuclear reactors; boilers; machinery and mechanical appliances; parts	Nuclear reactors; boilers; machinery and mechanical appliances; parts
Optical; photographic; cinematographic; measuring; checking; precision; medical instruments	Plastics and articles thereof
Furniture; bedding; mattress supports; cushions and similar stuffed furnishings; lighting fittings	Optical; photographic; cinematographic; measuring; checking; precision; medical instruments
Vehicles; other than railway or tramway rolling stock; and parts and accessories	Copper and articles thereof
Special classification provisions	Vehicles; other than railway or tramway rolling stock; and parts and accessories
Plastics and articles thereof	Articles of iron or steel
Articles of apparel and clothing accessories; not knitted or crocheted	Paper and paperboard; articles of paper pulp; of paper or of paperboard
Edible fruit and nuts; peel of citrus fruit or melons	Aluminum and articles thereof
Aircraft; spacecraft; and parts	Impregnated; coated; covered or laminated textile fabrics; textile articles for industrial use

Context for Studying Failure

Several recent instances of critical infrastructure failure were associated with large economic losses and social costs. On May 23, 2013, one span of the Interstate 5 bridge over the Skagit River at Mount Vernon in the state of Washington immediately collapsed into the river when it was struck by an over-height truck. This was not the result of aging infrastructure, but such events can happen unexpectedly.

The I-35W Mississippi River bridge (officially known as Bridge 9340) was an eight-lane, steel truss arch bridge that carried Interstate 35W across the Mississippi River in Minneapolis, Minnesota, United States. During the evening rush hour on August 1, 2007, it suddenly collapsed, killing 13 people and injuring 145. The bridge was Minnesota's fifth busiest, carrying 140,000 vehicles daily. The NTSB cited a design flaw as the likely cause of the collapse, and asserted that additional weight on the bridge at the time of the collapse may have contributed to the catastrophic failure. Since 2000, 15 bridge failure instances have been recorded due to aging infrastructure [*5*].

The 2013 Report Card for America's Infrastructure (issued by the American Society of Civil Engineers) gives the US infrastructure a D+ grade. Furthermore, a recent report by the Department of Homeland Security suggests that deteriorating critical infrastructure in the US could pose significant risk to the nation and its economy. According to the report, geographically, the entire US is at risk from aging infrastructure. Aging will affect all critical infrastructure sectors and ultimately reduce or erode their capacity and lifetimes in unexpected ways [*6*]. According to the National Risk Profile, lack of maintenance to the nation's aging infrastructure "will continue to result in occasional industrial disasters." The profile notes that public, civic media, policymakers, and politicians may simply accept this "inconvenience in the name of saving money." Increasing infrastructure loss of life could adversely affect the economy, "potentially causing the US to fall behind other countries and regions, particularly China and Europe."[*6*] In light of these circumstances, one has only to contemplate the consequences and risks associated with a critical infrastructure failure.

In general, the understanding associated impacts with an infrastructure failure are valuable for several reasons, not limited to:

- Understanding the economic value of an asset for use in the context of policy and planning discussions and decisions.
- Recognizing the economic effects of failures and disruptions, especially in the particular economic context of bi-national trade. Of particular interest is the hierarchy of effects or propagation of them from first order to higher order.
- Recognizing and identifying further propagation of risks through interdependent infrastructures, when meaningful.

Dynamic Traffic Assignment and Extreme Event Damage Assessments

Static methods based on average daily traffic will fail to identify the short term control actions necessary to manage non-recurring events. In 2004, Wirtz et al. [*7*] tested and studied the use of a dynamic traffic assignment (DTA) model for pre-planning strategies of major freeway incidents with the goal of identifying what type of mitigation responses might be the "best." DTA is particularly appropriate for modeling highway incidents because of the temporal aspect of incident timing, management, and recovery, allowing drivers to search for alternate routes. However, the literature showed no research that utilized DTA modeling and its dynamic spatial-temporal framework in the context of costs associated with disruptions.

DTA models estimate the best existing conditions—user equilibrium (UE)—in the network to assign vehicles to a user optimal path. User-optimal conditions are achieved as drivers develop knowledge of traffic conditions that will minimize their travel cost. However, an unexpected event that alters travel conditions may not necessarily lead the users to choose an optimal route in a shorter time span. In a well-managed highway system, drivers may find out about incidents via radio traffic reports, dashboards, RSS feeds, and other mechanisms. In the context of inter-linked systems (as observed under joint production sharing interactions that occur in the bi-national region) it is feasible for freight decision makers to maintain contingency route plans. This is to be expected in the case of the US–Mexico border where peril and prosperity have gone hand in hand over the years.

Bridge Collapse and its Effects

The last truly fatal major US bridge collapse occurred in 2007 [*8*]. Three major bridges collapsed in the United States that year:

- Harp Road Bridge in Greys Harbor County, Washington, collapsed under the weight of a truck hauling an excavator (none killed or injured).
- MacArthur Maze in Oakland, California, collapsed when a fire caused by a tanker truck crash and explosion weakened the steel support sections of the bridge (one injured in initial crash; no injuries from collapse).
- The I-35 bridge collapsed in Minneapolis, Minnesota.

The I-35 bridge stands out in this group for the amount of damage it caused. Out of the three collapses, this one had the most significant economic impact and was later studied to quantify the economic impacts of such infrastructure failure (see Figure 1).

Safety	13 people killed 145 people injured	
Environmental	?	
Customer Service	Loss of major transportation route (for >140,000 vehicles/day)	
Production-Schedule		
Material, Labor Cost	Increased commuting expenses ($400,000/day for 414 days)	$165,600,000
	Loss to economy (estimated)	$60,000,000
	Replacement of bridge	$234,000,000
	This incident	$459,600,000
Frequency	Infrequent	
	Annual Total	

Figure 1: I-35 Bridge Failure Costs.

Travel Impacts of the I-35 Bridge Collapse

In 2007, Tilayun and Levinson [*9*] examined the travel and behavioral effects from the I-35 collapse. They note that travelers can respond in different ways to the effects of the disruption. Changing their route and/or destination, adjusting departure time, changing their schedule, or not doing their trip are some of the ways in which they can cope. The trip purpose can influence which of these strategies are adopted. For instance, in the short run, a change of destination is not likely to be adopted for a work trip, whereas a change in route, adjusting departure time and/or changing schedule are very likely outcomes. Responses to a network disruption that arises from an isolated bridge collapse are very likely to be different from one that arises out of a natural disaster. Other hypotheses were tested using survey data. Zhu et al. [*10*] reported in 2010 no significant change in the total travel demand when the I-35 Mississippi River Bridge collapsed in Minnesota. This was possible due to the capacity provided by the nearby I-94 Mississippi River Bridge with additional lanes as a result of restriping.

Economic Effects of I-35 Collapse

Minnesota Department of Transportation (MnDOT) [*11*] conducted a study to quantify the economic costs of the collapse. The conclusions showed that the road-user costs (due to the unavailability of the river crossing) would total $400,000 per day. The estimate assigned a monetary value—associated with the detour rates—to both the value of auto travel time ($247,000) and heavy commercial truck travel time ($15,000). Furthermore, the variable operating costs (due to increased travel distance) for each auto and commercial trucks were $126,000 and $12,000, respectively. In addition to the road user cost study, the Minnesota Department of Employment and Economic Development (DEED) and MnDOT estimated an economic impact around $17 million in 2007 and $43 million in 2008. The MnDOT study focused on valuing how the unavailability of the river crossing affected road-users. Monetary values were assigned to auto travel time, heavy commercial truck travel time, as well as to variable operating costs. In addition to direct costs, the DEED study conducted (in collaboration with Regional Economic Models) an estimate of indirect and broader effects. The analysis assumed that the $153,000 due to longer road-time for commercial trucks and higher operating costs have measurable economic impacts. This is a reasonable assumption. The average daily net economic impact yields a $113,000 reduction in the state's economic output (i.e., Minnesota's economic pie, or gross state product), which translates to $17 million in 2007 and $43 million in 2008. These impacts are concentrated in the Twin Cities and translate to about 0.01 percent of the state's annual economy. This latter set of estimates is slightly lower than the earlier estimate of broader effects, but both show a sizeable effect on output.

In another study in 2012, Zhu et al. [*12*] show that people who worked or resided near the I-35 Mississippi River Bridge were the most affected by its failure. It was observed that frequent users of the bridge changed their route and/or departure time. The conclusions stated that simply re-assigning travel demand on the degraded network would not fully capture the effects of the bridge collapse.

Other Studies

In 2010, Jenelius [*13*] quantified the importance of back-up links (when other links fail in a network) by using the notion of "redundancy links." Two measures of importance were introduced for redundancy links based on traffic flows and travel impacts. These measures were recommended in order to study the effects of "authoritative" rerouting schemes for all heavy vehicles during a prominent link failure. Using a flow-based measure over the network from northern Sweden, the most important redundancy links were found to be located close to the largest highways in the area; while the impact-based measure showed that the links at the sparser part of the network became more important. Recommendations were further made "to divert traffic to other routes than the shorter ones in order to reduce the probabilities and consequences of additional failures or capacity excesses." [*13*]

Ševčíková et al. [*14*] investigated uncertainty about the future effects of tearing down the Alaskan Way Viaduct in downtown Seattle. The methodology used was based on Bayesian melding that utilized an integrated model of housing, jobs, land use, and transportation to predict average commute times. However, the methodology is only applicable for uncertainty analysis for long term changes that occur when transportation facilities are eliminated.

In 2011, Pant et al. [*15*] modeled the disruption operations of the Port of Catoosa, located on the Arkansas River navigation system near Tulsa, Oklahoma. The impact of a 2-week closure scenario was studied across interdependent industries and multiple regions. Quantification of the impacts was done with respect to output not being shipped and produced across the closed port. The economic losses were also analyzed due to the disruption in operations of inter-regional commodity flows. However, the entire analysis lacked examination of the losses resulting from the port closure for a dynamic inoperability. This case is more directly applicable to maritime ports.

Critical Infrastructure Failure and Possible Economic Costs/Effects

A critical infrastructure failure can vary from a short to long term temporary disruption of traffic when entire links in the network might fail. Capturing the economic consequences of a failure often follows a typology. Many authors have contributed to this literature and include Cochrane [*16*] and Rose [*17*] in the broader context of disaster modeling. It is typical to distinguish between the following:

- Direct losses refer to the immediate socioeconomic losses or consequences based on their incidence. These tend to include market and non-market (and sometimes intangible) losses. Market losses are those that are traded in the market and for which it is relatively simpler to observe valuation factors, prices, and replacement costs. The non-market losses include all those losses that cannot be repaired or replaced since the valuation factors are non-observable in the market.

- Indirect or higher order losses as in Rose [*17*] include all the losses that ripple from the initial incidence. It is often the case, for failures and disasters that impact the complete facility, that the indirect losses are often referred to broader economic outputs. For instance, business disruption costs are often tied back to economic output losses via recourse to input-output, computable generable equilibrium models. Indirect losses are dependent on behavioral responses of firms in the near and longer term.
    - At one extreme, for a longer term capital failure, for example, if manufacturing firms' transport linkages are damaged sufficiently in the context of interconnected systems, they may shift modes. This would lead to a demand reduction for trucking delivery services, which may impact the employment of drivers.
    - Firms may permanently accept/settle to an alternate route.

The difference between a disruption and a failure stems from the temporal nature of these categories, with the former being of much more permanent nature. In such a scheme, failures are typically associated with both direct and indirect losses.

This report focuses on utilizing the DTA model to assess the direct economic consequences. It is recognized that indirect losses will be much larger, but they will not be the focus of this study. In the context of critical infrastructure failure, links involved in trade movements for the region may have the following direct consequences/losses:

- Direct losses to immediate users (i.e., truckers) from route changes.
- Direct losses to those involved in goods shipment (i.e., industries and shippers) from route changes.
- Direct losses to immediate users and those involved in goods shipment from an altered POE choice.
- Safety or accident related losses from failure, including property damage costs.
- Capital or facility replacement costs.

Of these five possible direct loss categories, this research focused only on the first three types of user costs. In addition, there will be no discussions of possible broader impact including output losses or other spillovers.

Objectives of this Study

The specific objectives of this study are to:

- Develop and calibrate a DTA model for the bi-national region and to assess the effect of a critical infrastructure failure. In light of this discussion, "critical" infrastructure is defined as link(s) vital to the economy of the bi-national region that allow the movements of people and goods.

- Determine the traffic impact on the border region after the transportation infrastructure closure, specifically, at the POEs.
- Utilize the model to analyze the economic consequences of disruptions to the critical infrastructure.

SIMULATION MODEL DEVELOPMENT

Characteristics of Static and Dynamic Models

In a model defined on a relatively long time-of-day period, such as the peak period, the congestion properties of each link are described by a volume-delay function or link time/performance function that expresses the average or steady state travel-time on a link as a function of traffic volume on the link. Such models are called "static." In a static model, inflow to a link is always equal to the outflow: the travel time simply increases as the inflow and outflow increases. The volume on a link may increase indefinitely, and exceed the physical capacity of the link, as represented by a volume/capacity (V/C) ratio greater than one. Since the link volume does not conform to the traffic flow limit that results from the physical characteristics of the roadway, the assigned link volume can be considered as demand—trips desired to traverse the link—instead of the actual flow. As a consequence, static models do not describe congestion in any direct way, while dynamic models have a direct linkage between travel time and congestion. This ensures that if link density increases then speed will decrease, and therefore link travel time will increase. Furthermore, in a static model, the volume delay function (VDF) actually represents the congested condition, while in a dynamic model, the fundamental diagram describes how congestion at the exit node (reduced link outflow) is propagated upstream though the link, until it "spills back" onto the next upstream links. Such congestion spillback is not represented in static models. Given these differences between static and dynamic models, the research team utilized a dynamic model to better understand the consequences of having a critical transportation infrastructure failure in the system. In summary, some of the limitations of static models are [*18*]:

- Links may have a V/C ratio > 1.
- VDFs assume link first-in-first-out, which means no overtaking.
- VDFs have no explicit representation of individual lanes on a roadway.
- VDFs do not represent the phenomenon of congestion spillback.

Concept of Dynamic Traffic Assignment

Currently, transportation planning software used to model the El Paso–Juarez region often capture traffic patterns based on daily averages and, thus, no analysis can be performed at specific time periods of the simulation. However, with the incorporation of DTA, the temporal and spatial distribution of vehicles can be captured to provide detailed results throughout the simulation time period. DTA is a time-dependent methodology that captures travelers' route choice behavior as they traverse from origin to destination. The objective function known as dynamic user equilibrium (DUE) is based on the idea of drivers choosing their routes through the network according to their generalized travel cost, as experienced during the simulation. A generalized cost includes both travel time and any monetary costs (e.g., tolls) or other relevant attributes associated (preference) with a roadway. An iterative algorithmic procedure attempts to establish the DUE or time-dependent user equilibrium (TDUE) conditions by assignment vehicles departing at the same time between the same origin-destination (OD) pair to different paths. At any given point and after multiple iterations, travelers learn and adapt to the transportation network conditions. In the literature, there are two major DTA model categories—analytical and simulation-based DTA. Most of the existing commercially available models are simulation-based approaches because simulation-based DTA models are generally more flexible than analytical DTA models in accounting for various network traffic conditions such as traffic signals, incidents, or driver routing behaviors. A simulation-based DTA model typically consists of two principal model components:

- Simulation model.
- Traffic assignment model.

The simulation model is aimed at evaluating the quality of the assignment solution. The assignment model takes the inputs from the simulation to generate further paths and assign vehicles to different routes in order to get close to the DUE/TDUE condition over the iterations.

Simulation Model

Most exiting DTA models adopt a "mesoscopic" traffic simulation approach in which individual vehicles' position and speed are calculated based on average traffic conditions on the link following either macroscopic speed-density relationship [*19*], headway distributions [*20*], or queuing processes [*21*]. Mesoscopic simulation models generally have coarser simulation time resolutions (in the order of 5–10 seconds as opposed to 0.1–1 second resolution in microscopic models.) At times, some driver responses to roadway configurations (e.g., lane-changing, roadside parking, etc.) are also simplified through changing the capacity of either links for intersections. With the simplified simulation logics and coarser time resolution, the mesoscopic models are able to accommodate a much larger network with more vehicles and a longer simulation time period compared with microscopic models. In addition, all DTA simulation models are path-based, meaning that vehicles follow an assigned path from the origin to the destination. Diversion in response to roadway traffic condition changes or information provided to the drivers may also be modeled.

Traffic Assignment Model

The traffic assignment model is another critical component of the DTA model. The term "assignment" can be interpreted as assigning vehicles to routes following a specific objective. Vehicles with different routing objectives may be assigned with different routes computed with different respective objectives. The assignment model is generally an iterative numerical procedure, involving both analytical calculations and heuristics that are aimed at achieving a TDUE condition. The TDUE condition can be generally defined as the traffic condition in which those who travel between the same origin-destination pair at the same departure time taking different routes will experience the same travel time. No one can unilaterally improve their travel time without increasing the travel time on other routes at the TDUE condition. This definition highlights the key features required by the assignment model. First, experienced travel time needs to be captured. This means not only a traffic simulation approach is needed, but also a time-dependent (experienced) shortest path (least-cost algorithm) is needed to compute the shortest path with least experience travel time or cost. The traditional instantaneous shortest path algorithm relies on the link travel time at the time instance at which the shortest path is calculated. Second, the traffic state temporal interdependence needs to be captured. This is critical from modeling the traffic dynamic continuity standpoint. All traffic simulation models maintain such temporal continuity; however, certain time-sliced static traffic assignment approaches that fall short in maintaining the temporal state interdependence may produce inconsistent and counterintuitive results when examined from the traffic flow perspective.

Some traffic assignment models are specifically aimed at reaching the TDUE condition over iterations. A convergence criterion is typically defined. However, some model may adopt a different concept in which the traffic assignment is considered the route choice for individual drivers. Therefore, the assignment procedure let certain route choice behavior rule (e.g., discrete route choice model) dictate the route selection without explicitly seeking for the TDUE condition. The DTA algorithm is a heuristic iterative procedure that entails the following steps:

Initialization. Set the iteration counter $\iota = 0$. Assign the activity-based demand, r_{ih}^{τ}, ∀ i, τ, and h, to initial set of feasible paths $k \in k_{ij}$, where j is the first destination in the travel plan h. Accordingly, the initial solution is given by $r_{ijk}^{\tau,0}$, ∀ i, h, τ, and k.

Step 0. Under the set of departure time and path assignments, $r_{ihk}^{\tau,\iota}$, perform traffic network simulation to obtain the corresponding network performance including link travel times, T^{ta}, ∀ t, a. Calculate also the new demand at each node, which is equal to $r_{ij}^{\tau,\iota} = \sum_k r_{ijk}^{\tau,\iota}$ ∀ i, j, and τ.

Step 1. For each departure time interval, τ, compute the set of least travel time (or least generalized travel cost in case of link pricing consideration) paths between each origin-destination pair.

Step 2. Perform all or nothing assignment for all travel desires, $r_{ij}^{\tau,\iota}$. This gives an auxiliary number of vehicles on paths for each departure time interval, $y_{ijk^*}^{\tau^*,\iota}$, ∀ i, j, and τ.

Step 3. Update the path by checking if $k^* \in k_{ij}$, and include it if it does not, ∀ i and h. Assignments for the next iteration $r_{ijk}^{\tau,\iota+1}$ are obtained using the method of successive averages, ∀ i, h, τ, and k:

$$r_{ijk}^{\tau,\iota+1} = \frac{1}{(\iota+1)} \cdot [y_{ijk}^{\tau,\iota}] + \left(1 - \frac{1}{(\iota+1)}\right) \cdot [r_{ijk}^{\tau,\iota}]$$

Step 4. Check the convergence criterion that is based on the difference in numbers of vehicles assigned to various departure time intervals and paths over two successive iterations.

Hence, assignments to the next iterations $r_{ihk}^{\tau,\iota+1}$ are compared with current path assignments, $r_{ijk}^{\tau,\iota}$, ∀ i, j, τ, and k:

$$\left| r_{ijk}^{\tau,\iota+1} - r_{ijk}^{\tau,i} \right| \leq \varepsilon \qquad \text{where } \varepsilon \text{ is a predefined threshold.}$$

Step 5. The number of cases, N(ε), in which the above absolute value is greater than ε is recorded.

Step 6. Specify a pre-set upper bound,, Ω, on the number of violations, N(ε); terminate the algorithm if the number N(ε)≤ Ω,, and output the joint departure time-path assignments, $r_{ijk}^{\tau,\iota}$, as the solution to the assignment problem. On the other hand, if N(ε)>Ω, the convergence criterion is not satisfied. Update the iteration counter (ι=ι+1) and go to step 1 with the new path assignments $r_{ijk}^{\tau,\iota+1}$.

The integration of DTA allows dynamic control (i.e., time dependent) of the road network by representing variations in traffic flows and conditions such as vehicle overtaking, congestion, and spillback in order to anticipate problems rather than just react to existing conditions

Bi-National Model

Static Based Model

The development of the simulation-based bi-national DTA model was first derived from a static integrated land use and transport modeling system—TRANUS[1] [*22*]. It combined state-of-the-art modeling of the activities, locations, land use, and their interactions with a transportation system. In addition, TRANUS allowed estimating OD matrices for several traveler categories, modes, and trip purposes.

The model had a total of 264 traffic analysis zones (TAZs) in which the El Paso and Ciudad Juarez regions consist of 148 and 116 TAZs, respectively. The research team obtained the 24 hour matrix from a previously calibrated and validated bi-national model originally performed for mass transit purposes. The bi-national model was derived from a 2009 base year scenario. The transportation model incorporates a simplified roadway network with bi-national transit networks. The entire roadway network was composed of 8645 links, including the POEs and TAZ connectors. In addition, 20 individual link-types were used to define the free flow speed, penalizations, and tolls, and to model each POE individually. Due to the complexity of the bi-national modeling area and the uniqueness of each POE (i.e., different capacities, volumes, delays, etc.), individual link-types were used to model each POE using certain parameters, thus helping with the origin-destination matrix development. The final TRANUS model was converted to DynusT format (as seen in

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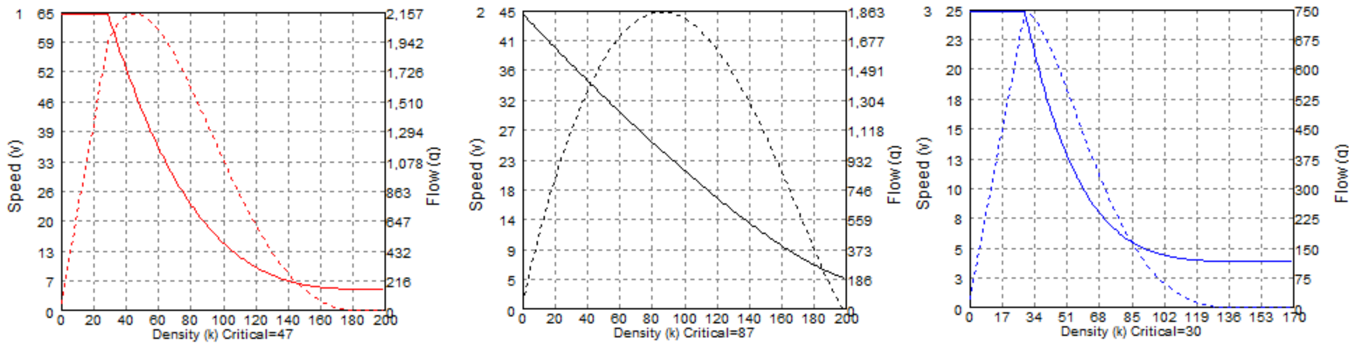
1 TRANUS is an integrated land use and transport modeling system developed by Modelistica.

Figure 2) by importing all the necessary layers (e.g., links, nodes, zones, etc.) as well as the demand tables into the DynusT graphical user interface (GUI).

Figure 2: DTA Bi-National Model in DynusT.

DTA Based Model

As part of the model development, the TTI team established the traffic flow models (TFM) necessary for simulation in the DTA model. In essence, a TFM describes the relationship between speed and density of vehicles depending on the capacity of the link (see Figure 3). Dual-regime models were applied to freeways and single-regime models to arterials and collectors. The flow model utilized in the simulation is based upon Greenshield's equation, which follows the basic traffic engineering principles of speed, density, and flow [*23*]. Freeway facilities have greater throughput than arterials and can hold larger densities near free-flow speeds. Arterial link-types are more sensitive to density changes due to interrupted flow (control signals) and ultimately less overall capacity. Researchers also created a separate TFM for the POEs as these types of links are heavily congested and experience significant delays due to vehicle inspections.



TFM for uninterrupted flow and high capacity (e.g. freeways, highways)

TFM for interrupted flow with low capacity (e.g. arterials)

TFM for POEs

Figure 3: TFMs used for Uninterrupted Flow, Interrupted Flow, and POEs.

The research team proceeded to validate the POE infrastructure so it represents current conditions and no coding errors exist. First, separate links were coded for each vehicle type as shown in Figure 4. Separate links for freight and passenger cars were necessary to conduct the origin-destination calibration, as well as specify the different operational hours for both vehicle types. The model includes the following POEs:

- Bridge of the Americas (BOTA).
- Ysleta (Zaragoza).
- Santa Teresa.
- Paso del Norte (PDN).

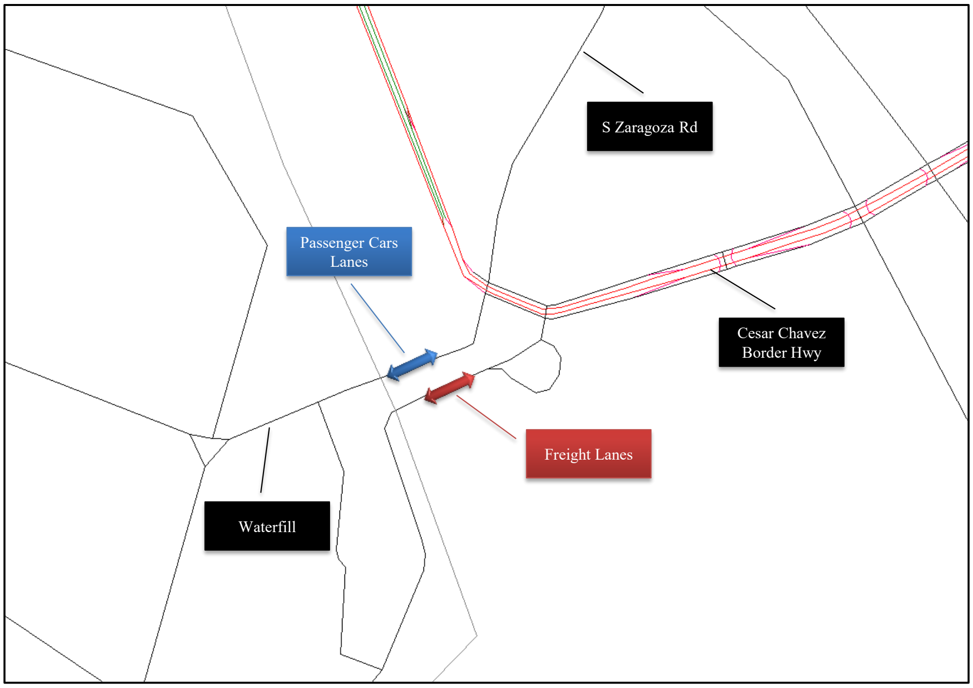


Figure 4: Example of the Ysleta (Zaragoza) POE in Dynustudio.

Origin-Destination Calibration

The seed OD matrix was developed from TRANUS and converted to DTA format. Researchers disaggregated the seed matrix into 24 one-hour matrices and used diurnal factors provided by the El Paso Metropolitan Planning Organization (MPO) to develop a profile of departure time distribution. Once the seed matrix profiles were established, OD calibration was performed using a linearized quadratic optimization tool developed by the University of Arizona [*24*]**.** The objective function was to minimize the absolute deviation between the simulated and actual link counts. The DTA model is run to a user defined number of iterations. Upon completion of simulation and assignment, the OD calibration tool calls for the optimization solver to solve the minimization problem, adjusting all OD pairs of routes that traversed through all screen line count areas resulting in new OD matrices (Figure 5). The iterations continue until the total deviation is less than a user defined threshold, or the maximum number of iterations is reached [*25*].

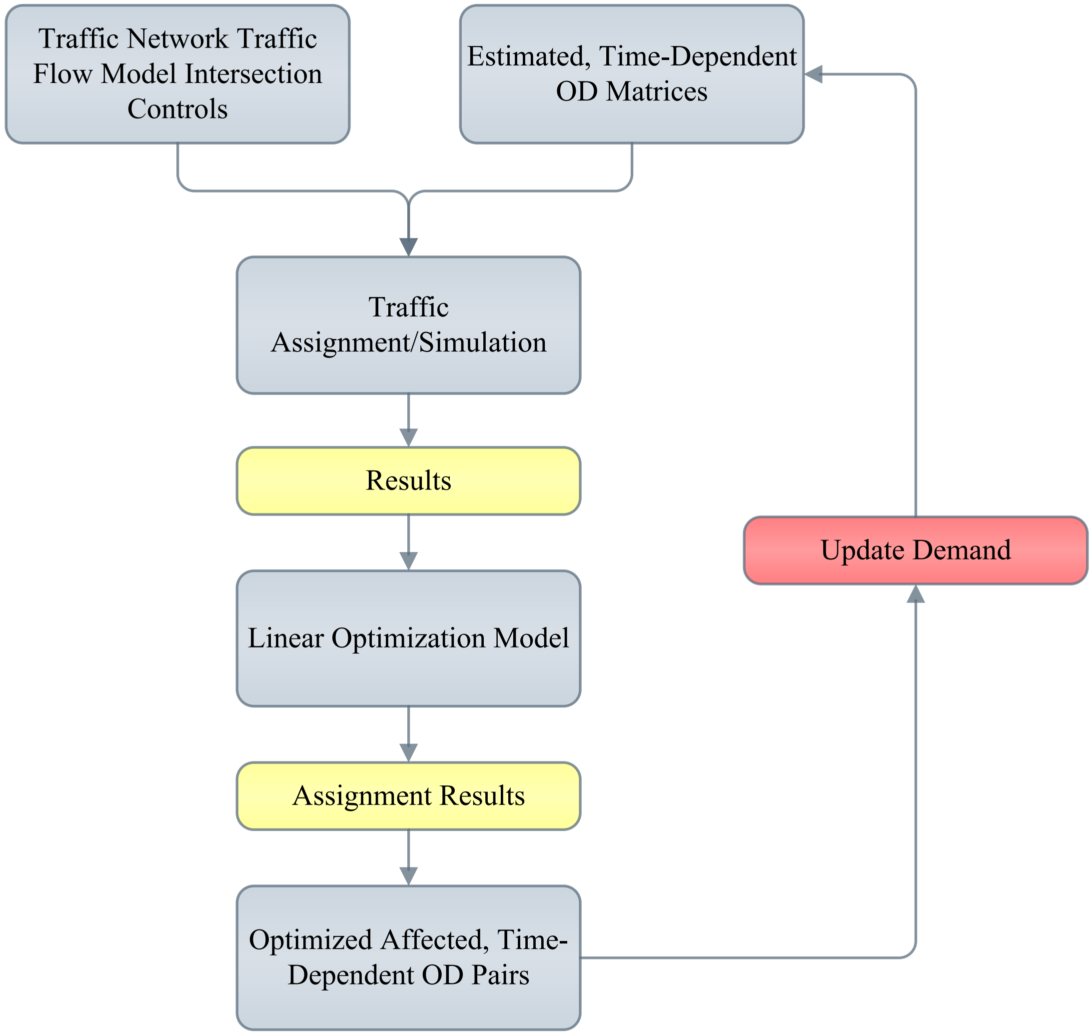


Figure 5: OD Demand Calibration Framework.

The screen line counts utilized to calibrate the auto and truck matrices included locations at major arterials and freeways/highways for El Paso, Texas. However, for the city of Juarez, screen line data were limited to auto. As a consequence, internal truck traffic (e.g., suppliers to maquiladoras) was not considered for this study. Furthermore, data for all four POEs were collected to ensure that the bi-national model replicated existing conditions for both auto and truck traffic at the border. The auto and truck OD matrices were calibrated to 2013 conditions based on a total of 22 iterations until it reached satisfactory results within a ±10 percent absolute error range. Figure 6 and Figure 7 show the calibration results for 24 hours of demand.

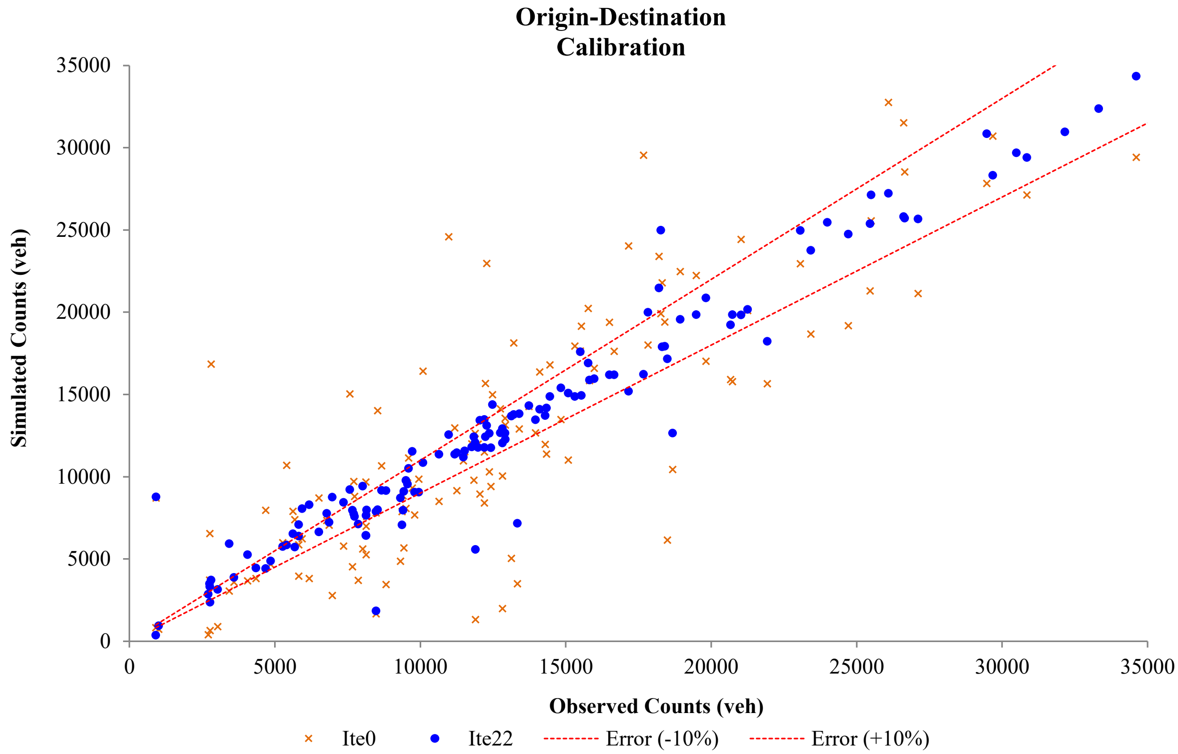


Figure 6: OD Auto Demand Calibration Results.

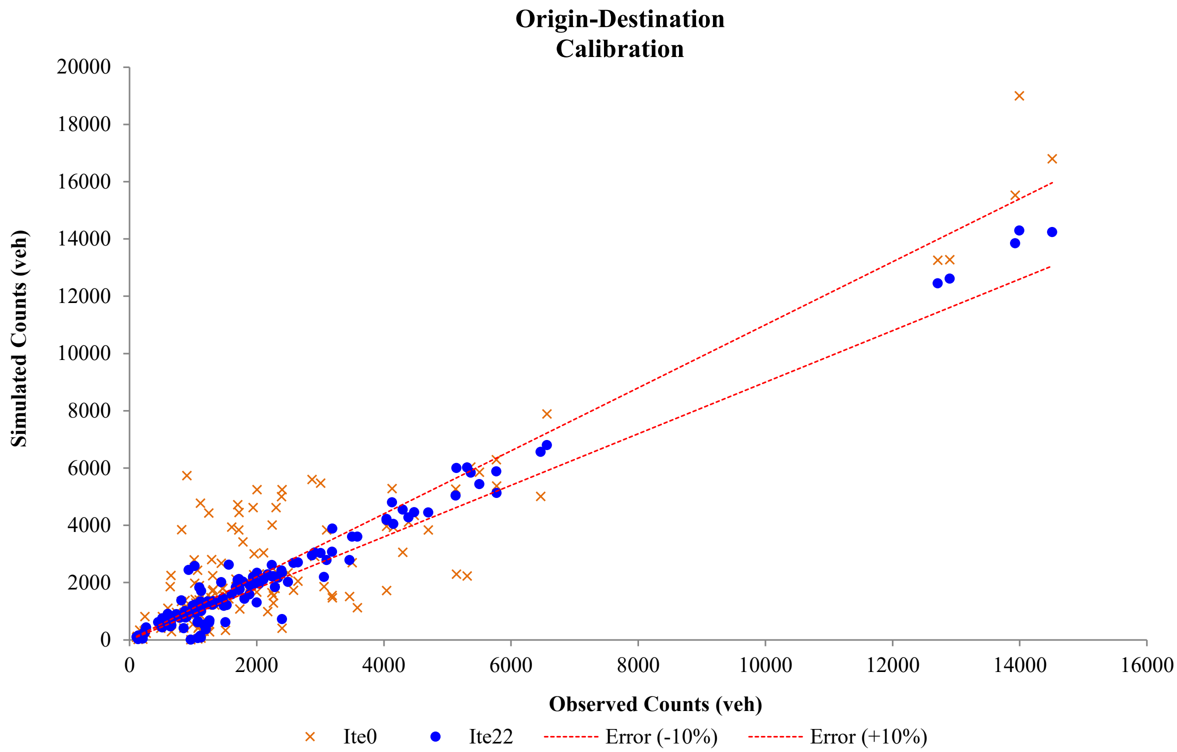


Figure 7: OD Truck Demand Calibration Results.

Model Scenarios

The critical transportation infrastructure failure consisted of simulating and analyzing the first three defined scenarios. Traffic was assigned to all scenarios with 24 hours of demand including both auto and trucks. However, it is important to note that the software platform utilized (DynusT) does not currently allow the feedback of assignment results to a travel demand model in order to update trip generations, distributions, or mode choice as a consequence of the infrastructure failure. In order to do this, a unique tool would need to be developed to feedback the DTA results into a TDM. However, this is considered to be beyond the scope of this project and would require a separate effort to develop such tool. This study only considered traffic assignment that allowed the team to visualize and quantify how vehicles re-route when the disruption occurs, mainly, across the POEs. Hence, the only travel impacts that are possible to simulate are route choice related impacts for the same origin-destination pair movements. Other behavioral impacts like departure time shifts or destination choice are not considered.

All scenarios include additional infrastructure coded-in such as the Cesar E. Chavez Border Highway tolls between S Zaragoza Rd and US 54, the Loop 375-Transmountain Road improvements from I-10 to East of Franklin Mountains State Park Entrance, and the Loop 375 road improvements 1 mile west of US 54 to Dyer Street. The infrastructure disruption scenarios (i.e., short and long term) assume that BOTA and the US 54/I-10 interchange are completely closed for the entire day as they represent critical transportation connectivity between I-10, US 54, and the border.

A brief description of each scenario follows:

Base Case: the do-nothing scenario ran for 15 iterations in order to reach UE (i.e., satisfactory convergence criteria) in the network. The model aimed to represent 2013 traffic conditions in main arterials, freeways/highways, and the POEs.

Short Term: to simulate the short term impact of a critical failure infrastructure in the network, the model assignment method was changed from iterative (e.g., UE) to one-shot. A one-shot method assigns vehicles with their habitual path previously obtained from the UE assignment. This allowed the TTI team to measure the immediate traffic impacts and related economic effects of shutting down a major interchange (US 54/I-10) and the BOTA POE.

Long Term: the long term model was run under an iterative UE assignment method to simulate the vehicles' change in routes as a result of the transportation infrastructure closure at the BOTA POE and the US 54/I-10 interchange. Under UE assignment, the vehicles adapted to the missing infrastructure by finding alternative paths (or a new POE if crossing the border) to arrive at their destination. In this scenario, the iterative UE process assumes that drivers have found new and generally cost-effective routes after approximately 2 to 3 weeks of adjusting to the missing transportation infrastructure.

Research Study Area

The following figures (Figure 8 and Figure 9) show the base scenario and the disrupted transportation infrastructure scenario of the bi-national model. All links with the dashed red lines represent complete closure. Links were kept at zero capacity for the full 24 hours of the simulation for both the short term and long term scenarios.

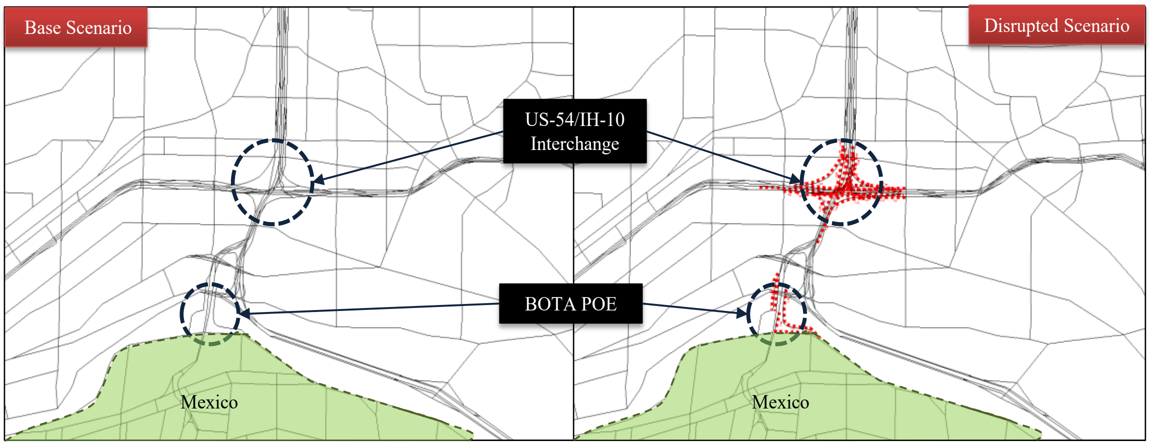


Figure 8: Base Case Scenario vs. Disrupted Scenario.

The transportation infrastructure in and around the BOTA POE is extremely important for the sustenance of industries thriving in the El Paso–Mexico border region. This can be assessed from numerous small and large industries that are scattered close to the international border, particularly along the major highways of the US. The map in

Figure 10 shows the locations of prominent firms close to the border from five basic industries [*26*]. The spatial locations of industries shown in the El Paso side consist of agriculture, construction, manufacturing, retail, and wholesale trade. Also included are the maquiladoras, which are assembly firms within Mexico where the end product is exported back to the original shipper [*27*]. Maquiladoras are vital for Mexico as they constitute almost 82 percent of the country's economy and international trade with the US [*28*]. They also engage in production sharing methods with industries on the US side. Collective industry-related transborder flows through the BOTA POE and other ports support almost 693,000 direct jobs in the El Paso–Juarez region [*29*].

Typically, the maquiladoras ship their final or finished products via freight. Trucks with finished products that head toward an industrial destination in the US have to go through US Customs inspection. Often, maquiladoras practice just-in-time operations of supplies and finished products, which can make travel time/delay at the border a very critical component in the overall production process.

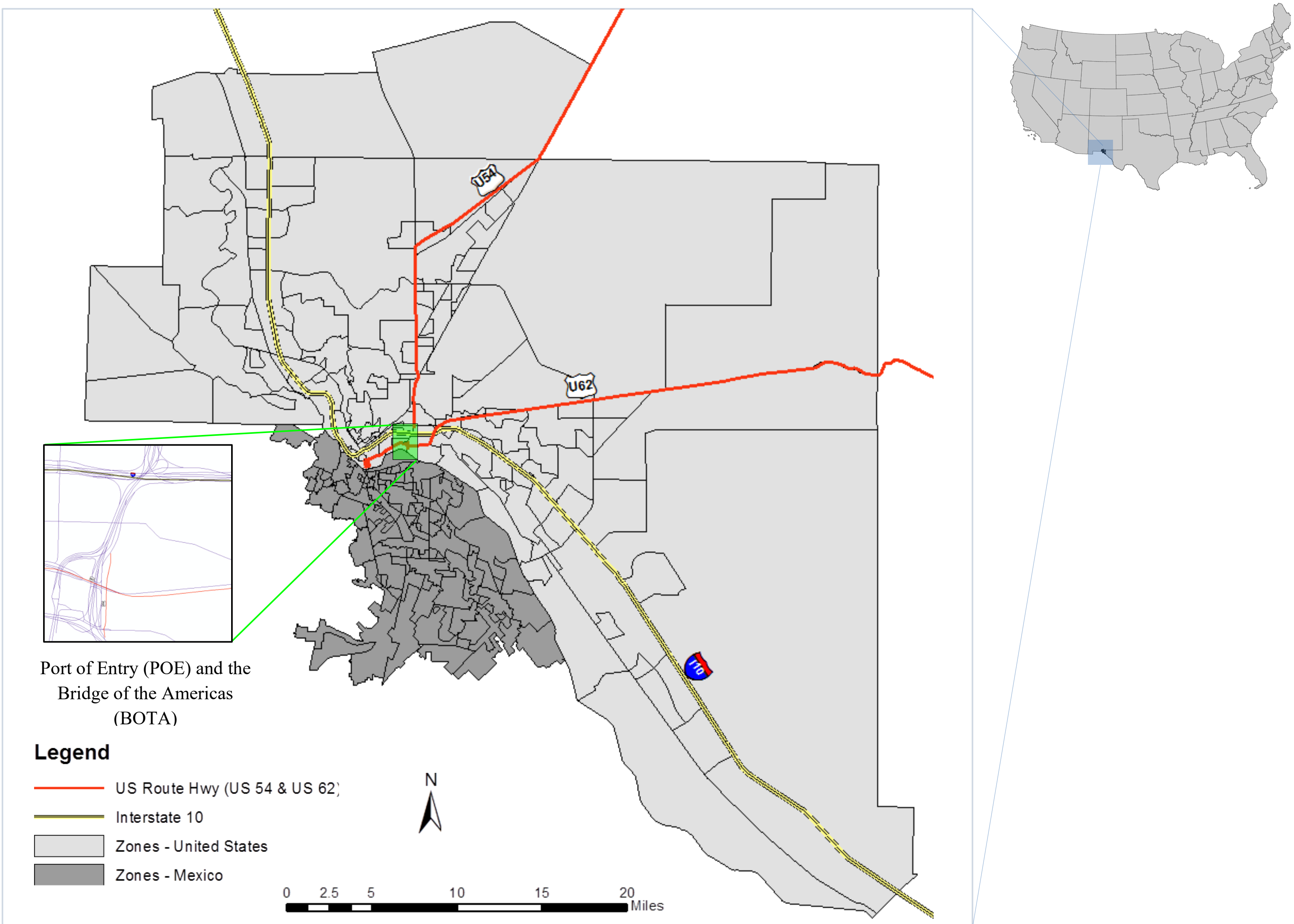


Figure 9: Disrupted Network as Part of the Entire Study Area.

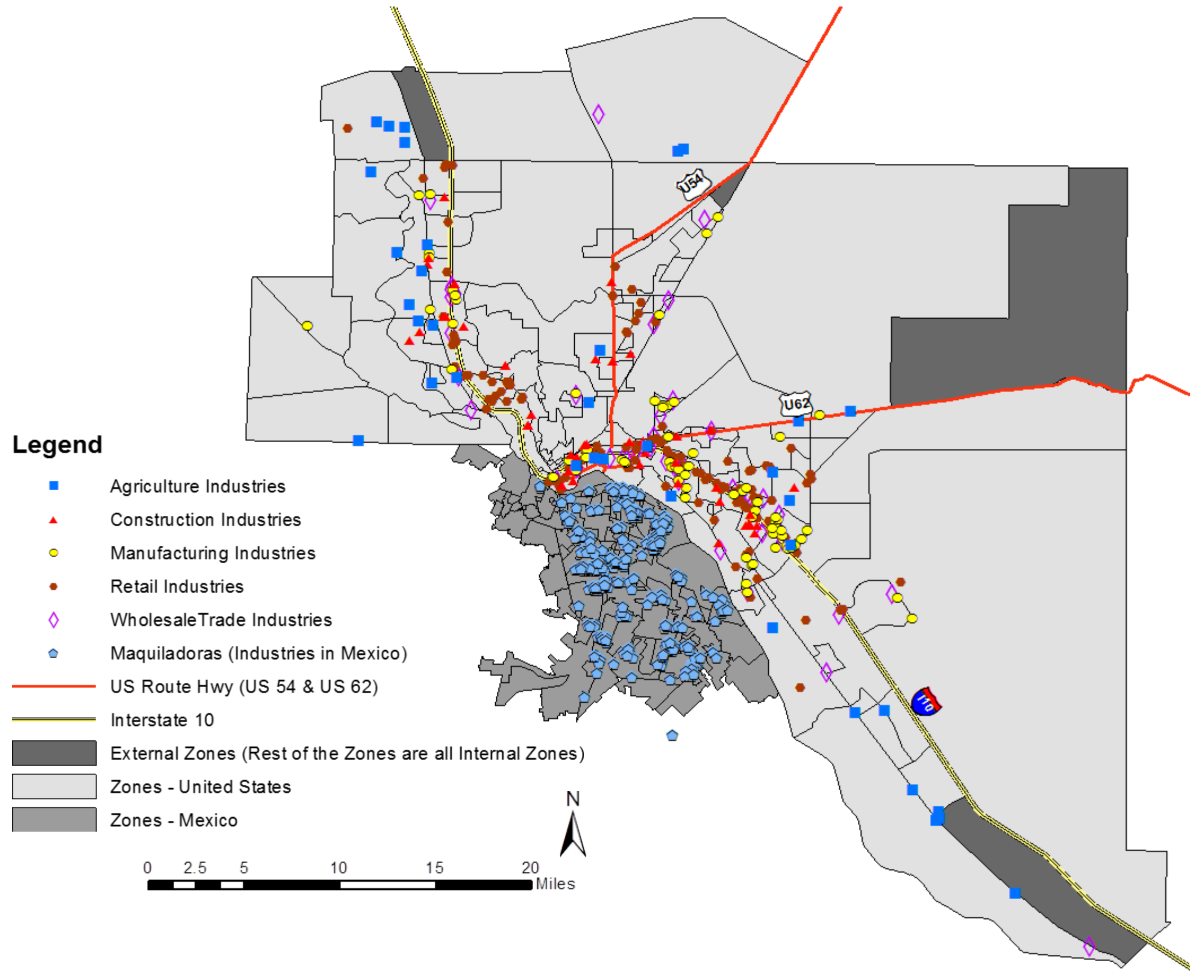


Figure 10: Map of the Study Area—the US–Mexico Bi-National Industry Concentrations.

FRAMEWORK FOR ASSESSING ECONOMIC COSTS

The critical transportation infrastructure failure consisted of simulating and analyzing the economic and traffic impact of three defined scenarios: a baseline scenario, a short term disruption scenario and a long term adjusted scenario. The impacts are examined as differences from the baseline. The focus of this research is on truck flows around the border region.

Given the directionality (northbound and southbound) of truck trips in the context of trade flows in the bi-national region, it is important to know where the trips originated or ended in the network. A total of six trip types were identified for the region:

- Internal US–External US Zone Trips (I_{US}–E_{US} and E_{US}–I_{US}).
- Internal Mexico–External US Zone Trips (I_M–E_{US} and E_{US}–I_M).
- Internal Mexico–Internal US Zone Trips (I_M–I_{US} and I_{US}–I_M).
- Internal US–Internal US Zone Trips (I_{US}–I_{US}).
- Internal Mexico–Internal Mexico Zone Trips (I_M–I_M).
- External US–External US Zone Trips (E_{US}–E_{US}).

Directionality is a critical aspect of economic evaluation. Most short haul Mexican dray trucks typically traverse the border within the combined bi-national area, as well as south of the border. However, both US short and long haul truckers characterize the movements along the US side. Fundamental differences in valuation factors for both types of truckers require a split in the trip types because, first, trucks differ in many ways, including age and fuel efficiency, among other factors. Second, most cargo that moves serves one of three specific end uses: a) final consumption, b) part of a production sharing flow, or c) outbound flow to other regions. The first factor has a significant affect on direct losses since Mexican trucks and US trucks have different factor prices. The second factor is not critical for the assessment of direct losses, but helps policymakers and researchers understand how large and spatially distributed a broader economic consequence might be. Figure 11 documents the specific approach used to analyze all scenarios as well as the trip breakdowns.

The DTA simulation output data were utilized to obtain different zonal trip performance measures within and outside the El Paso–Juarez region. These performance measures consist of truck volumes, travel times, and travel distances from a zonal origin to a zonal destination. Zonal centroids are treated as the point of origin (or destination) for a trip. These results are presented in Appendix A. The research team focused on analyzing the top five zones in the border region that experienced the highest truck volumes. The researchers validated the selection of these zones by observing strong correlation between the spatial distributions of different industry sectors and the maquiladoras in the El Paso–Juarez region (Figure 10)

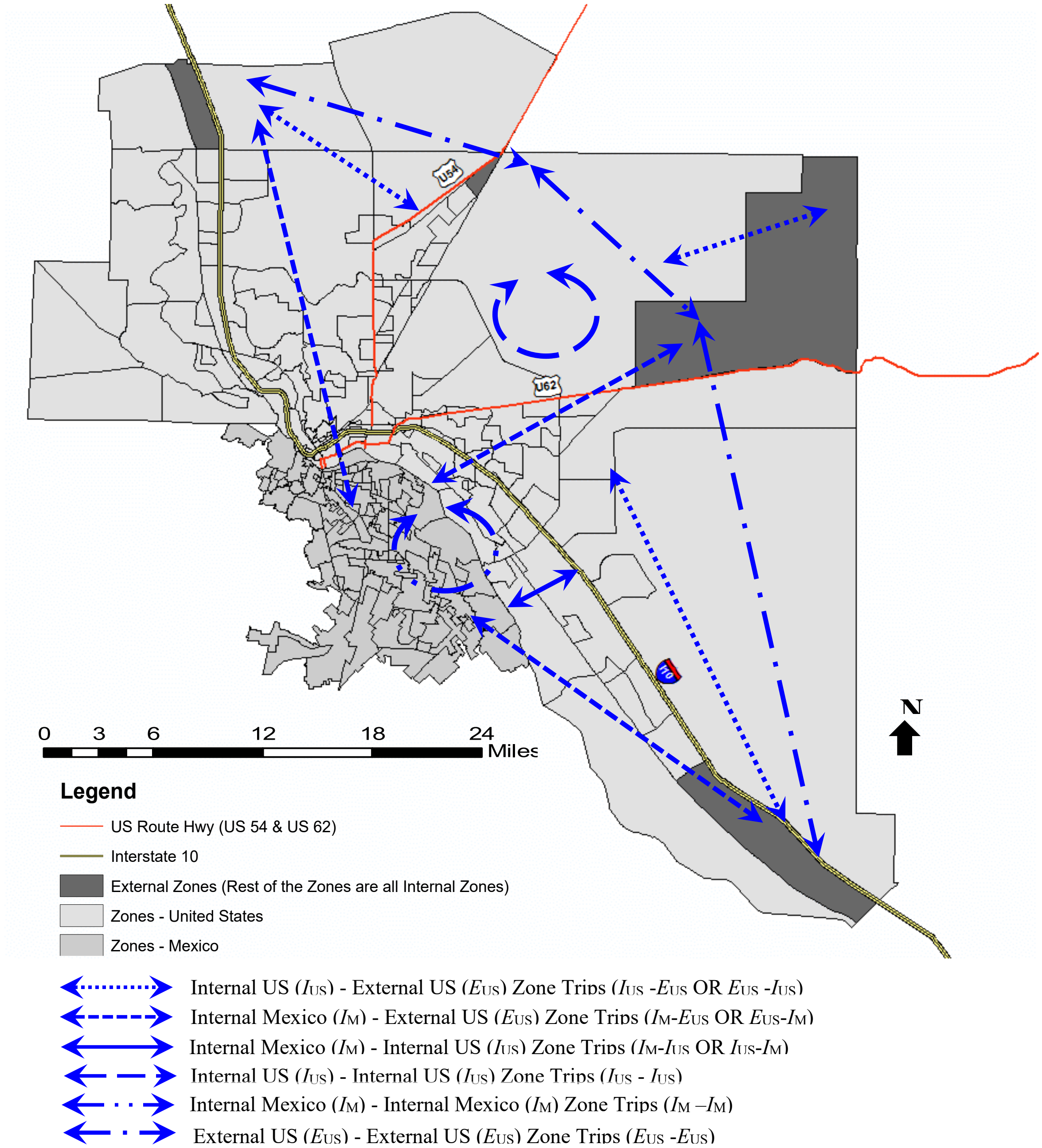


Figure 11: Map of the Study Area—the US–Mexico Bi-National Zones and Trip Types.

Direct Costs

Following Vadali and Kang [*3*], in the context of border research the following direct costs are considered as the first order in a hierarchy following Cochrane and Rose [*16, 17*].

- First order direct costs accruing to truckers. These include travel time costs, operating costs, and fuel related costs including time-based depreciation from a) rerouting due to a disruption at the US 54/I-10 interchange and the BOTA POE (some of these truckers will now have to use alternate POEs, specifically Ysleta Bridge [Zaragoza] or Santa Teresa) and b) from additional wait times experienced at POEs for clearing inspections.
- First order costs accruing to shippers and industry from having to reroute cargo. These include additional freight shipment costs and inventory losses due to rerouting to alternate POEs (only excess over average wait times at Ysleta and Santa Teresa were considered). The freight costs include lost savings to the shippers from supply chains disruptions, particularly in regard to inventory, storage, and handling costs.

These costs are discussed in Appendices B and C. Figure 12 and Figure 13 show the actual process used for the assessment, as well as the specific direct costs considered. Figure 14 shows the three major trip types that were considered in the analysis. Jointly, in terms of total trips observed, these three categories formulate approximately 94.5 percent of the total bi-national trips under normal conditions (baseline). Furthermore, approximately 88 percent of these three truck trip categories were effectively captured in the cost approximations.[2]

[2] Some trips have not been captured because of the selected time slots for opening, which do not necessarily span the full opening and closing times for POEs. A second factor was that some trips did not complete their route during simulation. This latter condition is observed for all trip types in the region.

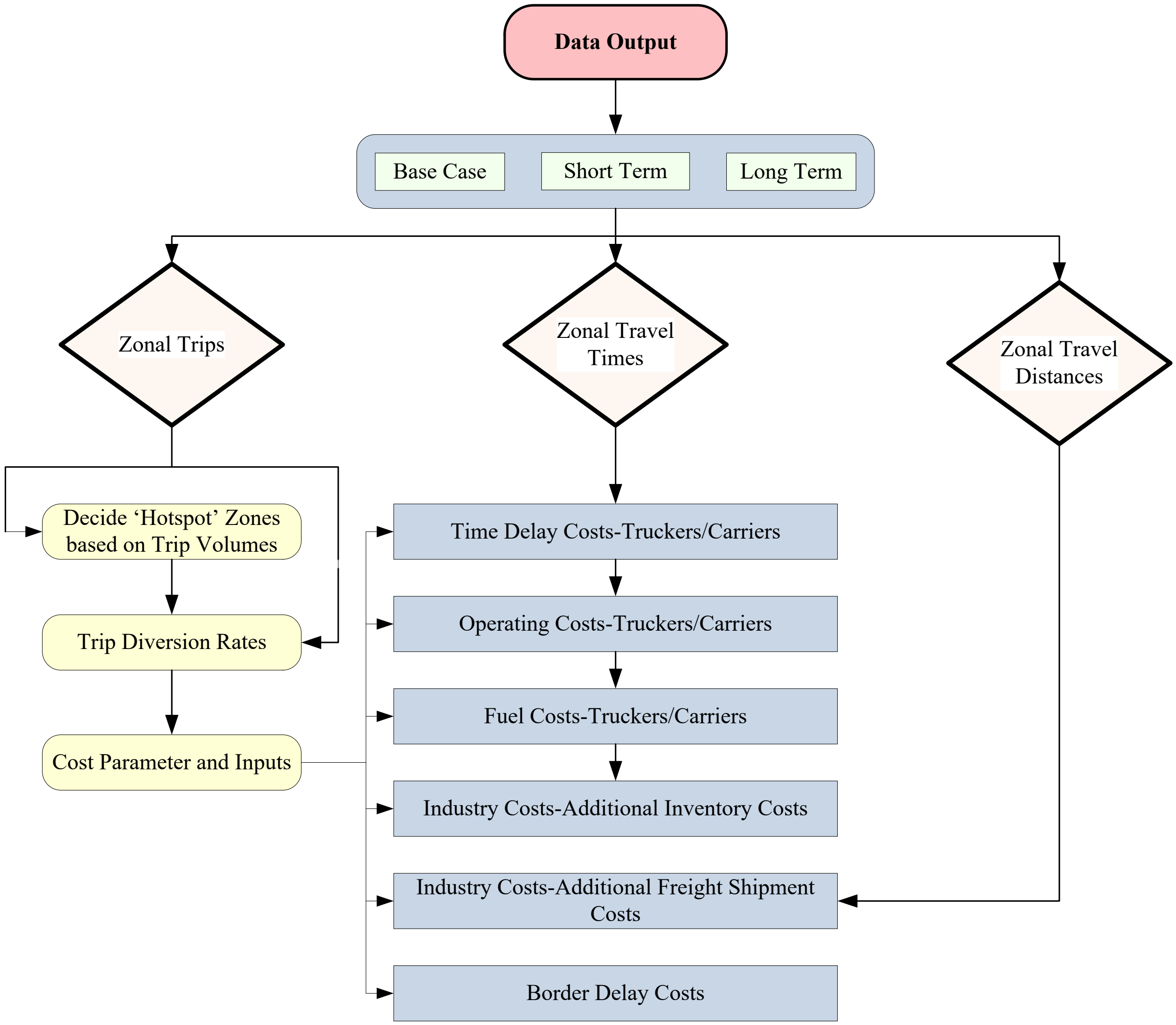


Figure 12: Framework for the Assessment of Direct Costs and Cost Categories.

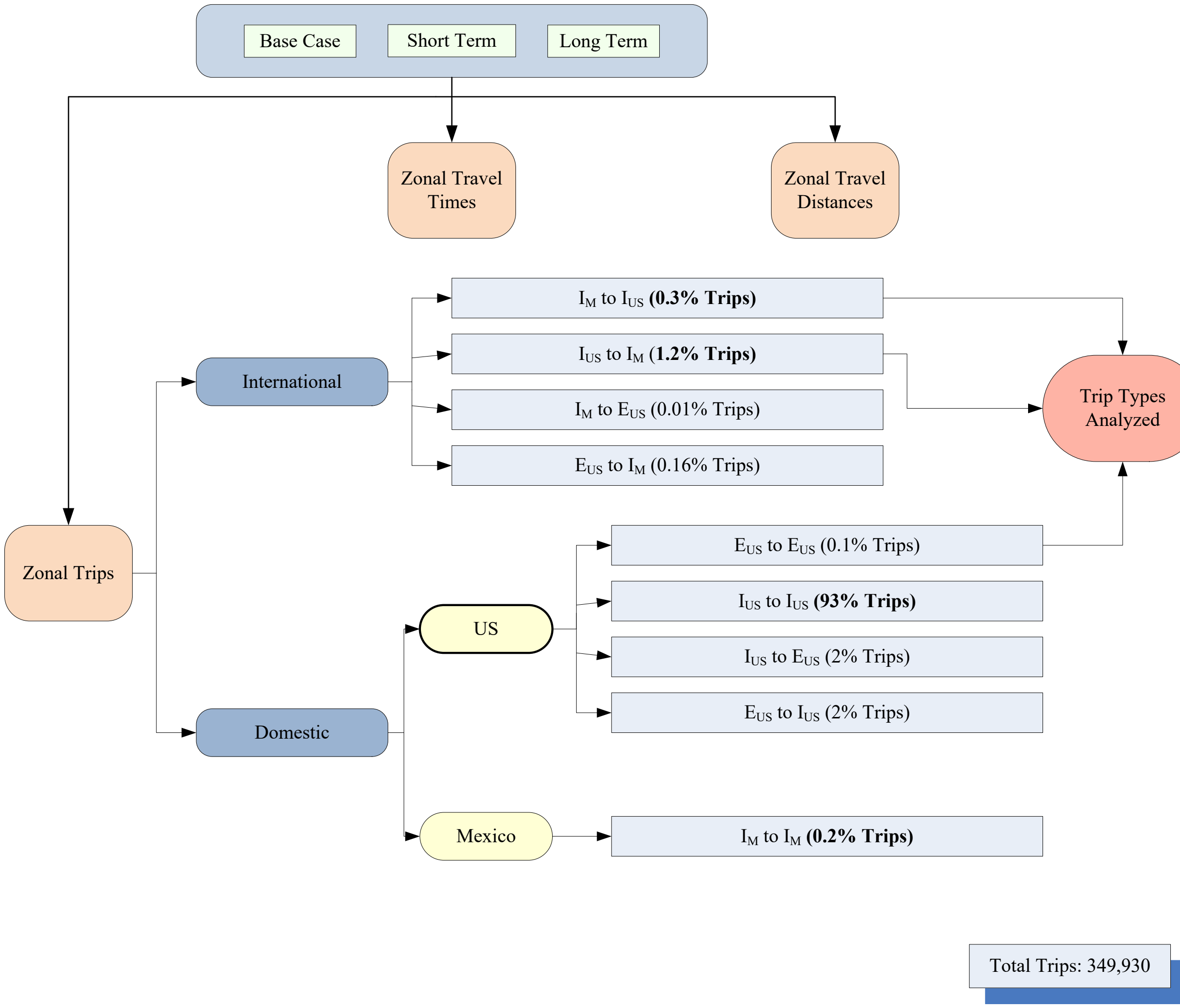


Figure 13: Framework for the Assessment of Direct Costs and Cost Categories—Breakdown of Zonal Data as Percent of Observed Total Volumes.

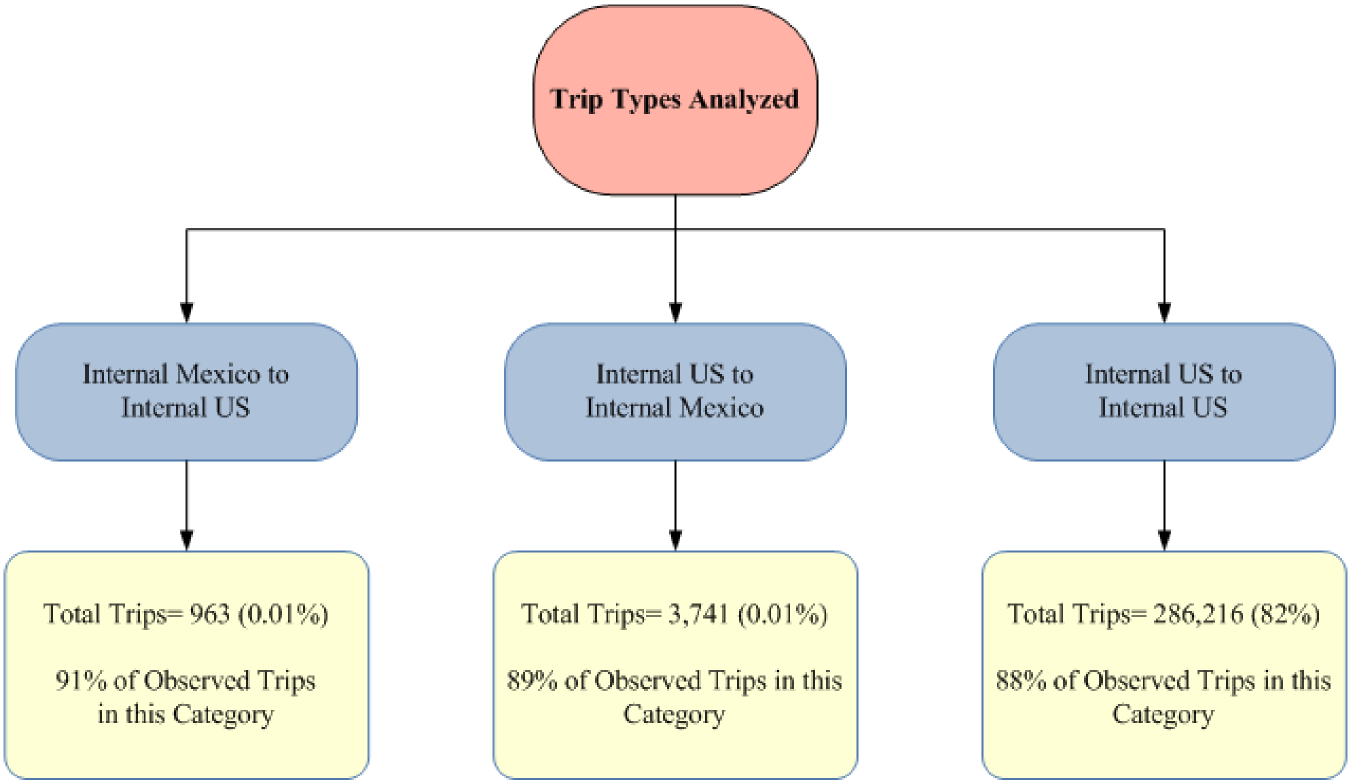


Figure 14: Selected Trip Types for Consideration in Cost Calculations.

Time Intervals

Costs were estimated for traffic moving at different times of the day in order to cover a broad spectrum of variability in the travel times, travel distances, and peak/off-peak time intervals. The following discrete time intervals were defined:[3]

- 6:30 am – 9:30 am (peak hours for trucks).
- 9:30 am – 3:30 pm (off-peak hours for trucks).
- 3:30 pm – 7:30 pm (peak hours for trucks).

Assumed Long Diversion Rates to Alternate POEs

The diversion rates (defined as the ratio of the diverted truck volume due to the POE disruption) were assumed for the long term equilibrium runs for the three previously discussed scenarios.

- For the southbound truck trips from El Paso (US) to Juarez (Mexico) via Ysleta and Santa Teresa, the average detour rates for the three time intervals was approximated as 42 percent,

[3] These time intervals took into account the operating times of each POE.

(long term equilibrium run compared to baseline). This suggests that in the long term run, approximately 42 percent of the baseline BOTA trips might divert to an alternate POE (i.e., Santa Teresa or Ysleta).

- For northbound truck trips from Juarez (Mexico) to El Paso (US) via Ysleta and Santa Teresa, the average detour rates for the three time intervals were estimated at 0.33 (long term equilibrium run compared to baseline). This suggests that in the long run approximately 33 percent of the baseline BOTA trips divert to an alternate POE (i.e., Santa Teresa or Ysleta).
- For the internal US–US trips, the detour rates were assumed at 100 percent.

These approximated diversion rates were derived based on behavioral assumptions of only route rationalization as seen in long run and baseline equilibria. In other words, these will not be reflective of any other behavioral effects such as changes in departure time or trip reduction because of mode choice. Diversion rates were also approximated at the individual link level close to the POEs. This approach was used to account for trip reductions occurring in the long term run equilibrium and the impracticality of racking actual paths/route choices of individual vehicles. Hence, these will be likely biased. In this research, trips that crossed the border were considered as sensitivity parameters alone.

Spatial Distribution of Change in Travel Times and Volume Hot Spots

Figure 15 and Figure 16 show the potential simulated immediate network effects from a critical infrastructure disruption and in an adapted longer term run equilibrium in the context of DTA models (as distinctly different from economic notions of long run equilibria). These figures include all trip types in the short term disrupted and long term run equilibrium scenarios (as trip origins). The figures show that all trips beginning from almost all zones (with the exception of trips starting further south in Juarez) experience a significant increase in travel time. The highest travel time increases were for trips starting along US 54, I-10, and zones in Juarez located near the US border. The long term run equilibrium travel time changes were also very similar to the short term disrupted scenario, both indicating a clear pattern of predominant hot spots in terms of most affected zones along US 54 and I-10. One of the obvious values for this spatial exploration arises from the need to consider mitigation options starting at the northern perimeter of El Paso County along I-10 and US 54.

Figure 17 and Figure 18 showcase similar distributions of travel time for trip destinations. Not surprisingly, the destinations along I-10, US 54, and Central Juarez experienced the highest impedances in both scenarios. Since these include all trip types, travel time increases on the Juarez side are primarily driven by spillovers from congestion in internal movements. Interestingly, most external zones also show a significant increase in travel times in both cases. This indicates that there is a significant potential for long haul trips outbound from the bi-national region to experience significant delays. However, combining this information with the framework from Figure 13 volume suggests that the large travel time changes are spread out over fewer truck trips and volumes. This lends further confidence to the included trip types for cost calculations shown in Figure 14.

Figure 19, Figure 20, Figure 21, and Figure 22 show the corresponding thematic volume maps showing specific destinations with peak volumes for three trip types described as part of the framework: a) I_M–I_{US}, b) I_{US}–I_{MX}, and c) domestic-I_{US}–I_{US} flows.

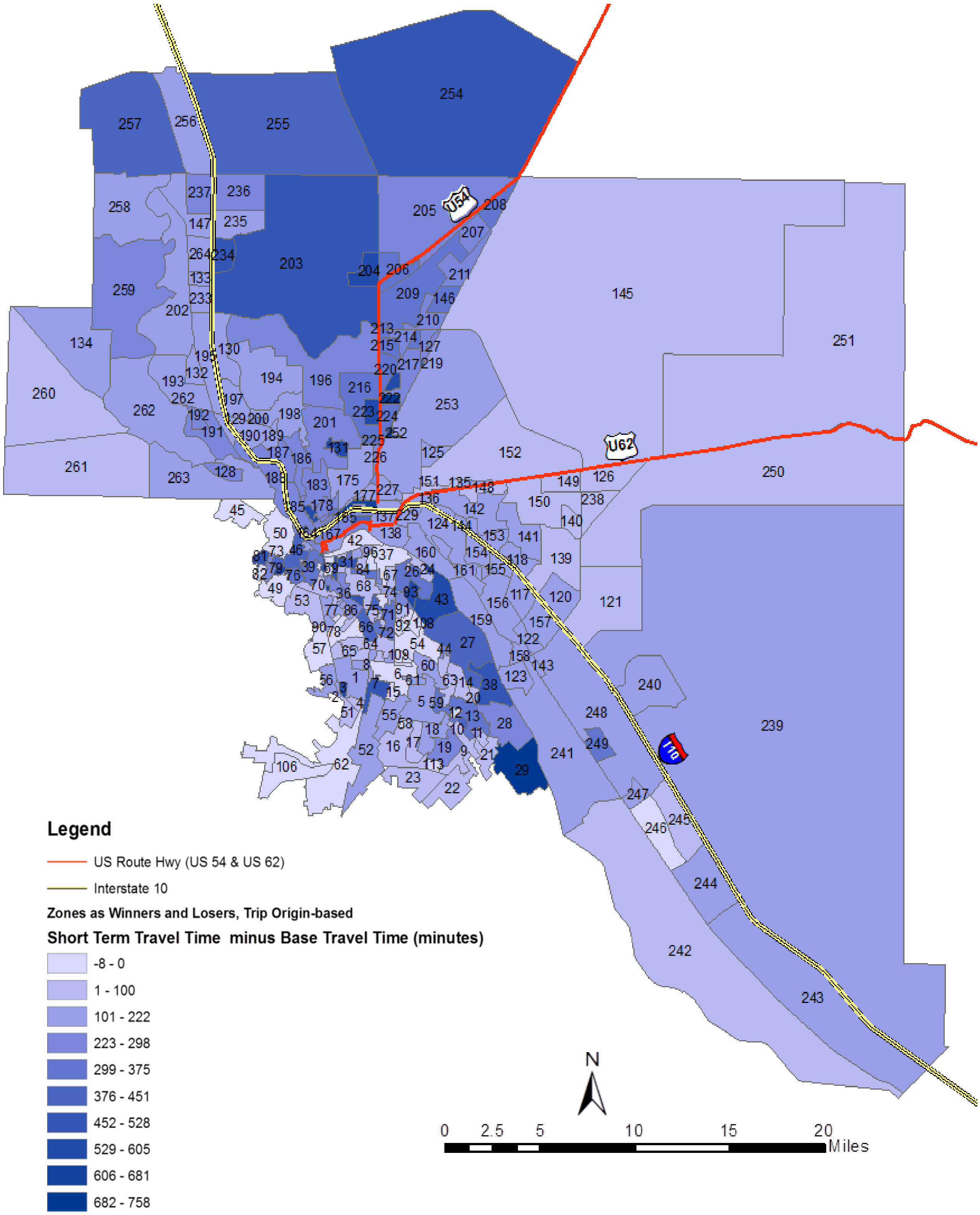


Figure 15: Spatial Distribution of Change in Travel Times—Short Term vs. Base (Origins).

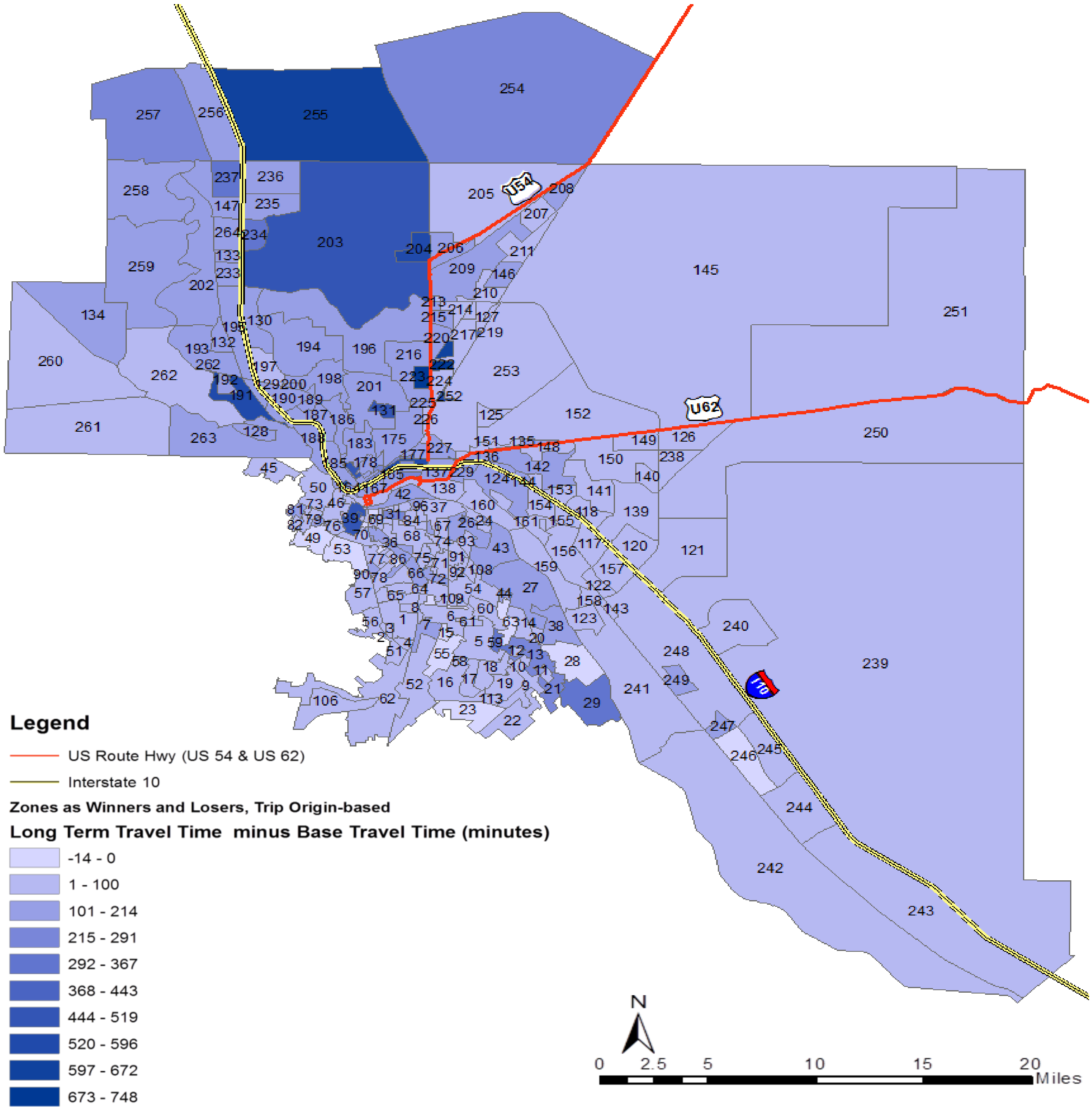


Figure 16: Spatial Distribution of Change in Travel Times—Long Term vs. Base (Origins).

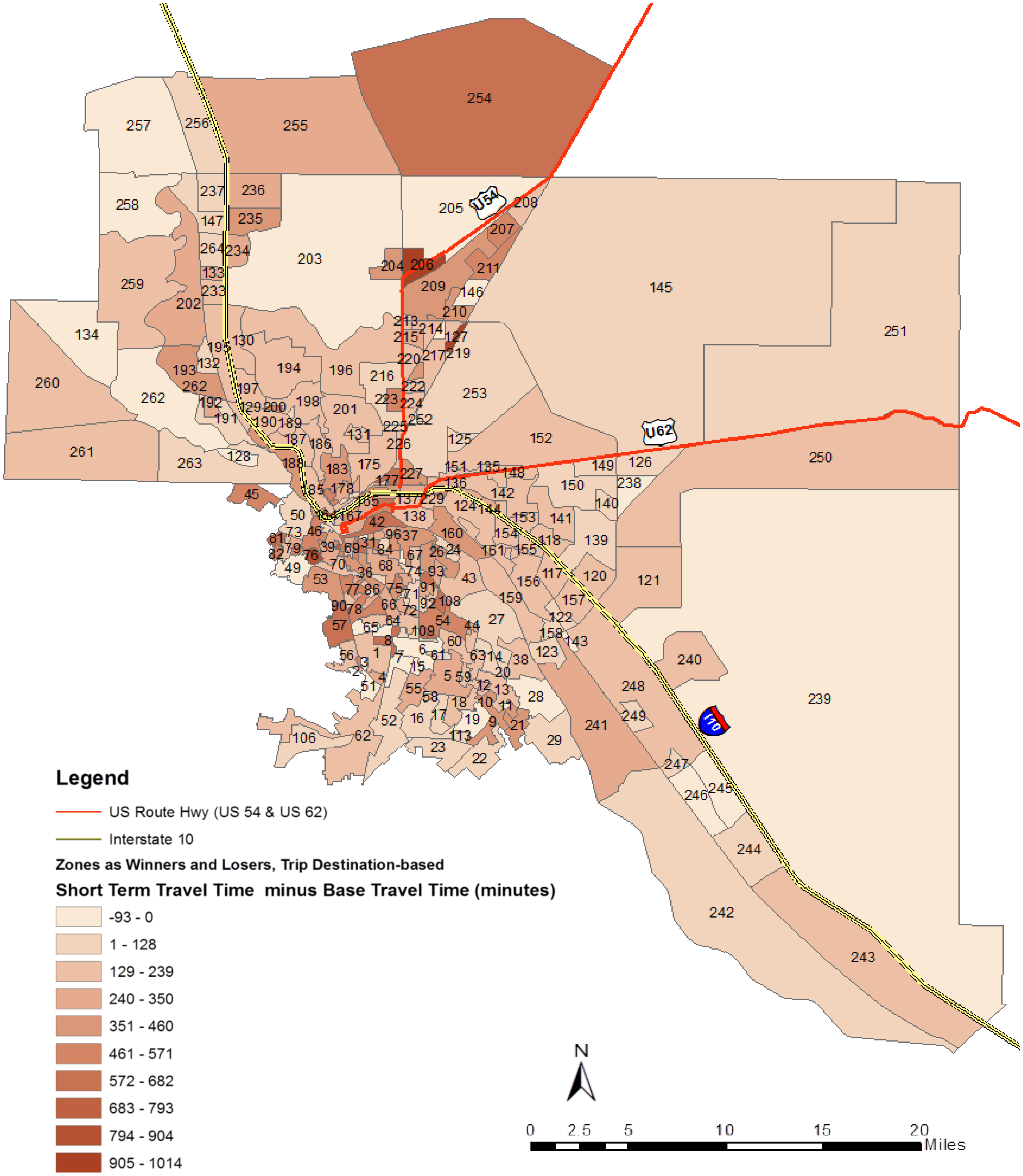


Figure 17: Spatial Distribution of Change in Travel Times—Short Term vs. Base (Destinations).

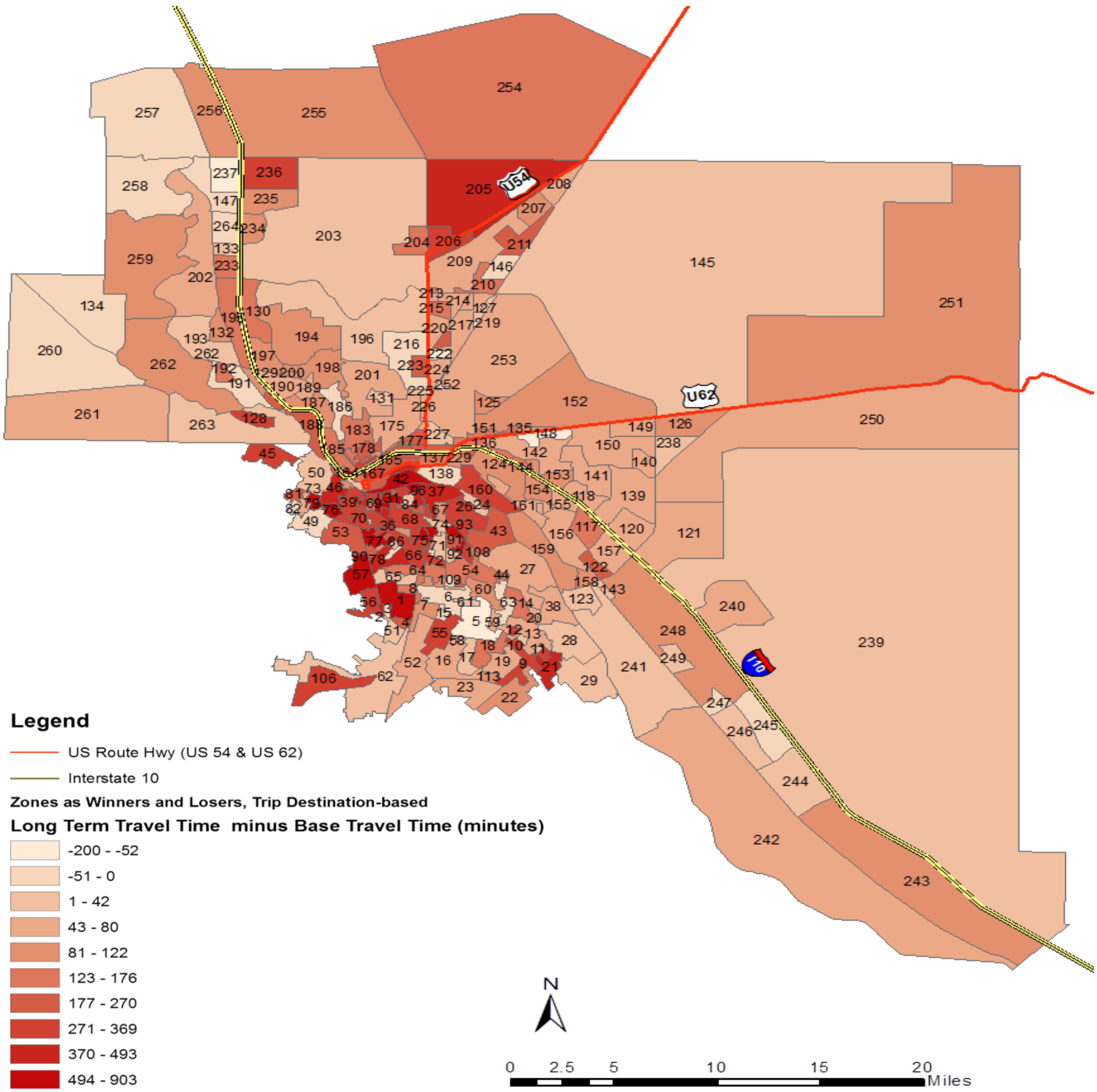


Figure 18: Spatial Distribution of Change in Travel Times—Long Term vs. Base (Destinations).

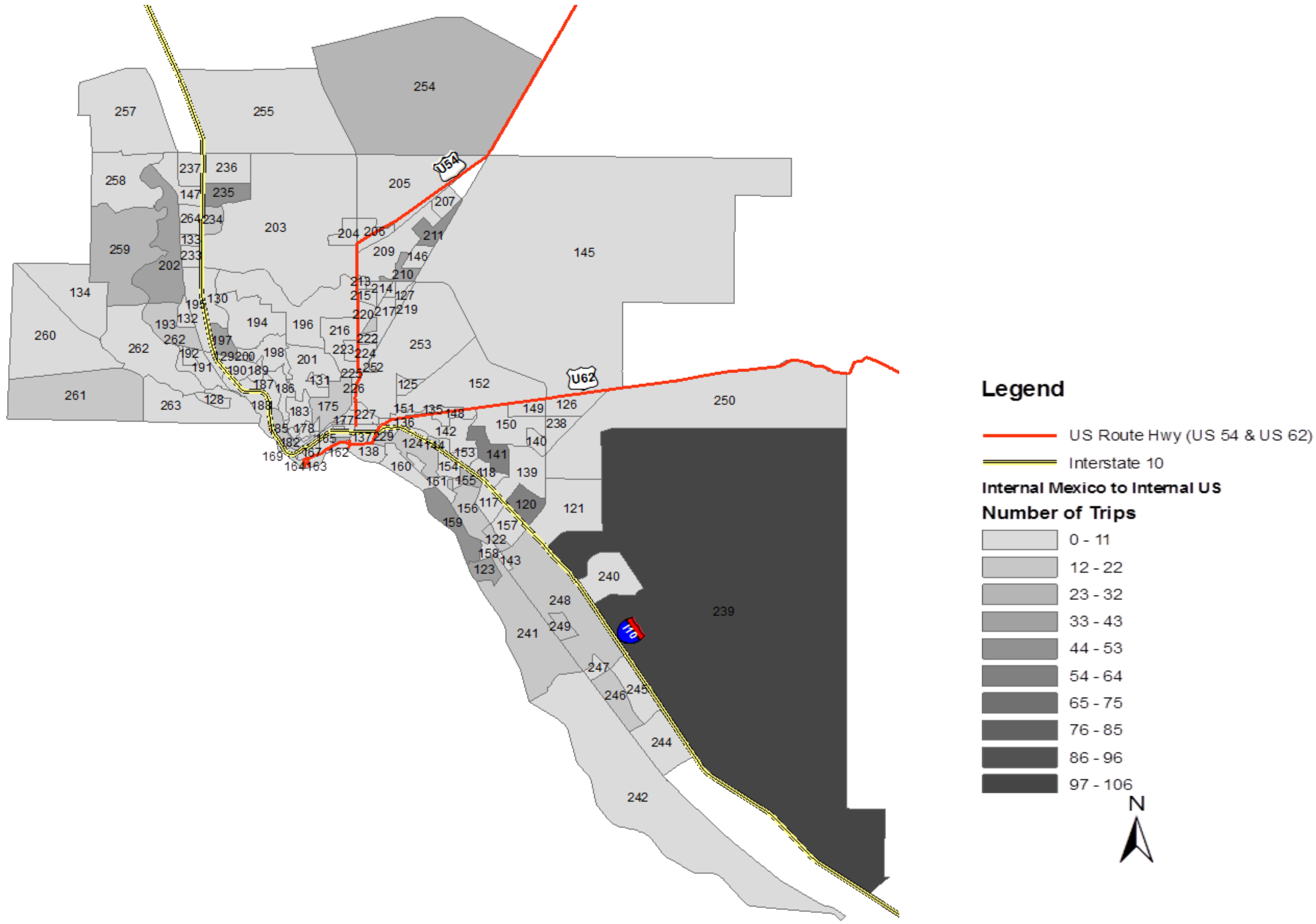


Figure 19: I_M to I_{US} Trip (Volume Hot Spots) (Along I-10, US 54).

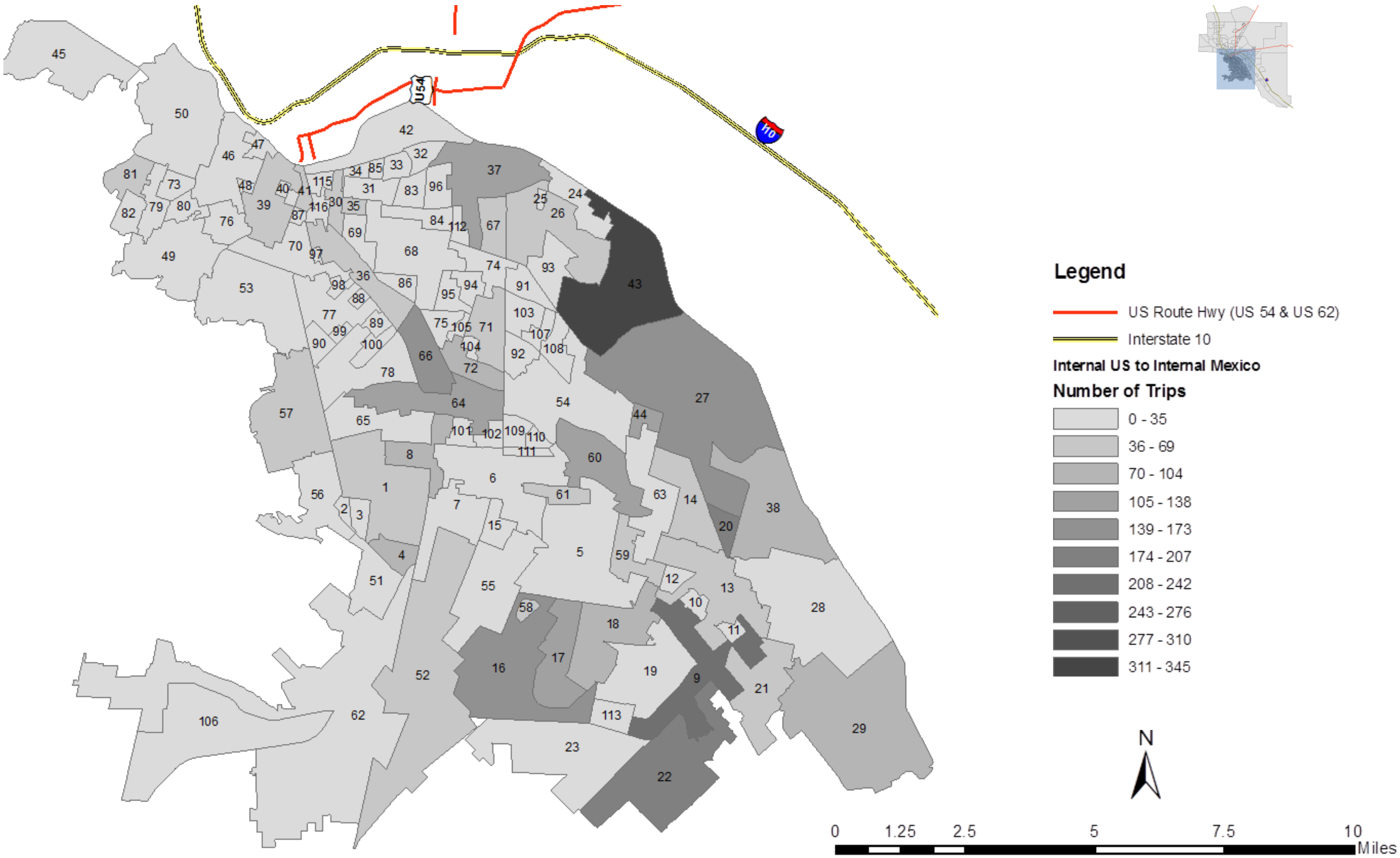


Figure 20: I_{US} to I_{M} Zone Trips (Volume Hot Spots).

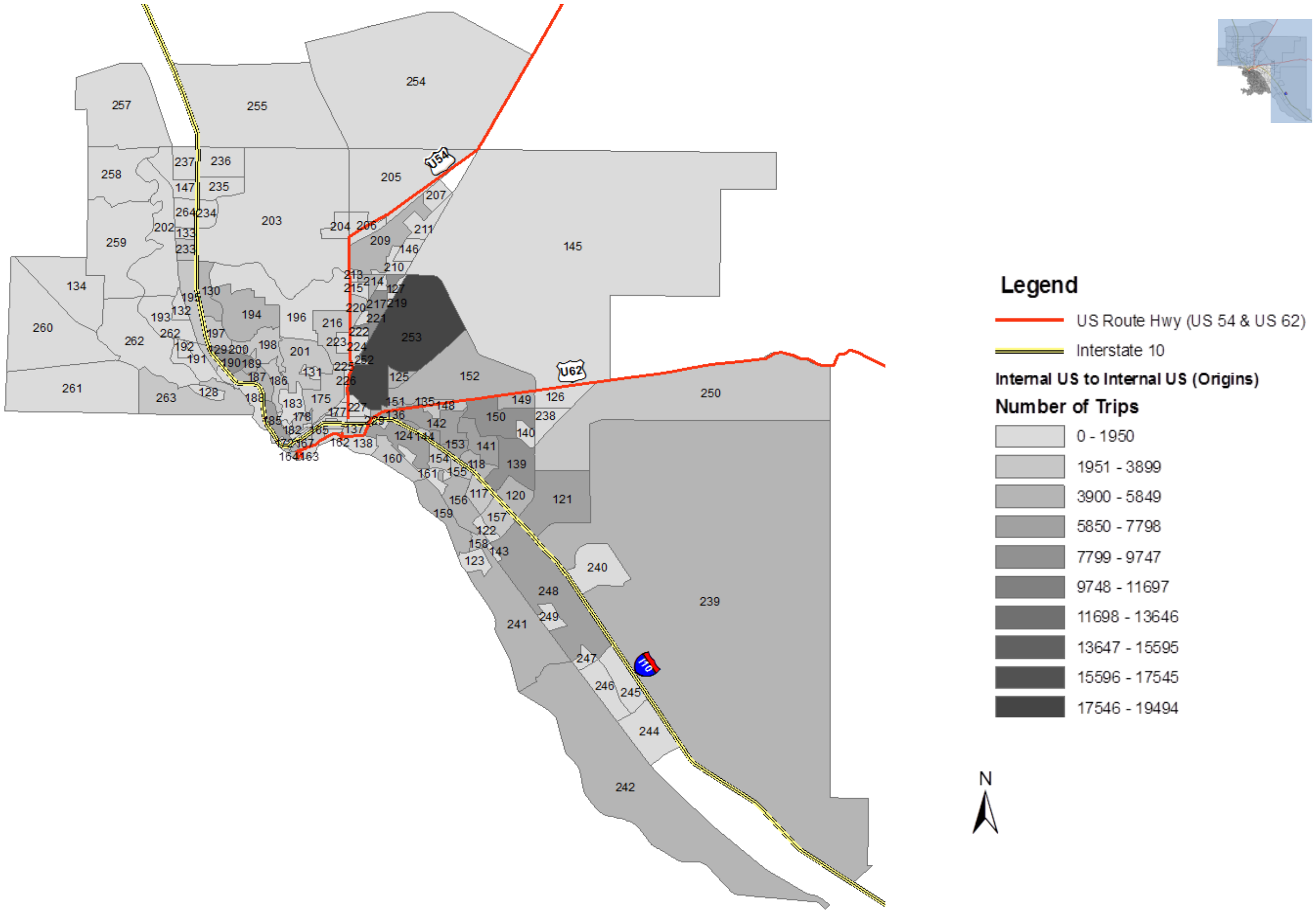


Figure 21: IUS to IUS Zone Trips (Volume Hot Spots)—Trip Origins.

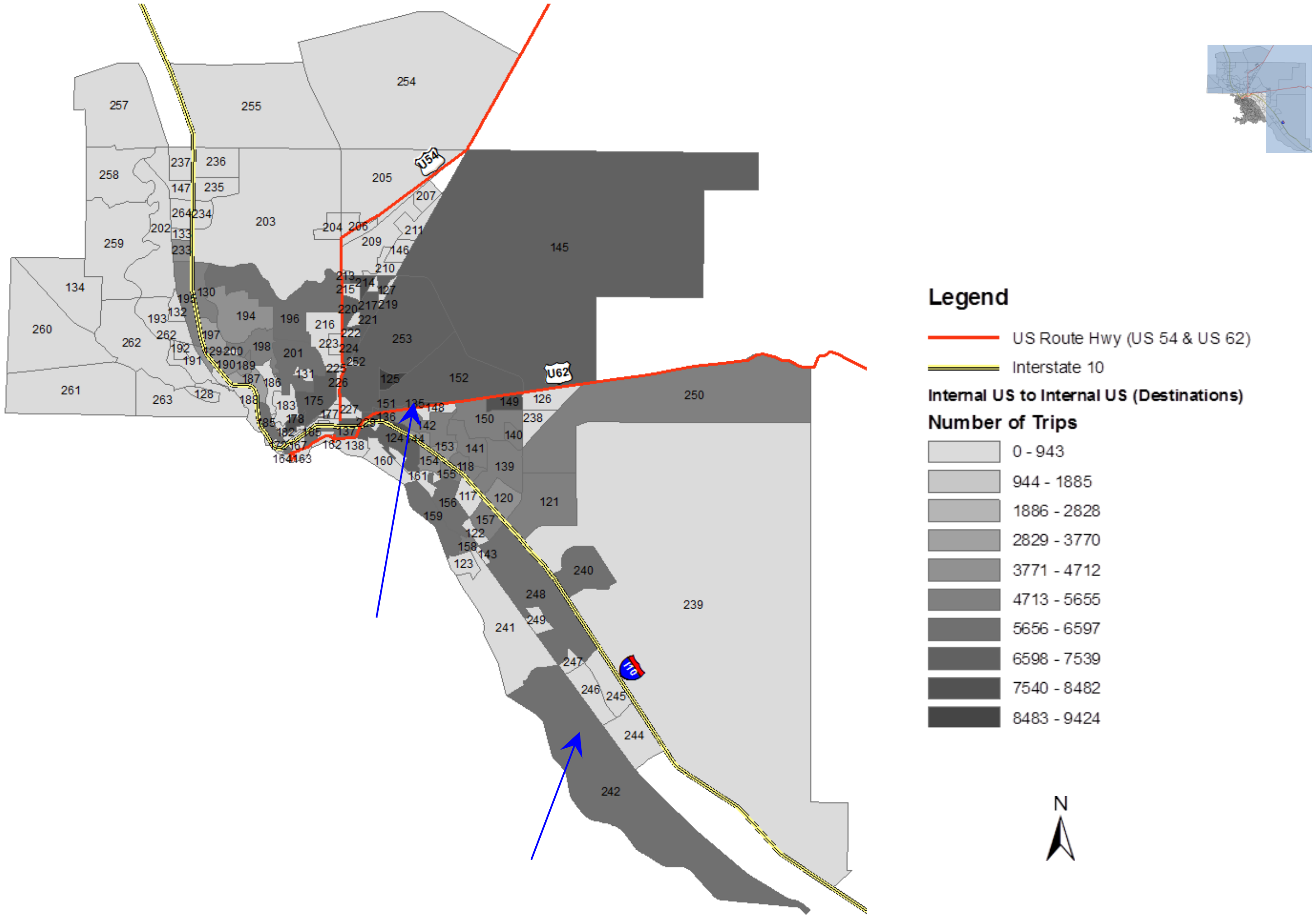


Figure 22: IUS to IUS Zone Trips (Volume Hot Spots)—Trip Destinations.

Average Travel Times, Distances for Trip Classes, and Trips

Trip Type—I_M–I_{US} (Northbound Flows): Table **2** and Table 3 show the baseline, and short and long term runs adapted equilibrium average travel times, distances covered, delay, and number of trips. The morning peak interval shows a mean zone–zone travel time of 42 minutes for 229 trips in the baseline. In the disrupted scenario, the travel time increases almost by a factor of 12 in comparison to baseline, while in the long run, travel times increase by a factor of 4.

The travel patterns, on the other hand, do suggest the following: a) a slight decrease in number of trips in the disrupted scenario (perhaps from trips not being able to finish the route) and b) an increase in the number of overall trips in the long run equilibrium in comparison to the baseline or indication of apparent induced demand. In Appendix A, Table A1 provides the observed ranges for a variety of travel variables observed for zonal pairs. Figure 21 demonstrates the zones associated with highest inflows for northbound trips. Many destinations immediately north of Ysleta POE and east of it appear as large trip attractors. Among those zones, is Zone 239—the largest trip attractor for northbound flows as well as industrial sites such as the Vista Del Sol Industrial area. Furthermore, various destination areas along I-10 and US 54 also appear as large attractors.

Trip Type—I_{US}–I_M (Southbound Flows): Table **4** and Table 5 show the baseline, and short and long term run adapted equilibrium average travel times, distances covered, delays, and number of trips. The morning peak interval shows a mean zone–zone travel time of 43 minutes for 867 trips in the baseline. On the other hand, the disrupted scenario (short term) shows that the travel time increases almost by a factor of 12 in comparison to the baseline. The travel patterns show a decrease in the number of overall trips in the longer run equilibrium in comparison to baseline. A rationale for this volume reduction could be the presence of unfinished trips, even in the long run. Appendix Table A2 provides the observed ranges for a variety of travel variables. Figure 20 shows zones registering the largest destination volumes for southbound flows toward Juarez (see Zone 43 in Juarez).

Trip Type—I_{US}–I_{US}: Table **6** and Table 7 show the baseline, and short and long term runs adapted equilibrium average travel times, distances covered, delays, and number of trips for three time intervals. The morning peak interval shows mean zone–zone travel time of 38 minutes for 66,121 trips in the baseline. In the disrupted scenarios, the travel time increased by almost a factor of 10 in comparison to the baseline. These travel time increases are spread out as a very large volume in every time interval as seen in Table **6**. Appendix Table A3 provides the observed ranges for a variety of travel variables. Figure 22 above shows the largest truck trip generators on the El Paso side, such as Zone 253 that comprises the airport and nearby industrial sites. As expected, trip destinations are concentrated along I-10, US 54, and along Montana Ave (US 180/62). These trips could typically include a variety of service and retail deliveries, which are usually of lower value, but they also include other delivery types. In all cases, the volumes in the 9:30 am – 3:30 pm slot are the highest, suggesting that costs are likely to be highest.

Table 2: Total Trips, Average Travel Times, Distance, and Delay for the Base Scenario (I_M–I_{US} All OD Pairs).

Time Period of Analysis (Hour)	**(Before Disruption, Base)**		
	Total trips	***Average travel time (min)***	***Average distance (miles)***
6:30 am – 9:30 am	229	42	21.2
9:30 am – 3:30 pm	435	49	21.2
3:30 pm – 7:30 pm	299	62	23.2

Table 3: Total Trips, Average Travel Times, Distance, and Delay for the Short Term and Long Term Scenarios (I_M–I_{US}, All OD Pairs).

Time Period of Analysis (Hour)	**(After Disruption, Short Term)**			**(After Disruption, Long Term)**		
	Total trips	***Average travel time (min)***[4]	***Average distance (miles)***	***Total trips***	***Average travel time (min)***	***Average distance (miles)***
6:30 am – 9:30 am	224	556	14.0	236	164	24.9
9:30 am – 3:30 pm	432	416	14.5	447	154	26.8
3:30 pm – 7:30 pm	295	255	16.8	318	141	27.2

[4] A significant number of vehicles departing later in the day (e.g., 3:30 pm – 7:30 pm) were not able to reach their destination within the time limits of the simulation (i.e., 0–1440 minutes). This explains why travel time appears to be decreasing, when, in fact, most of the trips did not reach their destination (i.e., unfinished trips) before the simulation period ended.

Table 4: Total Trips, Average Travel Times, Distance, and Delay for the Base Scenario (I_{US}–I_{M}).

Time Period of Analysis (Hour)	(Before Disruption, Base)		
	Total trips	***Average travel time (min)***	***Average distance (miles)***
6:30 am – 9:30 am	867	43	21.7
9:30 am – 3:30 pm	1,718	51	21.6
3:30 pm – 7:30 pm	1,156	63	23.1

Table 5: Total Trips, Average Travel Times, Distance, and Delay for the Short Term and Long Term Scenarios (I_{US}–I_{M}).

Time Period of Analysis (Hour)	(After Disruption, Short Term)			(After Disruption, Long Term)		
	Total trips	***Average travel time (min)***	***Average distance (miles)***	***Total trips***	***Average travel time (min)***	***Average distance (miles)***
6:30 am – 9:30 am	867	556	17.1	849	556	18.0
9:30 am – 3:30 pm	1,716	421	16.2	1,689	407	17.5
3:30 pm – 7:30 pm	1,154	235	18.2	1,198	233	19.8

Table 6: Total Trips, Average Travel Times, Distance, and Delay for the Base Scenario (IUS–IUS).

Time Period of Analysis (Hour)	(Before Disruption, Base)		
	Total trips	*Average travel time (min)*	*Average distance (miles)*
6:30 am – 9:30 am	66,121	38	16.6
9:30 am – 3:30 pm	129,256	51	17.1
3:30 pm – 7:30 pm	90,839	78	18.0

Table 7: Total Trips, Average Travel Times, Distance, and Delay for the Short Term and Long Term Scenarios (IUS–IUS).

Time Period of Analysis (Hour)	(After Disruption, Short Term)			(After Disruption, Long Term)		
	Total trips	*Average travel time (min)*	*Average distance (miles)*	*Total trips*	*Average travel time (min)*	*Average distance (miles)*
6:30 am – 9:30 am	66,121	375	13.6	66,137	232	15.1
9:30 am – 3:30 pm	129,260	280	13.8	129,225	180	15.3
3:30 pm – 7:30 pm	90,842	178	14.7	90,839	134	16.1

Direct and Total Costs

The following figures (Figure 23, Figure 24, and Figure 25) show the approximated direct costs for each of the three trip types, comprising typical costs accruing to users (truckers), freight shipments, and inventory costs to the industry, but also those associated with changing to other POEs. In each of these cases, the costs associated with disruptions are shown by time of day including the costs associated with the short term scenario and after a transition or adaptation to long term run equilibrium. Regarding the wait times at POEs (since actual wait times cannot be known), a simple queuing model based on an M/D/1 was used to approximate the processing costs for wait times over an average temporal wait time (as distinctly different from crossing times at POEs) as observed at the Ysleta (Zaragoza) POE for the most immediate past period from September 1 – September 20, 2013 [30]. The use of an M/D/1 queue model assumes the arrival rate at the POE based on a Poisson process, which is not an onerous assumption.

In each trip type, the carrier and shipper costs during the 9:30 am – 3:30 pm interval showed that short term costs were significantly higher than long term equilibrium costs, as expected. The most significant contributors in all cases are the travel time and shipper inventory costs.

Short Term Disruption and Adjustment Phase Costs – Spatial and Temporal Dimensions

The short term northbound trip costs from Mexico to the US (internal–internal) amount to \$841,613 and \$307,696 for the long term scenario for a total of \$1.15 million for the 6:30 am – 9:30 am period (Figure 23). The costs amount to \$2.90 million for the 9:30 am – 3:30 pm period and to \$850,911 for the 3.30 pm – 7.30 pm period. The total combined costs for the Mexico–US internal trips amount to \$3.75M. That includes trip costs for both short and long term disruption scenarios. When the new long run equilibrium state is reached, it will persist as long as the network and travel demand do not change any further since travelers have no incentives to further rationalize their routes. The estimated costs assume that this adjustment phase from a supply side disruption takes approximately 2 weeks. In addition, it is assumed that the entire transition from the short run disruption to the new long run equilibrium is achieved in 28 days.

The following assumptions were made in this analysis:

- All trucks crossing from Mexico (internal) to the US (internal) are Mexican dray trucks as is amply documented in the literature. Hence, all valuation factors pertain to Mexican trucks. In addition Highway Development and Management Model (HDM) values for operating costs are used for the Latin American region. All of these values and factors are described in Appendix B. Similarly, cargo values for northbound flows were obtained and screened from the Bureau of Transborder Statistics (BTS) and the Texas Center for Border Economic and Enterprise Development (TCBEED). The value distributions are included in Appendix C.

- The costs associated with wait times at POEs were approximated using queuing theory with a Poisson service rate. This was utilized for vehicles set for Ysleta POE and Santa Teresa (30).

The equivalent estimates for internal US–internal Mexico (southbound flows) are shown in Figure 23**Error! Reference source not found.**. The combined costs for the three time intervals approximate $1.9 million, $2.7 million, and $1.1 million, respectively. The total combined costs for all three intervals total $5.6 million for the adjustment phase to a new equilibrium.

- All assumptions made for northbound flows apply to southbound flows and are included separately in Appendix C.
- The costs associated with wait times at POEs were approximated using the same queuing theory for southbound flows. The northbound and southbound flows were assigned identical wait times for this approximation.

Finally, Figure 24 shows the costs for all internal–internal US trips, which account for a large portion of the observed trips. The direct costs associated with each of the time intervals are as follows: 6:30 am – 9:30 am, $102 million; 9:30 am – 3:30 pm, $215 million; and 3:30 pm – 7:30 pm, $63.4 million. The total combined costs are approximately $315 million through initial adjustment.

- The assumptions used for costing the US–US trips are included in Appendix B. All trucks were assumed to be US-based trucks.
- The analysis assumed that values for cargo moving internally are significantly lower than those involved in a production sharing move characterized by northbound and southbound flows.

Overarching Assumptions

The most critical assumptions were those relating to the behavioral time-dependent route choices. For a critical failure, some or all of these are eventually relevant considerations. Additional assumptions were made with respect to the cargo flows and valuation factors when conducting the cost analysis.

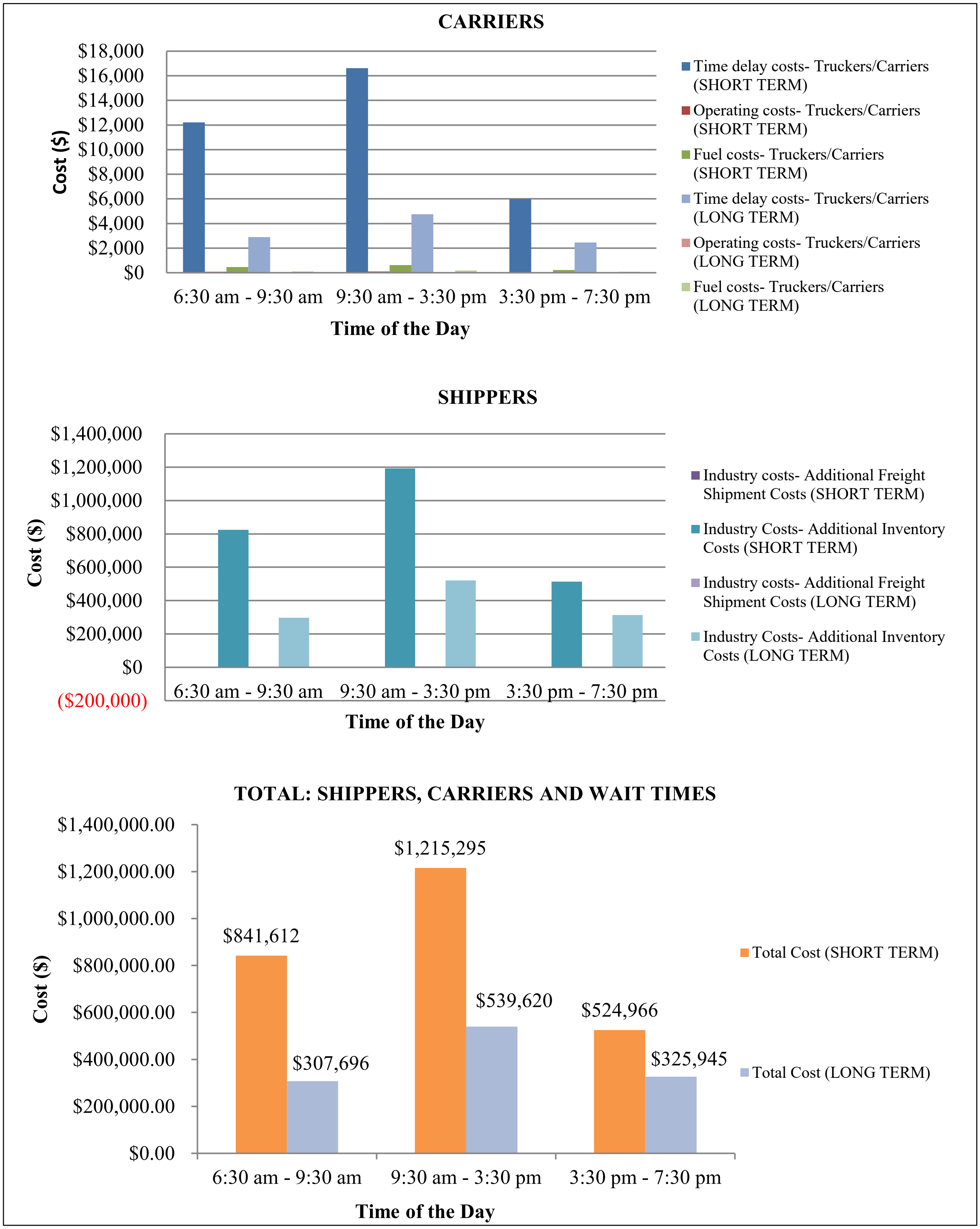


Figure 23: Direct Costs (Internal Mexico to Internal US, Northbound Flows)—Shipper and Carrier Costs (Internal Mexico to Internal US), and Total Costs Across All OD Pairs (Through Disruption and Adjustment to Long Term Run Equilibrium).

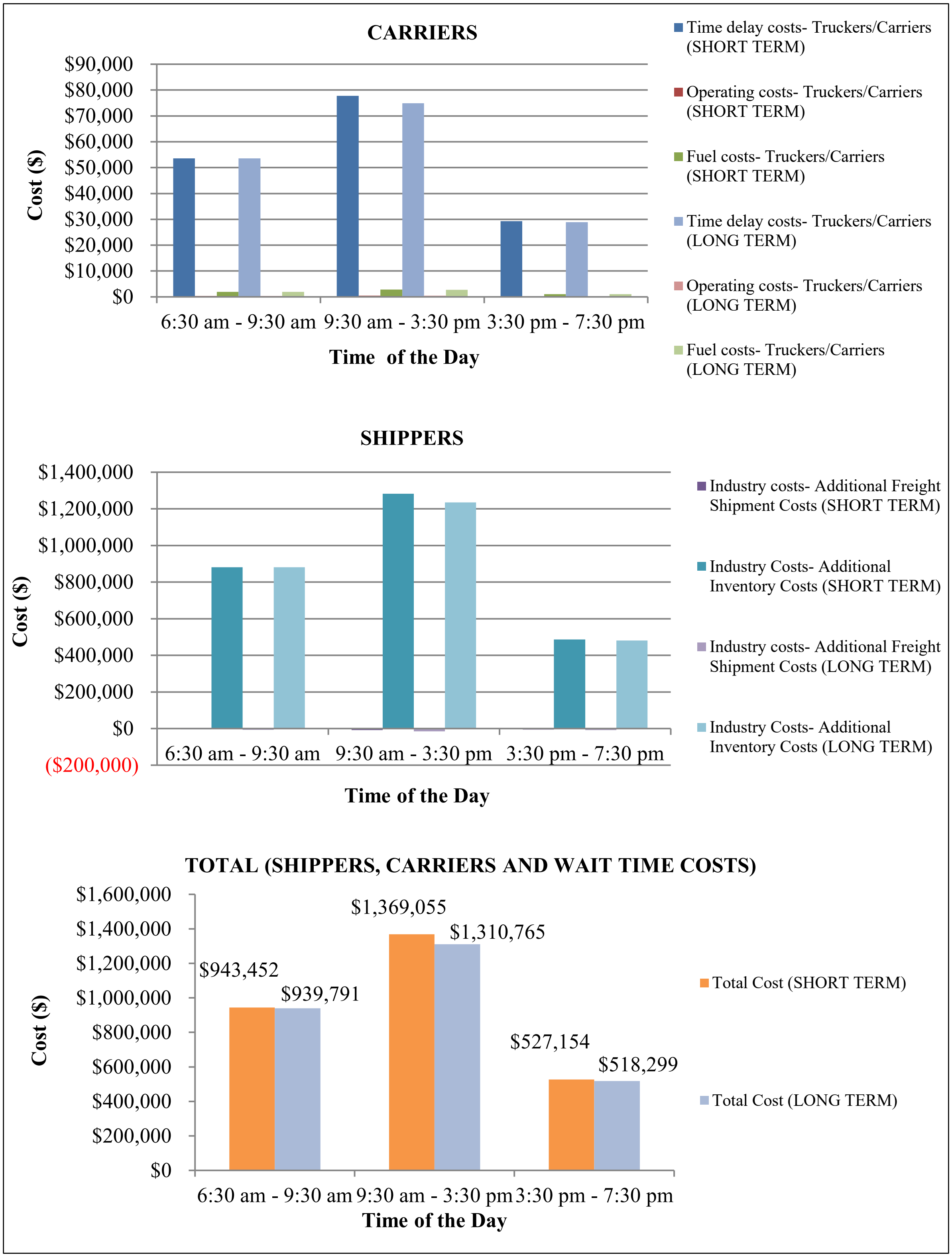


Figure 24: Direct Costs (Internal Mexico to Internal US, Southbound Flows)—Shipper, Carriers, Wait Time Costs, and Total Costs Through Long Term Run Equilibrium.

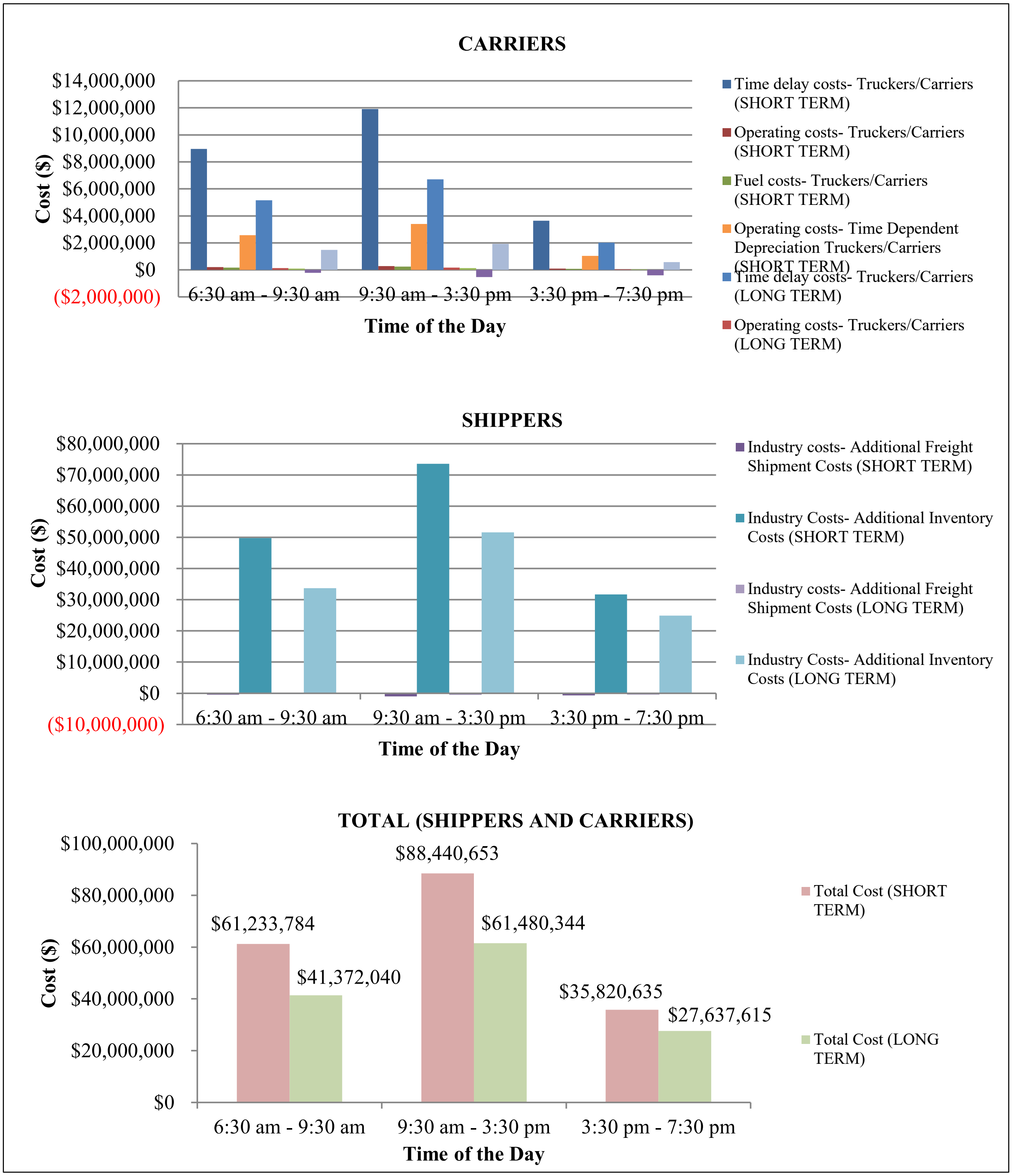


Figure 25: Direct Costs (Internal US to Internal US)—Shippers, Carriers, and Total Costs Through Long Term Run Equilibrium.

Cumulative Costs for an Assumed Disruption of One Year

Under a scenario of a disruption lasting 1 year, the total costs obtained for each of the three trip types were extrapolated for 250 working days minus the 28 days in attaining the short run user equilibrium. If the failure involves critical infrastructure links, it is considered that 1 year is a relatively conservative duration for a replacement facility or reconstruction. A more likely assessment of the duration could be 3 years.

Figure 26 summarizes the total cumulative working year costs for truck trips alone to be $29.3 billion for the early morning time interval, $620 million for the mid-period interval, and $264 million for the late afternoon/evening time interval. The total cumulative direct annual costs for truck trips, comprising time-related productivity costs, fuel, operating costs, and freight supply chain related inventory logistics costs, are approximated at $30.2 billion. The bulk of these costs accumulate during the morning peak time slot.

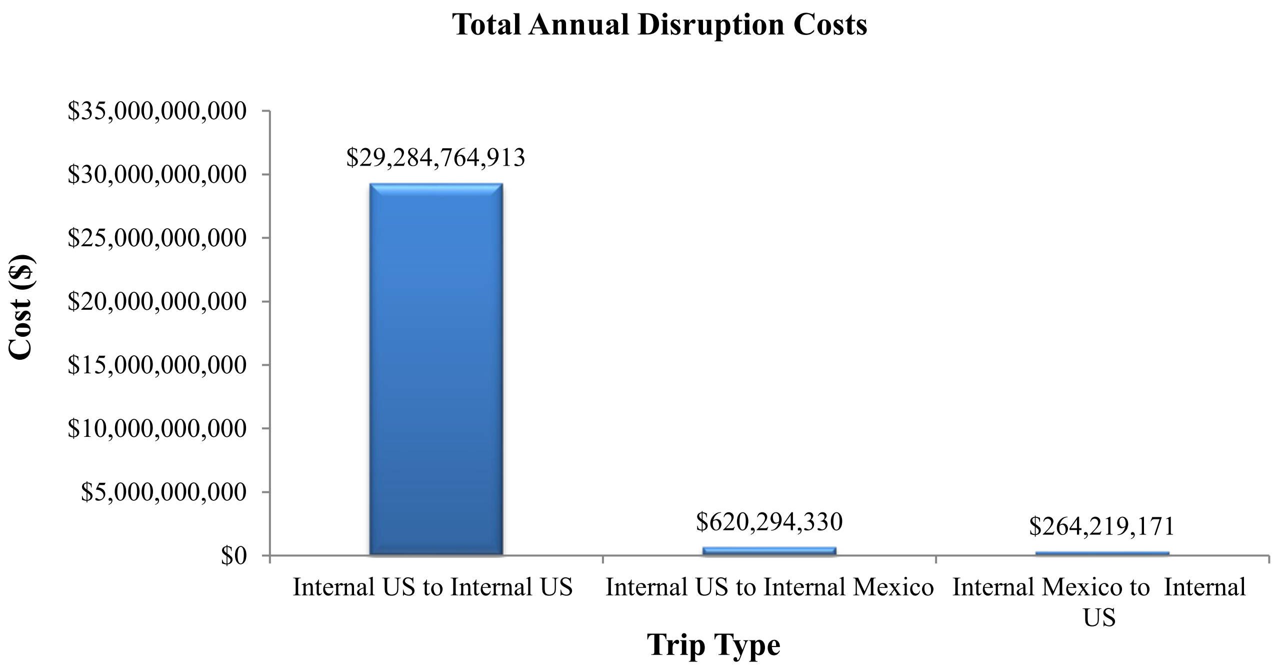


Figure 26: Total Direct Costs for 1 Year Following a Critical Infrastructure Failure.

Local Spillovers from Disruptions

Figure 27 shows an additional effect of a disrupted system on at least 70+ local businesses that lie within the immediate radius of the simulated failure, whose continuity may be affected severely. Based on 2010 data, these businesses are predominantly of the retail variety and hospitality type. However, other types of firms that were identified in the area also were exposed to large losses depending on the severity of the event. In an extreme event situation, these businesses may be completely uprooted financially.

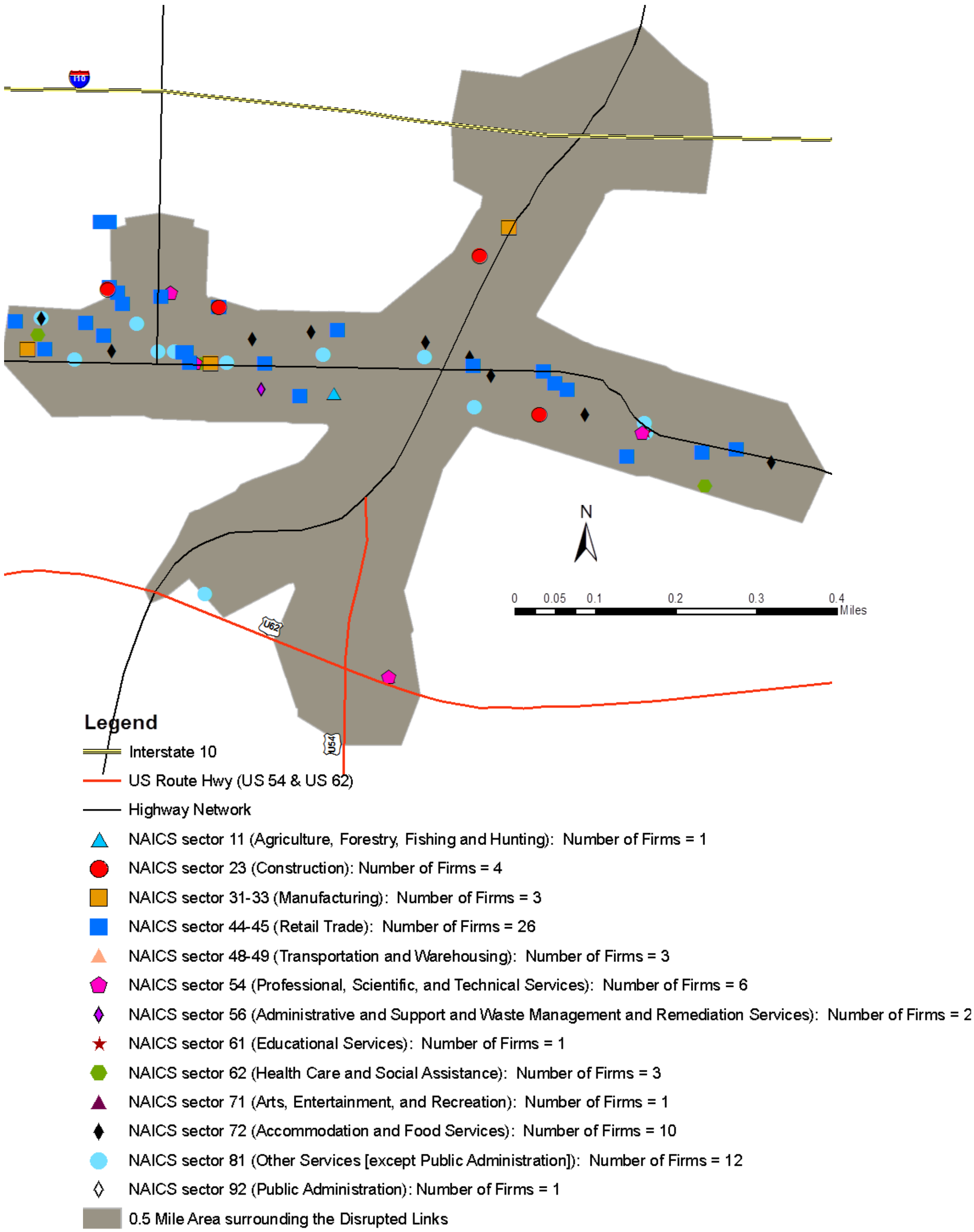


Figure 27: Potential Local Business Economic Continuity Areas (25).

NATIONAL ENVIRONMENTAL POLICY ACT

The National Environmental Policy Act was established in 1969 and its policy is based on three main principles:

1. Assessment of the environmental effects of proposed federal action.
2. Multi-generational environmental sustainability.
3. Citizen participation.

NEPA Requirements

NEPA requires federal agencies to analyze all projects for potential impacts on the human and natural environment (see Figure 28). Each project must satisfy the federal NEPA requirements, which depend on the scope of the project. It can consist of the three following categories [*31*]:

- Categorical Exclusion Projects: There are projects that do not significantly impact the environment and thus do not need to be subject to all the rigorous evaluations of the NEPA process. These sorts of projects can be referred to as "categorical exclusions." During the proposal process, the agency needs to file a categorical exclusion, which completes the required environmental review process contained in the Code of Federal Regulations (23 CFR §771.117) [*32*]. This significantly reduces the delays and paperwork that are commonly associated with the NEPA process.
- No Significant Impact Projects: There are projects that are unclear as to the significance of the environmental consequences. In such cases, an environmental assessment document is required. An environmental assessment document includes a brief discussion of the purpose and need for the project, an evaluation of all reasonable alternative actions, the environmental impacts of the project and the alternatives, and a description of the assessment process [*31*]. Two conclusions could be derived from the assessment:
    - If the project has no significant environmental impact then a no significant impact document is prepared.
    - If significant impacts will occur, an environmental impact statement must be prepared before the project can continue.
- Environmental Impact Statement: An environmental impact statement (EIS) has to be provided to evaluate a range of alternative actions to assess the environmental impacts associated. During this process, both the general public and agencies involved in the project are frequently consulted. Furthermore, agencies conduct field studies and environmental analyses to resolve project-specific issues. After there has been an agreement and all the comments have been considered and incorporated, the lead federal agency publishes the final EIS for review. This is followed by a signed record of decision.

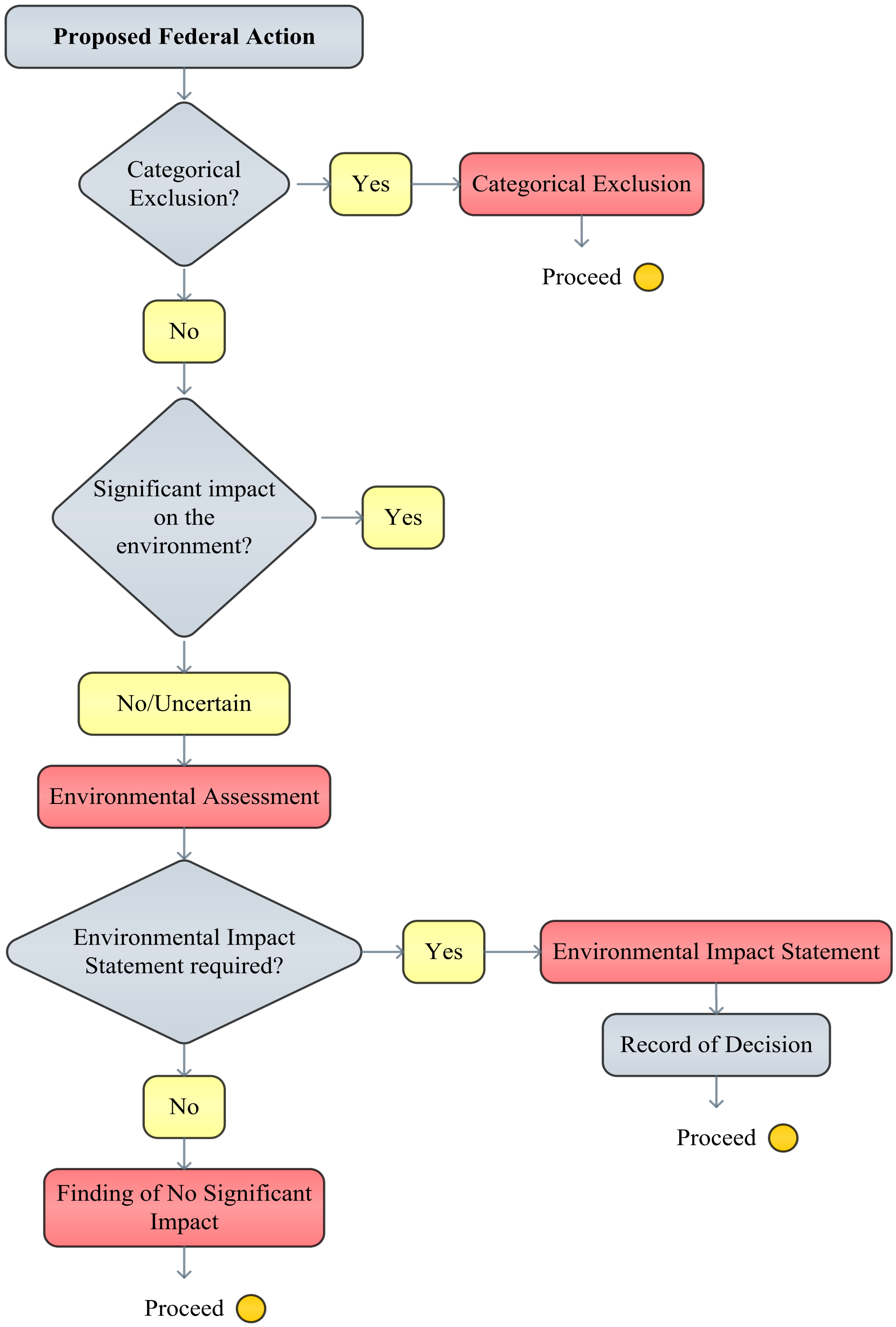


Figure 28: NEPA Process.

Ways to Expedite the Process

As discussed, the NEPA offers various paths to clear a project. Unfortunately, the amount of time, paperwork, and money needed to comply with NEPA requirements has continued to increase throughout the years (see Figure 29**Error! Reference source not found.**).

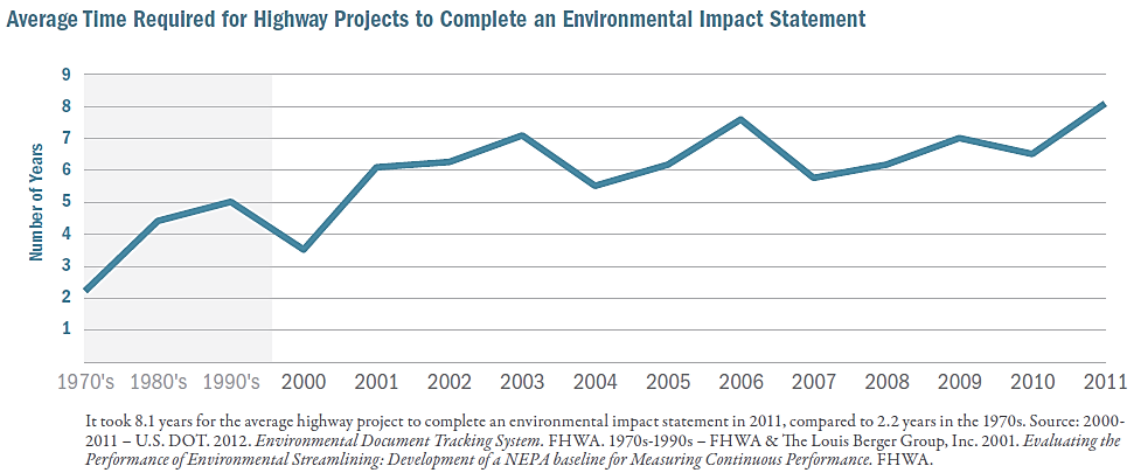


Figure 29: Average Time to Complete an EIS.

Six steps were proposed by Starner to help facilitate this process [*32*]:

1. Effective Scoping: This step involves the discussion of the project with stakeholders. This would result in a better understanding of the community's interests and concerns as well as an understanding of associated environmental implications.
2. Continuous Coordination: It is important to maintain good communication and coordination between the stakeholders and jurisdictional officials throughout the process. This continuous involvement allows assessment of possible engineering concerns related to a change in the design. This helps prevent unexpected future costs.
3. Design Flexibility: This includes maintaining the capability to make adjustments to the design as necessary to minimize environmental impacts. This could translate into having a successful project delivery, no project delivery, or an unnecessary delay.
4. Accurate Impact Assessment: Evaluating environmental impacts accurately is a key component to moving a project forward in a timely and effective manner. This would ensure that project's effect on the environment has been identified and accounted for as part of the NEPA review process.
5. Mitigation Negotiation: This step consists of mitigating, avoiding, or rectifying the environmental impacts of a project. In other words, the agency in charge of the project has to develop a list of agreed-upon items that are needed to satisfy certain NEPA conditions. From a stakeholder's or official's perspective, it is a commitment to mitigate, avoid, rectify, or compensate to resolve the effects on the environment.

6. Proper Documentation: The last step includes maintaining an accurate record of all documents (e.g., meeting minutes, written correspondence, e-mails, telephone communication logs, memoranda, etc.), acquiring the appropriate written agreements, and preparing the applicable documentation of NEPA decisions and commitments.

In order to expedite the delivery of important infrastructure projects, federal strategies are seeking to reform agency implementation policies and procedures. The following list presents four different federal strategies:

- Planning & Environment Linkages: This approach was developed by the Federal Highway Administration (FHWA) in 2008, to better integrate the planning and environmental review phases of a project. This was achieved by creating a unified transportation decision making process that minimized duplication of efforts and delays.
- NEPA Pilot Program: This program was proposed by the Council on Environmental Quality (CEQ) in 2010, to enhance the public's involvement, increase transparency, and ease the implementation of the NEPA process. The lessons learned could eventually lead to the creation and adoption of new or revised NEPA procedures.
- Executive Order 13563: In January 2011, President Barack Obama issued this Executive Order to the CEQ to reexamine all NEPA regulations and identify those that contribute to unnecessary delays. On August 2011, President Obama sent a memo to all of the heads of executive departments and agencies directing them to immediately speed the NEPA process for major infrastructure projects. The lessons learned from the 14 selected infrastructure projects by the CEQ could lead to new steps to expedite the environmental review. Depending on the project, those steps will include, but are not limited to:
  - Integrating planning and environmental reviews.
  - Coordinating multi-agency or multi-governmental reviews and approvals to run concurrently.
  - Setting clear schedules for completing steps in the environmental review and permitting process.
  - Utilizing information technologies to inform the public about the progress of environmental reviews, as well as the progress of federal permitting and review processes.
- Council on Environmental Quality Guidance: The CEQ was created to establish compliance standards for the NEPA and ensure that all federal agencies adhere to the requirements in the NEPA process. Over the years the council has issued several guidance documents in an effort to strengthen the NEPA process, clarify NEPA regulations, and assist federal agencies throughout the NEPA implementation. The most recent guidance, "Improving the Process for Preparing Efficient and Timely Environmental Reviews under the National Environmental Policy Act," gives basic principles for federal agencies to follow for improving the efficiency of the NEPA process [33].

Case Studies

The following case studies illustrate the tools and techniques that are available to environmental specialists to expedite the environmental review process. It is important to mention that the case studies described did not require a change in the NEPA law, waivers, or exemptions from the NEPA.

I-35W Mississippi River Bridge Reconstruction – Minneapolis

One of the busiest bridges in the state of Minnesota (the I-35W bridge) collapsed into the Mississippi River on August 1, 2007. This tragic collapse captured the attention of the federal, state, regional, and local agencies to move quickly and expedite the permitting and review process for the reconstruction effort. Project sponsors were able to deliver this complex bridge construction project from the drawing board to completion in less than 14 months due to the following [*31*]:

- Having a strong leadership, communication, and relationship between federal, regional, state, and local agencies that allowed for better coordination.
- Restraining the scope of the project. Since the new bridge would have the same capacity and alignment as the old bridge, there would be no significant impact on the environment. This reduced its complexity to ensure an expedited NEPA process.
- Utilizing performance incentives and other contracting mechanisms that ensured expedited project delivery.

Henry's Woods Bridge Replacement – Pennsylvania

In September 2004, flooding caused by Hurricane Ivan severely damaged the existing Henry's Woods Bridge located in the state of Pennsylvania. The need for a bridge replacement had to be well planned as it was next to a State Park and a National Historic District. From the initial scoping, the project team recognized that the coordination between the local and state representatives had to be strong in order to discuss the design of the bridge, assess the impact on the park, and identify mutually acceptable mitigation measures. As a result, a "no adverse effect" was documented as a Categorical Exclusion that allowed the project to advance into the final design and construction in a timely and efficient manner.

SUMMARY AND MAIN FINDINGS

This research developed a DTA simulation bi-national model in order to understand the potential travel effects of an extreme event. In addition, the researchers developed a method to link the DTA modeling method to a cargo diversion method in order to analyze the economic costs of a critical transportation infrastructure failure. The analysis was limited to first order direct costs alone. These costs were estimated for the short term immediately following the disruption, but also through the adjustment phase to the new DTA long term run equilibrium. Furthermore, costs were also estimated for the duration of 1 year. The framework developed took into account the type of flows that occur in the entire bi-national region. It considered the following aspects:

- Temporal (across the time of day and over time).
- Spatial variations (US, Mexico, international trade).
- Flow directionality.
- Adjustment to traffic equilibrium in the context of DTA.

In reality, extreme events (like the ones considered in this research) would take longer than a year to either repair or replace the affected facility. As a result, the obtained estimates comprising direct costs and number of businesses in the critical path represent a first order approximation of the magnitude of cost implications. Of all possible trip types, the analysis focused on three trip types as they seemed to cover 94.5 percent of the observed trips in the DTA model and comprise: a) flows within US, and b) internal flows across the border (both northbound and southbound).

- The total cumulative working year (annual) costs for truck trips by time-of-day were estimated to \$29.3 million for the early morning time interval, \$620 million for the mid-morning/afternoon interval, and \$264 million for the late afternoon/evening time interval through the initial adjustment.
- The total cumulative direct costs (annual costs) for truck trips comprising of time related productivity costs, fuel, operating costs, and freight supply chain related inventory logistics costs were approximated at \$30.2 billion with the bulk of the costs accumulating during the morning peak time slot.
- The I_{US}-I_{US} trips comprising of 93% of observed trips account for 97% of the estimated costs. Southbound flows are costlier than northbound flows. The mid-morning/afternoon intervals were estimated to be most expensive relative to other time periods in all cases.
- Business continuity of at least 70+ businesses in the critical failure path will be impaired. These businesses are largely retail. The retail economy is critical to El Paso economy. A complete disruption could impact not only these 70+ businesses, but several others in the county and in the bi-nation region.

Mitigation

Mitigation planning is a key component if a disruption/disaster occurs in the transportation infrastructure. Should such an event occur, the economy of El Paso needs to be prepared with appropriate mitigation measures, including:

Mitigation of Traffic Effects

- Mitigation of traffic diversion effects for international flows. There are several resources and tools already in place to help communicate the effects of such disruptions at POEs, through RSS feeds.
- Mitigation of traffic diversion effects for minimizing congestion on I-10, US 54, and other major transportation infrastructure.

Mitigation of Business Continuity Effects

Mitigation of business continuity (BC) and/or supply chain continuity is vital due to the size of the potential losses that can be faced by businesses and industry in the bi-national region. The variety of trip types indicates that businesses of all sizes and types will be impacted. In addition, with the bi-national area being home to several major manufacturing firms, the disruption effects could spill over to other regions in the country. The strategies suggested include the following:

- Highly recommended suggestions to mitigate BC effects include obtaining a fuller understanding of the nature, extent, and spread of such effects.
- Maintaining and managing BC requires improving the region's business resilience by developing plans and strategies that will enable the region's business to manage such situations. Furthermore, a higher order policy action by top officials toward business strategy would be called for. Such a policy action item could include a mitigation planning strategy requiring the bi-national regions, particularly the El Paso region, to consider business continuity training. Such training is offered by the Business Continuity Institute (BCI: http://www.thebci.org) and requires a few top officials in the region to undertake training so they are better prepared to protect their economy from incurring large losses. Candidate officials could include El Paso MPO and the City of El Paso.

CONCLUSIONS AND FUTURE RESEARCH

The DTA model route choice effects after a disruption in the network allowed much insight in terms of how traffic can propagate across the entire network and over time. The research team developed an assessment of costs based on connections between origin-destination pairs for three major trip types. Not surprisingly, the analysis also showed that the annual cost approximations from a critical infrastructure failure are very large. While both regions stand to lose, it is a given that these costs will ripple not only across the El Paso–Juarez bi-national region, but also to the main trading partner regions across the United States. However, the El Paso region has more to lose financially.

The costs approximated in this study are only first order costs accruing to immediate users and from the direct movement of cargo. The costs were developed under the assumption that it is an isolated event with no interactions to other infrastructure systems. Costs that were not considered in this analysis are the following:

- Costs associated with any other user class, such as passengers. In principle, the DTA model results are multi-class assignments—for this analysis, we have limited our discussions to truck trips alone.
- Safety costs.
- Costs of reinstating a replacement infrastructure.
- Any broader spillover effects to the region, spatial spillovers to other regions.
- Broader spillovers across industries and sectors.
- Modal diversion possibilities, contingency routing.
- Larger scale business disruption costs.
- Any other agency costs.
- Job losses from any impacted facilities.

Each of these factors could warrant further study. More significantly, behavioral effects and queuing effects are a significant component requiring follow-up investigation in the context of the DTA.

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APPENDIX A. OBSERVED RANGES ON TRAVEL RELATED VARIABLES

Table A1: Observed Ranges for Zone-to-Zone Trips, Travel Time, Distance, and Delay—Base, Short Term, and Long Term Scenarios (Internal Mexico–Internal US).

Time Period of Analysis (Hour)	**(Before Disruption, Base)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	12	8.9	135.0	5.1	42.7	0.1	93.9
9:30 am – 3:30 pm	1	21	8.3	207.0	4.6	50.7	0.0	174.0
3:30 pm – 7:30 pm	1	15	9.5	300.0	4.6	53.5	0.3	254.0
Time Period of Analysis (Hour)	**(After Disruption, Short Term)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	12	16.1	1043.0	3.6	37.5	0.0	57.5
9:30 am – 3:30 pm	1	21	17.4	848.3	2.3	50.7	0.0	21.2
3:30 pm – 7:30 pm	1	15	17.0	507.0	2.6	53.5	0.0	191.4
Time Period of Analysis (Hour)	**(After Disruption, Long Term)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	12	18.4	1016.7	7.7	57.1	0.0	60.8
9:30 am – 3:30 pm	1	21	18.1	793.1	7.6	56.6	0.1	217.3
3:30 pm – 7:30 pm	1	17	8.6	505.3	4.9	57.7	0.2	276.4

Table A2: Observed Ranges for Zone-to-Zone Trips, Travel Time, Distance, and Delay—Base, Short Term, and Long Term Scenarios (Internal US–Internal Mexico).

Time Period of Analysis (Hour)	(Before Disruption, Base)							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	minimum	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*
6:30 am – 9:30 am	1	62	22.4	75.2	11.8	31.5	0.3	30.0
9:30 am – 3:30 pm	1	120	22.3	112.5	7.7	32.8	0.1	63.8
3:30 pm – 7:30 pm	1	76	23.2	219.0	7.9	34.7	0.2	180.0
Time Period of Analysis (Hour)	**(After Disruption, Short Term)**							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	minimum	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*
6:30 am – 9:30 am	1	62	20.7	977.9	5.0	29.3	0.5	36.1
9:30 am – 3:30 pm	1	120	24.1	717.3	3.2	33.6	0.1	61.5
3:30 pm – 7:30 pm	1	81	20.8	459.1	3.2	33.0	0.0	151.6
Time Period of Analysis (Hour)	**(After Disruption, Long Term)**							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	minimum	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*
6:30 am – 9:30 am	1	59	25.8	989.0	5.5	36.6	0.1	39.2
9:30 am – 3:30 pm	1	112	30.7	702.7	4.2	32.3	0.0	55.5
3:30 pm – 7:30 pm	1	87	25.9	437.1	5.4	36.3	0.2	74.1

Table A3: Observed Ranges for Zone-to-Zone Trips, Travel Time, Distance, and Delay—Base, Short Term, and Long Term Scenarios (Internal US–External US).

Time Period of Analysis (Hour)	**(Before Disruption, Base)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	5	59.8	104.0	36.6	61.1	4.8	7.1
9:30 am – 3:30 pm	1	6	56.8	81.3	36.7	57.0	2.4	8.4
3:30 pm – 7:30 pm	1	4	63.3	73.8	37.7	54.8	3.8	8.7
Time Period of Analysis (Hour)	**(After Disruption, Short Term)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	5	57.1	996.7	14.6	55.5	2.8	4.1
9:30 am – 3:30 pm	1	6	53.0	800.4	9.0	57.0	2.2	5.5
3:30 pm – 7:30 pm	1	4	58.4	74.0	37.7	54.8	2.4	5.3
Time Period of Analysis (Hour)	**(After Disruption, Long Term)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	3	59.1	78.6	37.7	53.2	3.2	11.2
9:30 am – 3:30 pm	1	6	57.1	95.3	37.0	66.0	2.7	8.4
3:30 pm – 7:30 pm	1	5	62.4	87.7	39.0	52.7	5.0	31.3

Table A4: Observed Ranges for Zone-to-Zone Trips, Travel Time, Distance, and Delay—Base, Short Term, and Long Term Scenarios (External US–Internal Mexico).

Time Period of Analysis (Hour)	**(Before Disruption, Base)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	6	7	69.7	90.7	39.7	51.2	9.6	16.7
9:30 am – 3:30 pm	10	12	68.0	97.1	37.3	48.7	10.5	23.7
3:30 pm – 7:30 pm	6	9	77.9	114.4	39.3	51.5	7.6	50.0
Time Period of Analysis (Hour)	**(After Disruption, Short Term)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	3	7	246.3	986.2	36.1	40.5	21.3	37.2
9:30 am – 3:30 pm	7	12	287.5	697.9	33.4	40.8	38.8	60.7
3:30 pm – 7:30 pm	4	9	141.1	399.0	34.2	48.0	19.7	70.7
Time Period of Analysis (Hour)	**(After Disruption, Long Term)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	5	7	81.6	981.4	35.4	47.3	7.2	17.9
9:30 am – 3:30 pm	12	13	256.7	692.5	36.4	45.7	11.6	53.1
3:30 pm – 7:30 pm	6	10	85.9	408.4	41.5	50.0	9.7	49.3

Table A5: Observed Ranges for Zone-to-Zone Trips, Travel Time, Distance, and Delay—Base, Short Term, and Long Term Scenarios (Internal US–Internal US).

Time Period of Analysis (Hour)	(Before Disruption, Base)							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	minimum	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*
6:30 am – 9:30 am	1	256	0.7	135.5	0.6	38.7	0.0	71.4
9:30 am – 3:30 pm	1	505	1.0	205.7	0.6	44.6	0.0	150.2
3:30 pm – 7:30 pm	1	357	1.3	419.0	0.6	48.3	0.0	364.0
Time Period of Analysis (Hour)	**(After Disruption, Short Term)**							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	minimum	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*
6:30 am – 9:30 am	1	254	0.6	1019.3	0.6	32.8	0.0	47.6
9:30 am – 3:30 pm	1	504	0.7	732.5	0.6	37.5	0.0	77.4
3:30 pm – 7:30 pm	1	355	0.7	451.9	0.6	39.8	0.0	239.2
Time Period of Analysis (Hour)	**(After Disruption, Long Term)**							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	minimum	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*	*minimum*	*maximum*
6:30 am – 9:30 am	1	250	0.7	965.1	0.6	37.0	0.0	52.7
9:30 am – 3:30 pm	1	506	0.6	685.3	0.5	47.7	0.0	204.5
3:30 pm – 7:30 pm	1	347	1.5	409.2	0.7	38.5	0.0	326.1

Table A6: Observed Ranges for Zone-to-Zone Trips, Travel Time, Distance, and Delay—Base, Short Term, and Long Term Scenarios (Internal US–Internal US, Destinations).

Time Period of Analysis (Hour)	**(Before Disruption, Base)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	161	1.8	180.7	1.4	74.7	0.0	125.4
9:30 am – 3:30 pm	1	318	1.3	294.6	1.1	71.6	0.0	243.2
3:30 pm – 7:30 pm	1	236	1.2	301.3	1.2	63.6	0.0	248.0
Time Period of Analysis (Hour)	**(After Disruption, Short Term)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	161	1.7	1029.9	1.1	74.7	0.0	100.4
9:30 am – 3:30 pm	1	318	1.1	791.4	1.1	46.4	0.0	122.0
3:30 pm – 7:30 pm	1	235	1.2	501.9	0.8	62.3	0.0	189.7
Time Period of Analysis (Hour)	**(After Disruption, Long Term)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	162	0.9	1030.0	1.1	63.0	0.0	98.4
9:30 am – 3:30 pm	1	327	1.7	846.6	1.4	68.1	0.0	124.9
3:30 pm – 7:30 pm	1	222	2.0	502.9	1.4	77.2	0.0	256.9

Table A7: Observed Ranges for Zone-to-Zone Trips, Travel Time, Distance, and Delay—Base, Short Term, and Long Term Scenarios (Internal US–External US).

Time Period of Analysis (Hour)	**(Before Disruption, Base)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	78	8.9	181.5	7.8	82.6	0.0	110.0
9:30 am – 3:30 pm	1	155	10.6	275.0	9.5	80.9	0.0	189.3
3:30 pm – 7:30 pm	1	85	6.7	342.0	7.5	85.9	0.0	259.7
Time Period of Analysis (Hour)	**(After Disruption, Short Term)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	78	8.9	1018.1	1.7	82.6	0.0	98.3
9:30 am – 3:30 pm	1	156	10.7	732.4	1.7	72.4	0.0	158.0
3:30 pm – 7:30 pm	1	104	6.6	454.0	0.9	72.4	0.0	166.9
Time Period of Analysis (Hour)	**(After Disruption, Long Term)**							
	trips		***travel time (min)***		***distance (miles)***		***delay (min)***	
	minimum	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***	***minimum***	***maximum***
6:30 am – 9:30 am	1	77	12.1	1006.4	1.0	85.4	0.0	70.2
9:30 am – 3:30 pm	1	158	11.2	759.2	1.6	72.8	0.0	156.1
3:30 pm – 7:30 pm	1	105	12.5	453.8	1.3	81.5	0.0	289.0

Table A8: Observed Ranges for Zone-to-Zone Trips, Travel Time, Distance, and Delay—Base, Short Term, and Long Term Scenarios (External US–External US).

Time Period of Analysis (Hour)	(Before Disruption, Base)							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	min	*max*	*min*	*max*	*min*	*max*	*min*	*max*
6:30 am – 9:30 am	1	30	11.3	152.9	10.5	85.5	0.0	36.1
9:30 am – 3:30 pm	2	58	11.2	171.9	10.5	91.3	0.0	57.6
3:30 pm – 7:30 pm	2	37.0	11.3	238.0	10.5	90.5	0.0	137.2
Time Period of Analysis (Hour)	**(After Disruption, Short Term)**							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	min	*max*	*min*	*max*	*min*	*max*	*min*	*max*
6:30 am – 9:30 am	1	30	11.3	960.4	10.5	71.7	0.0	48.8
9:30 am – 3:30 pm	2	58	11.2	637.4	10.5	86.3	0.0	53.1
3:30 pm – 7:30 pm	2	42	11.3	393.4	10.5	73.1	0.0	122.6
Time Period of Analysis (Hour)	**(After Disruption, Long Term)**							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	min	*max*	*min*	*max*	*min*	*max*	*min*	*max*
6:30 am – 9:30 am	1	28	11.3	529.2	10.5	72.6	0.0	26.6
9:30 am – 3:30 pm	2	64	11.2	346.5	10.5	78.4	0.0	43.9
3:30 pm – 7:30 pm	1	39	10.6	262.1	10.5	83.1	0.0	126.5

Table A9: Observed Ranges for Zone-to-Zone Trips, Travel Time, Distance, and Delay—Base, Short Term, and Long Term Scenarios (Internal MX–Internal MX).

Time Period of Analysis (Hour)	(Before Disruption, Base)							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	min	*max*	*min*	*max*	*min*	*max*	*min*	*max*
6:30 am – 9:30 am	1	6	7.1	25.3	3.9	16.4	0.0	2.7
9:30 am – 3:30 pm	1	11	6.6	47.7	3.8	16.8	0.0	31.0
3:30 pm – 7:30 pm	1	8	6.7	27.7	3.6	15.9	0.0	4.5
Time Period of Analysis (Hour)	**(After Disruption, Short Term)**							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	min	*max*	*min*	*max*	*min*	*max*	*min*	*max*
6:30 am – 9:30 am	1	6	7.2	25.1	3.9	16.4	0.0	3.1
9:30 am – 3:30 pm	1	11	6.4	45.7	3.8	16.8	0.0	29.2
3:30 pm – 7:30 pm	1	7	6.7	28.9	3.6	15.9	0.3	4.5
Time Period of Analysis (Hour)	**(After Disruption, Long Term)**							
	trips		*travel time (min)*		*distance (miles)*		*delay (min)*	
	min	*max*	*min*	*max*	*min*	*max*	*min*	*max*
6:30 am – 9:30 am	1	7	4.6	45.3	3.0	11.2	0.0	29.4
9:30 am – 3:30 pm	1	11	6.4	22.8	3.4	12.3	0.1	5.1
3:30 pm – 7:30 pm	1	9	6.7	36.2	3.8	16.8	0.0	19.0

APPENDIX B: DIRECT COSTS

Total Direct Disruption Costs $C = C_{d,p} + C_{voc,p} + C_{f,p} + C_{d,p} + DC_p + IL_p$ + Border Wait Time Costs

Table B1: Disruption Costs (Internal–Internal Movements) Per Time Interval for Select OD Hot Spot Zones That Cross POE.[5,6]

Cost Category (Additional)	Costs	Global Constants and Sensitivity Parameters
(NB/SB) Truck Movements		
Time delay costs – Truckers/Carriers C_d	$C_d = \{r \times (V_o \times \tau_o) \times (t_a - t_o)\}$ Where, o, a = original and disrupted scenarios t, V = travel time and volume at any time interval r = detour rate or percentage of original path volume which detours to an alternate path. ***Applicable User Class: Freight (Freight factors) and Passengers (Passenger factors)***	Value of time evaluated at driver wages (Mexican) (2013): Geographical Zone A truck driver wages $17/ hour assuming 8 hours per working day (*1*) (adjusted for 1.1 vehicle occupancy and fringe) ($\tau_{o,p}$). Value of time evaluated at driver wages (US): driver wages $21.94/ hour (*2*) adjusted for 25% fringe and 1.1 vehicle occupancy (*2*) (adjusted to 2013).
Operating costs – Truckers/Carriers C_{voc}	$C_{voc} = \{r \times (V_o \times \alpha_o) \times (t_a - t_o)\}$ ***Applicable User Class: Freight (Freight factors) and Passengers (Passenger factors)***	$\alpha_{o,m}$= $0.12 per mile (based on HDM 4 values for Latin America-Heavy truck category) (*3*) or $\alpha_{o,t}$ cents per hour at speeds in mph (adjusted down to include only maintenance, wear and tear, depreciation, and interest). *There are no time related depreciation constants readily available for Mexican trucks.*

[5] Not including delay costs from border crossings and queues at the border. This will add an additional element of costs which can be significant on an hourly basis. These need to be aggregated across time intervals.
[6] Not including any indirect spillovers to output effects especially critical for manufacturing which occurs via a production sharing mode across borders.

Fuel costs – Truckers/Carriers C_f	$C_f = \{r \times (V_o \times \; f_o) \times (t_a - t_o)\}$ ***Applicable User Class: Freight (Freight factors) and Passengers (Passenger factors)***	f_o= f_a (unit fuel cost per mile) = \$0.69 per mile (based on current Mexican diesel prices and assuming fuel efficiency of 5 mpg and adjusted using speed to unit fuel cost per hour. f_o= f_a (unit fuel cost per mile) = \$0.69 per mile (based on current Mexican diesel prices and assuming fuel efficiency of 5 mpg and adjusted using speed to unit fuel cost per hour.
Industry costs – Additional Freight Shipment Costs (Loaded Trucks) (Peak Flow) (Traffic Diverted)	$C_{fs} = \{(l_a - \; l_0 \,) \times FC \times V_o \times T \,\} \times k \; \times r$ Where $l_a - \; l_0$ is the observed difference in additional distance traversed. ***Applicable User Class: Freight only***	FC = unit cost of freight shipment ton-mile = \$0.2117/mile[7] (*4*). T = average cargo tonnage per truck assumed at a conservative 10.4 US Short Tons per truck (*5*). K = peak adjustment factor = ($V_{a,p}/V_{o,p}$)>1 for peak and 1 for off-peak.
Industry costs – Additional Inventory Costs[8,9]	Disruption Costs Associated with Inventory Losses (DC) from Route Change + Inventory losses from Reliability (IL) $DC = \left\{ \frac{\frac{(t_a - \; t_0 \,) \times CV}{\partial}}{\left(1 + \frac{.18}{365}\right)^n} \right\}$ $IL = n \times CV \; \times \left\{ \left(1 + \frac{.18}{365}\right)^n - 1 \right\} (1 - r f_a)$ ***Applicable User Class: Freight only***	∂ = weight for cargo value ($\partial_{high} < \; \partial_{medium} \; < \partial_{low}$ (Subject to sensitivity assume: 30-40-50 weights). .18= Council of Supply Chain Management (CSM) typical inventory premium (18%) values used for inventory loss due to a disruption adjusted to a daily discount factor. This is conservative. The values provided by CSM range from 18–25% of annual inventory value. n = number of days of disruption simulated here. CV = Disrupted cargo value per time interval = $r \times V_o$ x (tons per truck) x (%high value) x (value per truck per ton) + V_o x (tons per truck) x

[7] The freight cost to operate a truck, considering all private costs, varies by the distance traveled, ranging from 21.17 cents per ton-mile for shipments of less than 25 miles to 7.69 cents per ton-mile for shipments of over 500 miles.

[8] Adapted from Freidman et al. (2006) (5). Vadali and Kang (2013) (6) applies a more disaggregated version; however, for this purpose we restrict ourselves to the cumulative form.

[9] Includes adjustments for all carrying costs.

		(%medium value) x (value per truck per ton) V_o x (tons per truck) x (%low value) x (value per truck per ton). $rf_a =$ reliability factor assigned to just-in-time delivery requirements = 0.5 (assumed). This is a sensitivity parameter. Assumptions (*Source: Estimated from BTS*) tons per truck = 10.4 (*7*). Average cargo value per truck per ton (North bound) as approximated from BTS: *High = $8764* *Medium = $5843* *Low = $2921* Average cargo value per truck per ton (Southbound) as approximated from BTS: *High = $2534.68* *Medium = $1689.7* *Low = $844.89* Average cargo value per truck per ton (Northbound) = $44,434.17 Average cargo value per truck per ton (Southbound)= $90,828.91 % high = 40; % medium = 40; % low = 20 (SB, NB)

Table B2: Disruption Costs (External–Internal, Internal–External, External–External Movements, and Internal-Internal US) Per Time Interval for OD Hot Spots.[10,11]

Cost Category and Entity	Costs	Global Constants and Sensitivity Parameters
	Truck Movements US Trucks	
Time delay costs – Truckers/Carriers C_d	$C_d = \{r \times (V_o \times \tau_o) \times (t_a - t_o)\}$ Where, o, a = original and disrupted scenarios t, V = travel time and volume at any time interval r = detour rate or percentage of original path volume which detours to an alternate path. ***Applicable User Class: Freight (Freight factors) and Passengers (Passenger factors)***	Value of time evaluated at driver wages (US) (2012): driver wages \$21.94/ hour (*2*) adjusted for 25% fringe and 1.1 vehicle occupancy (*2*) (adjusted to \$2013). This is a conservative estimate since truck classes are unknown.
Operating costs – Truckers/Carriers C_{voc}	$C_{voc} = \{r \times (V_o \times \alpha_o) \times (t_a - t_o)\}$ ***Applicable User Class: Freight (Freight factors) and Passengers (Passenger factors)***	$\alpha_{o,p,m}$ = \$0.58 per mile[12] (based on ATRI data values*(8)*adjusted to year 2013. $\alpha_{o,p,t}$ = \$0.xx per hour at speeds in mph (adjusted down to include only maintenance, wear and tear, depreciation, and interest).
Operating costs – Time-Dependent Depreciation Truckers/Carriers $C_{voc,p}$	$C_{voc,p} = r \times (V_o \times \alpha_d) \times (t_a - t_o)$ ***Applicable User Class: Freight (Freight factors) and Passenger Cars***	α_d= \$6.90 per hour *(9)*[13].

[10] Not including delay costs from border crossings and queues at the border. This will add an additional element of costs which can be significant on an hourly basis. These need to be aggregated across time intervals. (Source: Occupational Employment Statistics, Published by Bureau of Labor Statistics, US Department of Labor.)
[11] Not including any indirect spillovers to output effects especially critical for manufacturing which occurs via a production sharing mode across borders.
[12] Source: American Trucking Research Institute (ATRI, 2013) data values (*6*) adjusted to year 2013.
[13] Based on Highway Economic Requirements System (HERS).

Fuel costs – Truckers/Carriers C_f	$C_f = \{r \times (V_o \times f_o) \times (t_a - t_o)\}$ ***Applicable User Class: Freight (Freight factors) and Passengers (Passenger factors)***	f_o= (unit fuel cost per mile) = \$0.48 per mile (*8*) adjusted to 2013 dollars.
Industry costs – Additional Freight Shipment Costs	$C_{fs} = \{(l_a - l_0) \times FC \times V_{o,p} \times T \} \times k \times r$ ***Applicable User Class: Freight (Freight factors) only***	FC = unit cost of freight shipment ton-mile= \$0.2117/mile[14] (*4*). T = average cargo tonnage per truck assumed at a conservative 10.4 US Short Tons per truck (*7*). K = peak adjustment factor = $(V_{a,p}/V_{o,p})$>1 for peak and 1 for off-peak.
Industry costs – Additional Inventory Costs (Peak period)	Disruption Costs Associated with Inventory Losses (DC) from Route Change + Inventory losses from Reliability (IL) $DC = \left\{ \frac{(t_a - t_0) \times CV}{\frac{\partial}{\left(1 + \frac{.18}{365}\right)^n}} \right\}$ $IL = n \times CV \times \left\{\left(1 + \frac{.18}{365}\right)^n - 1\right\} (1 - rf_a)$ ***Applicable User Class: Freight only***	∂ = weight for cargo value ($\partial_{high} < \partial_{medium} < \partial_{low}$ (Subject to sensitivity assume: 30-40-50 weights. .18 = Council of Supply Chain Management value inventory premium (18%) loss due to a disruption adjusted to a daily discount factor. The values provided by CSM range from 18–25% of annual inventory value. *n* = number of days of disruption simulated here. CV = Disrupted cargo value per time interval = $r \times V_{o,p}$ x (tons per truck) x (%high value) x (value per truck per ton) + $V_{o,p}$ x (tons per truck) x (%medium value) x (value per truck per ton) $V_{o,p}$ x (tons per truck) x (%low value) x (value per truck per ton) rf_a = reliability factor assigned to just-in-time delivery requirements = 0.5 (assumed)

[14] The freight cost to operate a truck, considering all private costs, varies by the distance traveled, ranging from \$21.17 cents per ton-mile for shipments of less than 250 mile to \$7.69 cents per ton-mile for shipments of over 500 miles.

		Assumptions (*Source: Estimated from BTS*) tons per truck= 10.4 (*7*). Average cargo value per truck per ton (Northbound) as approximated from BTS: *High=$8764* *Medium=$5843* *Low =$2921* Average cargo value per truck per ton (Southbound) as approximated from BTS: *High = $2534.68* *Medium = $1689.7* *Low = $844.89* Average cargo value per truck per ton (NB) = $44,434.17 Average cargo value per truck per ton (SB) = $90,828.91 % high = 40; % medium = 40; % low = 20 (SB, NB)

Table B3: Additional Border Wait Time Costs As a Consequence of Disruption and Increased Wait Times at Alternate POEs.[15]

Cost Category and Entity	Excess Wait Time Costs	Constants
Northbound		
Time delay costs – Truckers/Carriers C_d	$C_d = \left\{r \times V_O \times \frac{1}{\mu_{port}}\left(\frac{2-\rho}{2-2\rho}\right) \times \tau_o\right\}$ Where, $\rho = \frac{\lambda_{port}}{\mu_{port}}$ $\lambda_{port} = rate\ of\ arrival\ of\ trucks\ at\ the\ port$ $\mu_{port} = Service\ rate\ at\ the\ port$ ***Comments: The mean or median crossing time is taken from (bcis.tamu.edu) for Ysleta.*** ***Applicable User Class: Freight (Freight factors) and Passengers (Passenger factors)***	**US** Value of time evaluated at driver wages (Mexican) (2013): Geographical Zone A truck driver wages $17/ hour assuming 8 hours per working day (*1*) (adjusted for 1.1 vehicle occupancy and fringe) ($\tau_{o,p}$) **Mexico** Value of time evaluated at driver wages (US) (2012): driver wages $21.94/ hour (*2*) adjusted for 25% fringe and 1.1 vehicle occupancy (*2*) (adjusted to $2013). This is a conservative estimate since truck classes are unknown.
Operating costs – Time Dependent Depreciation Truckers/Carriers C_{voc}	$C_{voc,dep} = C_{voc} = \left\{r \times V_O \times \frac{1}{\mu_{port}}\left(\frac{2-\rho}{2-2\rho}\right) \times \alpha_o\right\}$ Where, $\rho = \frac{\lambda_{port}}{\mu_{port}}$	**US** α_o= $6.90 per hour *(9)*[16]. **Mexico** Not available

[15] Initial approximation based on a simple queuing process. We make no reference to queue build ups as part of this research. However, queue length build ups will likely have a significant impact on crossing times, which we do not examine in this study.
[16] Based on HERS (2013).

	$\lambda_{port} = rate\ of\ arrival\ of\ trucks\ at\ the\ port$ $\mu_{port} = service\ rate\ at\ the\ port$ ***Applicable User Class: Freight (Freight factors) and Passenger Cars***	
Time fuel costs – Truckers/Carriers C_f	$C_f = C_{fuel,dep} = C_{voc} = \left\{ r \times V_O \times \frac{1}{\mu_{port}} \left(\frac{2-\rho}{2-2\rho} \right) \times f_o \right\}$ ***Applicable User Class: Freight (Freight factors) and Passengers (Passenger factors)***	**Mexico** $f_{o,p,t}$= $f_{a,p,t}$ (unit fuel cost per mile) = \$0.69 per mile (based on current Mexican diesel prices and assuming fuel efficiency of 5 mpg and adjusted using idling speed to unit fuel cost per hour.
Industry costs – Additional Time-based Inventory Capital Costs	$C_{f,p} = C_{fuel,dep} = C_{voc} = \{ (V_{port} \times f_{a,,p,t} \times D) \}$ ***Applicable User Class: Freight (Freight factors) and Passengers (Passenger factors)***	**Mexico** $f_{o,p,t}$= $f_{a,p,t}$ (unit fuel cost per mile) = \$0.69 per mile (based on current Mexican diesel prices and assuming fuel efficiency of 5 mpg and adjusted using idling speed to unit fuel cost per hour.
Industry costs – Time-based Inventory and Handling Costs	$DC_{port} = \left\{ \frac{\frac{D \times CV_{port}}{\partial}}{\left(1+\frac{.18}{365}\right)^n} \right\} + IL_{port}$ $IL_{port} = n \times CV_{port} \times \left\{ \left(1 + \frac{.18}{365}\right)^n - 1 \right\} (1 - RF_{port})$	Where CV_{port} = weighted cargo value at the port of entry. $RF_{port} = reliability\ factor\ for\ the\ port$. It is approximated by the extent to which D exceeds normal survey derived buffer windows of 1 hour (60 min).

APPENDIX C: DIRECT COSTS VALUE DATA DEFAULTS (SOUTHBOUND AND NORTHBOUND)

Table C1: Truck Export Value Frequency Distribution (Source: Developed from BTS at 320 working days) (US–Mexico Trade).

Trade Type and Mode	Commodity Code	Commodity Description	2012
Exports Value	24	Tobacco and manufactured tobacco substitutes	$0
Exports Value	99	(Imports only) Temporary legislation; temporary modifications established pursuant to trade legislation	$0
Exports Value	50	Silk	$8,521
Exports Value	43	Fur skins and artificial fur; manufactures thereof	$26,727
Exports Value	53	Other vegetable textile fibers; paper yarn and woven fabrics of paper yarn	$42,643
Exports Value	13	Lac; gums; resins and other vegetable saps and extract	$52,344
Exports Value	45	Cork and articles of cork	$60,999
Exports Value	97	Works of art; collectors' pieces and antiques	$72,882
Exports Value	46	Manufactures of straw; of esparto or of other plaiting materials; basket ware and wickerwork	$95,433
Exports Value	89	Ships; boats; and floating structures	$109,303
Exports Value	14	Vegetable plaiting materials; vegetable products not elsewhere specified or included	$140,528
Exports Value	92	Musical instruments; parts and accessories of such articles	$179,509
Exports Value	67	Prepared feathers and down and articles made of feathers or of down; artificial flowers	$276,515
Exports Value	78	Lead and articles thereof	$715,388
Exports Value	66	Umbrellas; sun umbrellas; walking sticks; seat sticks; whips; riding crops and parts thereof	$748,834
Exports Value	9	Coffee; tea; mate and spices	$790,893
Exports Value	3	Fish and crustaceans; mollusks and other aquatic invertebrates	$799,511
Exports Value	36	Explosives; pyrotechnic products; matches; pyrophoric alloys; certain combustible preparations	$1,292,488
Exports Value	64	Footwear; gaiters and the like; parts of such articles	$1,542,058
Exports Value	6	Live trees and other plants; bulbs; roots and the like; cut flowers and ornamental foliage	$1,610,111
Exports Value	91	Clocks and watches and parts thereof	$1,840,309
Exports Value	86	Railway or tramway locomotives; rolling stock and parts thereof; railway fixtures and parts thereof	$2,252,209
Exports Value	25	Salt; sulfur; earths and stone; plastering materials; lime and cement	$2,987,323
Exports Value	65	Headgear and parts thereof	$3,343,931
Exports Value	51	Wool; fine or coarse animal hair; Horsehair yarn and woven fabric	$3,705,183
Exports Value	11	Products of the milling industry; malt; starches; inulin; Wheat gluten	$4,276,555
Exports Value	93	Arms and ammunition; parts and accessories thereof	$4,285,898
Exports Value	1	Live animals	$4,893,787
Exports Value	31	Fertilizers	$5,142,838

Exports Value	10	Cereals	$7,729,976
Exports Value	98	Special classification provisions	$9,418,566
Exports Value	23	Residues and waste from the food industries; prepared animal feed	$9,593,773
Exports Value	47	Pulp of wood or of other fibrous cellulosic material; waste and scrap of paper or paperboard	$9,803,088
Exports Value	33	Essential oils and resinoids; perfumery; cosmetic or toilet preparations	$10,397,105
Exports Value	16	Preparations of meat; of fish; or of crustaceans; mollusks or other aquatic invertebrates	$12,177,510
Exports Value	80	Tin and articles thereof	$13,473,657
Exports Value	61	Articles of apparel and clothing accessories; knitted or crocheted	$14,599,364
Exports Value	57	Carpets and other textile floor coverings	$15,743,798
Exports Value	75	Nickel and articles thereof	$16,000,971
Exports Value	18	Cocoa and cocoa preparations	$16,081,032
Exports Value	20	Preparations of vegetables; fruit; nuts; or other parts of plants	$16,639,594
Exports Value	96	Miscellaneous manufactured articles	$16,679,779
Exports Value	12	Oil seeds and oleaginous fruits; miscellaneous grains; seeds and fruit; industrial plants	$17,102,831
Exports Value	81	Other base metals; cemets; articles thereof	$17,586,247
Exports Value	5	Products of animal origin; not elsewhere specified or included	$18,085,001
Exports Value	29	Organic chemicals	$20,744,186
Exports Value	79	Zinc and articles thereof	$21,719,945
Exports Value	22	Beverages; spirits and vinegar	$22,440,852
Exports Value	28	Inorganic chemicals; Organic or inorganic compounds of precious metals; of rare-earth metals	$25,359,069
Exports Value	34	Soap; organic surface-active agents; washing preparations; lubricating preparations; prepared waxes	$27,126,740
Exports Value	68	Articles of stone; plaster; cement; asbestos; mica or similar materials	$27,605,706
Exports Value	19	Preparations of cereals; flour; starch or milk; bakers' wares	$27,914,346
Exports Value	7	Edible vegetables and certain roots and tubers	$28,404,669
Exports Value	15	Animal or vegetable fats and oils and their cleavage products; prepared edible fats; animal waxes	$28,912,154
Exports Value	37	Photographic or cinematographic goods	$32,725,935
Exports Value	42	Articles of leather; saddlery and harness; travel goods; handbags and similar containers	$34,759,651
Exports Value	55	Man-made staple fibers	$37,555,815
Exports Value	58	Special woven fabrics; turfed textile fabrics; lace; tapestries; trimmings; embroidery	$38,722,461
Exports Value	60	Knitted or crocheted fabrics	$38,830,729
Exports Value	71	Natural or cultured pearls; precious or semi-precious stones; precious metals; articles thereof	$39,918,766
Exports Value	69	Ceramic products	$40,212,007
Exports Value	35	Albuminoidal substances; modified starches; glues; enzymes	$40,664,844
Exports Value	41	Raw hides and skins; other than fur skins	$42,718,841
Exports Value	49	Printed books; newspapers; pictures and other products of the printing industry; manuscripts	$46,580,519

Exports Value	62	Articles of apparel and clothing accessories; not knitted or crocheted	$46,715,271
Exports Value	21	Miscellaneous edible preparations	$47,607,583
Exports Value	32	Tanning or dyeing extracts; tannins and their derivatives; dyes; pigments and other coloring matter	$52,738,901
Exports Value	82	Tools; implements; cutlery; spoons and forks; of base metal; parts thereof of base metal	$53,503,862
Exports Value	63	Other made-up textile articles; needle craft sets; worn clothing and worn textile articles; rags	$61,796,321
Exports Value	38	Miscellaneous chemical products	$62,244,083
Exports Value	26	Ores; slag and ash	$63,948,379
Exports Value	70	Glass and glassware	$65,464,430
Exports Value	44	Wood and articles of wood; wood charcoal	$69,957,841
Exports Value	30	Pharmaceutical products	$75,051,136
Exports Value	52	Cotton	$77,112,284
Exports Value	54	Man-made filaments	$91,219,713
Exports Value	88	Aircraft; spacecraft; and parts thereof	$101,389,744
Exports Value	17	Sugars and sugar confectionery	$101,415,497
Exports Value	95	Toys; games and sports equipment; Parts and accessories thereof	$104,598,005
Exports Value	8	Edible fruit and nuts; Peel of citrus fruit or melons	$106,597,837
Exports Value	27	Mineral fuels; mineral oils and products of their distillation; bituminous substances; mineral waxes	$125,293,271
Exports Value	83	Miscellaneous articles of base metal	$127,487,202
Exports Value	56	Wadding; felt and nonwovens; special yarns; twine; cordage; ropes and cables and articles thereof	$130,490,496
Exports Value	94	Furniture; bedding; mattress supports; cushions and similar stuffed furnishings; lighting fittings	$151,282,197
Exports Value	72	Iron and steel	$170,133,510
Exports Value	40	Rubber and articles thereof	$213,449,063
Exports Value	2	Meat and edible meat offal	$270,686,083
Exports Value	4	Dairy produce; birds' eggs; natural honey; edible products of animal origin; not elsewhere included	$287,737,128
Exports Value	59	Impregnated; coated; covered or laminated textile fabrics; textile articles for industrial use	$314,569,093
Exports Value	76	Aluminum and articles thereof	$497,246,212
Exports Value	48	Paper and paperboard; articles of paper pulp; of paper or of paperboard	$514,385,961
Exports Value	73	Articles of iron or steel	$611,606,565
Exports Value	87	Vehicles; other than railway or tramway rolling stock; and parts and accessories thereof	$674,601,266
Exports Value	74	Copper and articles thereof	$945,406,238
Exports Value	90	Optical; photographic; cinematographic; measuring; checking; precision; medical instruments	$1,305,985,193
Exports Value	39	Plastics and articles thereof	$2,140,129,980
Exports Value	84	Nuclear reactors; boilers; machinery and mechanical appliances; parts thereof	$5,835,948,797
Exports Value	85	Electrical machinery and equipment and parts thereof; sound recorders and reproducers	$8,819,538,424

Table C2: Truck Import Values (Source: Developed from BTS at 320 working days) (US–Mexico Trade).

Trade Type and Mode	Commodity Code	Commodity Description	2012
Imports Value	1	Live animals	$0
Imports Value	2	Meat and edible meat offal	$0
Imports Value	13	Lac; gums; resins and other vegetable saps and extract	$0
Imports Value	15	Animal or vegetable fats and oils and their cleavage products; prepared edible fats; animal waxes	$0
Imports Value	24	Tobacco and manufactured tobacco substitutes	$0
Imports Value	36	Explosives; pyrotechnic products; matches; pyrophoric alloys; certain combustible preparations	$0
Imports Value	45	Cork and articles of cork	$0
Imports Value	50	Silk	$0
Imports Value	53	Other vegetable textile fibers; paper yarn and woven fabrics of paper yarn	$0
Imports Value	5	Products of animal origin; not elsewhere specified or included	$5,000
Imports Value	3	Fish and crustaceans; mollusks and other aquatic invertebrates	$7,089
Imports Value	29	Organic chemicals	$7,320
Imports Value	92	Musical instruments; parts and accessories of such articles	$7,990
Imports Value	14	Vegetable plaiting materials; vegetable products not elsewhere specified or included	$9,796
Imports Value	51	Wool; fine or coarse animal hair; horsehair yarn and woven fabric	$11,233
Imports Value	67	Prepared feathers and down and articles made of feathers or of down; artificial flowers	$13,404
Imports Value	46	Manufactures of straw; of esparto or of other plaiting materials; basket ware and wickerwork	$16,076
Imports Value	79	Zinc and articles thereof	$17,144
Imports Value	10	Cereals	$19,283
Imports Value	12	Oil seeds and oleaginous fruits; miscellaneous grains; seeds and fruit; industrial plants	$49,939
Imports Value	78	Lead and articles thereof	$63,694
Imports Value	23	Residues and waste from the food industries; prepared animal feed	$104,243
Imports Value	57	Carpets and other textile floor coverings	$133,691
Imports Value	11	Products of the milling industry; malt; starches; inulin; wheat gluten	$134,664
Imports Value	43	Fur skins and artificial fur; manufactures thereof	$164,938
Imports Value	60	Knitted or crocheted fabrics	$172,014
Imports Value	97	Works of art; collectors' pieces and antiques	$228,639

Imports Value	27	Mineral fuels; mineral oils and products of their distillation; bituminous substances; Mineral waxes	$245,340
Imports Value	35	Albuminoidal substances; modified starches; glues; enzymes	$274,681
Imports Value	86	Railway or tramway locomotives; rolling stock and parts thereof; railway fixtures and parts thereof	$387,981
Imports Value	37	Photographic or cinematographic goods	$510,053
Imports Value	32	Tanning or dyeing extracts; tannins and their derivatives; dyes; pigments and other coloring matter	$621,306
Imports Value	34	Soap; organic surface-active agents; washing preparations; lubricating preparations; prepared waxes	$639,794
Imports Value	22	Beverages; spirits and vinegar	$717,525
Imports Value	31	Fertilizers	$816,058
Imports Value	47	Pulp of wood or of other fibrous cellulosic material; waste and scrap of paper or paperboard	$903,350
Imports Value	55	Man-made staple fibers	$977,526
Imports Value	80	Tin and articles thereof	$1,257,026
Imports Value	75	Nickel and articles thereof	$1,527,924
Imports Value	66	Umbrellas; sun umbrellas; walking sticks; seat sticks; whips; riding crops and parts thereof	$1,548,465
Imports Value	82	Tools; implements; cutlery; spoons and forks; of base metal; Parts thereof of base metal	$1,568,877
Imports Value	6	Live trees and other plants; bulbs; roots and the like; cut flowers and ornamental foliage	$1,618,200
Imports Value	52	Cotton	$1,907,376
Imports Value	81	Other base metals; cemets; articles thereof	$2,260,194
Imports Value	9	Coffee; tea; mate and spices	$2,362,130
Imports Value	25	Salt; sulfur; earths and stone; plastering materials; lime and cement	$2,428,552
Imports Value	58	Special woven fabrics; turfed textile fabrics; lace; tapestries; trimmings; embroidery	$2,689,350
Imports Value	4	Dairy produce; birds' eggs; natural honey; edible products of animal origin; not elsewhere included	$2,908,527
Imports Value	54	Man-made filaments	$3,052,533
Imports Value	16	Preparations of meat; of fish; or of crustaceans; mollusks or other aquatic invertebrates	$3,796,475
Imports Value	65	Headgear and parts thereof	$3,908,215
Imports Value	21	Miscellaneous edible preparations	$4,673,721
Imports Value	93	Arms and ammunition; parts and accessories thereof	$4,787,235
Imports Value	71	Natural or cultured pearls; precious or semi precious stones; precious metals; articles thereof	$5,029,619

Imports Value	42	Articles of leather; saddlery and harness; Travel goods; handbags and similar containers	$6,720,746
Imports Value	41	Raw hides and skins; other than fur skins	$9,016,328
Imports Value	18	Cocoa and cocoa preparations	$10,392,298
Imports Value	28	Inorganic chemicals; organic or inorganic compounds of precious metals; of rare-earth metals	$10,989,434
Imports Value	30	Pharmaceutical products	$13,744,463
Imports Value	19	Preparations of cereals; flour; starch or milk; bakers' wares	$13,909,013
Imports Value	7	Edible vegetables and certain roots and tubers	$15,138,164
Imports Value	64	Footwear; gaiters and the like; parts of such articles	$15,140,260
Imports Value	72	Iron and steel	$16,142,079
Imports Value	89	Ships; boats; and floating structures	$16,418,026
Imports Value	70	Glass and glassware	$17,109,667
Imports Value	56	Wadding; felt and nonwovens; special yarns; twine; cordage; ropes and cables and articles thereof	$22,857,371
Imports Value	26	Ores; slag and ash	$29,953,427
Imports Value	96	Miscellaneous manufactured articles	$30,078,643
Imports Value	91	Clocks and watches and parts thereof	$32,243,167
Imports Value	38	Miscellaneous chemical products	$35,601,731
Imports Value	69	Ceramic products	$39,991,340
Imports Value	68	Articles of stone; plaster; cement; asbestos; mica or similar materials	$40,488,931
Imports Value	49	Printed books; newspapers; pictures and other products of the printing industry; Manuscripts	$44,031,971
Imports Value	17	Sugars and sugar confectionery	$44,911,560
Imports Value	20	Preparations of vegetables; fruit; nuts; or other parts of plants	$49,775,473
Imports Value	74	Copper and articles thereof	$50,139,857
Imports Value	33	Essential oils and resinoids; perfumery; cosmetic or toilet preparations	$52,264,424
Imports Value	48	Paper and paperboard; articles of paper pulp; of paper or of paperboard	$57,987,684
Imports Value	95	Toys; games and sports equipment; parts and accessories thereof	$71,352,099
Imports Value	44	Wood and articles of wood; wood charcoal	$77,848,232
Imports Value	61	Articles of apparel and clothing accessories; knitted or crocheted	$97,157,100
Imports Value	40	Rubber and articles thereof	$98,176,637
Imports Value	73	Articles of iron or steel	$110,000,079
Imports Value	63	Other made-up textile articles; needle craft sets; worn clothing and worn textile articles; rags	$123,283,949
Imports Value	83	Miscellaneous articles of base metal	$125,037,475
Imports Value	59	Impregnated; coated; covered or laminated textile fabrics; textile articles for industrial use	$127,366,033

Imports Value	76	Aluminum and articles thereof	$140,043,890
Imports Value	88	Aircraft; spacecraft; and parts thereof	$162,194,539
Imports Value	8	Edible fruit and nuts; Peel of citrus fruit or melons	$211,791,419
Imports Value	62	Articles of apparel and clothing accessories; not knitted or crocheted	$438,061,744
Imports Value	39	Plastics and articles thereof	$458,298,462
Imports Value	98	Special classification provisions	$746,387,608
Imports Value	87	Vehicles; other than railway or tramway rolling stock; and parts and accessories thereof	$1,703,612,363
Imports Value	94	Furniture; bedding; mattress supports; cushions and similar stuffed furnishings; lighting fittings	$1,937,352,775
Imports Value	90	Optical; photographic; cinematographic; measuring; checking; precision; medical instruments	$2,672,985,910
Imports Value	84	Nuclear reactors; boilers; machinery and mechanical appliances; parts thereof	$6,457,796,448
Imports Value	85	Electrical machinery and equipment and parts thereof; sound recorders and reproducers	$13,496,643,180

Table C3: Time-Dependent Depreciation—US Trucks/Autos (Source: HERS).

Vehicle Type	Total Depreciation ($/hr) ($1995)	Time-Related Depreciation ($/hr) ($1995)	Time-Based Values Adjusted to 2013 (Based on Producer Price Index) (adj. factor=1.421
Passenger Cars			
Small autos	$1.72	$1.09	$1.55
Medium-sized to large autos	$2.02	$1.45	$2.06
Trucks			
Four-tire single-unit trucks	$2.18	$1.90	$2.70
Six-tire trucks	$3.08	$2.65	$3.77
3+ axles combination trucks	$8.80	$7.16	$10.18
3 or 4 axles	$7.42	$6.41	$9.11
5+ axles	$7.98	$6.16	$8.76
Average Trucks	**$5.89**	**$4.86**	**$6.90**

Source: HERS-ST (2013) (*9*)

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