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Routing Opportunities for Commercial Crossings between El Paso and Juarez

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ROUTING OPPORTUNITIES FOR COMMERCIAL CROSSINGS BETWEEN EL PASO AND JUAREZ

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by

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THESIS

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DECLARATION

This thesis is an output of the International Dual Master's Degree Program in Smart Cities and Engineering, a collaboration between the Czech Technical University in Prague, Czech Republic and The University of Texas at El Paso, USA.

This research is jointly supervised by the following faculty members:

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ABSTRACT

This thesis explores the topic of commercial movements between the El Paso and Ciudad Juarez road networks and the implications of the possible changes in their routing. This area houses several ports of entry, which present one of the busiest commercial and personal border crossings in the whole nation. The primary focus was to evaluate the recently proposed reconstruction scenario of removing trucks from the Bridge of the Americas and study the impacts on the flows throughout the other ports. The chosen tool to support the analysis is a mesoscopic simulation software called DynusT, which is capable of modeling the whole bi-national network and answering questions on a macroscopic scale while still providing a sufficient level of detail. As part of the modeling efforts, a base scenario representing the current transportation network calibrated with traffic flows from 2022 was compared with two alternatives. One scenario simulated the closure of the Bridge of the Americas for commercial trucks without any other provisions. The second scenario included adjustments to the toll rates. The results uncovered that without any additional provisions, the vast majority of trucks would reroute to the nearest Ysleta-Zaragoza port, which would suffer from high volumes, leading to possible deterioration of the quality of service. However, in the second scenario, the toll change led to a nearly 900 % increase in crossing volumes at Tornillo in the southbound direction. This increase could help address the recent concerns about the port's severe underutilization. In order to ensure success, several recommendations were given. The most vital suggestion is to bring the demand closer to the vicinity of Tornillo, relieving the Ysleta port while still enabling the shift of trucks away from the downtown area, paving the path towards a more sustainable, cleaner, safer, and smarter El Paso.

Keywords: El Paso, Border, Port of Entry, Commercial Traffic, Routing, Traffic Simulation

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1. INTRODUCTION

1.1. Background

In today's world of globalization, where borders do not seem like a constraint, all consumers have access to a wide variety of products and goods, often at the click of a button. To satisfy their needs, a huge number of shipments have to be made every day. While they do not have to acknowledge the fact that their parcel has to cross the borders, in reality, the process of moving freight from one country to another is lengthy and difficult and poses many risks and restrictions not only on the logistic companies and operators but also on the border cities and communities.

The latest data shows that mainly due to supply chain problems fueled by COVID-19, many Chinese producers have established new branches in Mexico to satisfy the demand for their products while maintaining their competitiveness and rentability (Gantz, 2023). This transformation from offshoring to reshoring or near-shoring concept is crucial and has great impacts on the national economies as well as the border communities. In 2022, Mexican exports to the USA totaled $454.8 billion, which is an increase of almost 19 % from the year 2021 and around 64 % increase over the last decade (U.S. Census Bureau, 2022b).

To sustain such extensive growth, it is inevitable to consider the limits of the current infrastructure and whether it will be able to accommodate the rising number of vehicles moving onwards. Naturally, the port of entry (POE), in the context of this thesis, the land POEs, are the most impactful bottlenecks on the road network. The cities in places with these bottlenecks suffer from many externalities, mainly pollution, vibrations, lowered safety, and overall decreased quality of life due to long queues of vehicles taking up valuable space and hindering the development potential of the community.

1.2. El Paso – Ciudad Juarez Border Crossings

The border POE is a key point for facilitating trade and vehicle and personnel movements. It ensures that everyone entering the state is entitled to do so and that all imported goods are legitimate and up to standard. There are 44 active ports of entry along the 2,000-mile-long borderline between the USA and Mexico (Rodríguez et al., 2022). The vast majority of them, 29, are located in the state of Texas (Texas U.S. Ports of Entry, n.d.). The City of El Paso officially accommodates four POEs, although, in some statistics, the Ysleta Port of Entry has been separated. The border line was originally established by the banks of the Rio Grande River. Therefore, all the border crossings within the El Paso area are realized as bridge connections. The location of each of the bridges can be observed in Figure 1.

From the east to the west, there is the Ysleta-Zaragoza Bridge, which is slightly displaced from the downtown area of the City of El Paso, followed by the Bridge of the Americas (BOTA), Stanton Bridge, and Paso del Norte. Additionally, further west, the Santa Teresa POE can be found alongside the planned Sunland Park border crossing (El Paso MPO, 2019). Recently, a Tornillo-Guadalupe border crossing, officially called Marcelino Serna, was opened approximately 20 miles east of El Paso. However, only the four POEs displayed in Figure 1 directly border the City of Juarez.

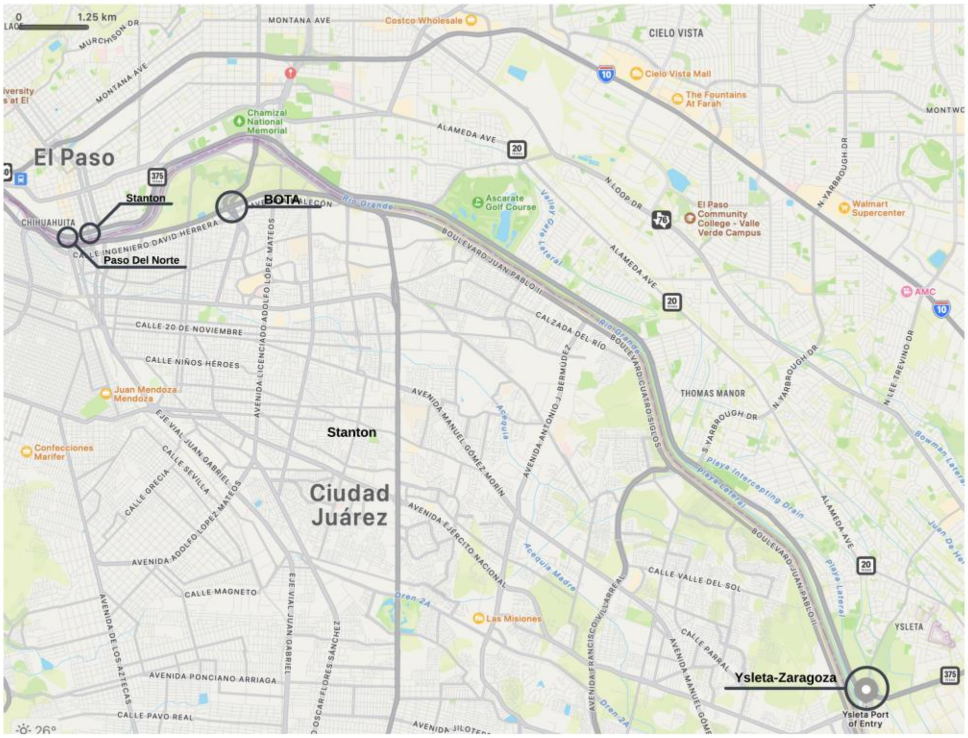


Figure 1: Bridges of El Paso, source: Apple Maps, captions created by the author

The main focus of this thesis will be the Bridge of the Americas POE, often referred to as BOTA. Based on the description provided by the U.S. General Services Administration (GSA) website, the bridge connects El Paso with the Mexican land port of Cordova in Ciudad Juarez, Chihuahua, MX. The port on both sides accommodates toll-free commercial, non-commercial, and pedestrian movements, making it the only bridge in El Paso that offers toll-free crossing for all transport modes, resulting in permanently high volumes of traffic. Built in 1967, with the last major renovation in 1998, the port is becoming obsolete. That is the main reason why the U.S. General Service Administration presented four alternatives for its renovation, working with different levels of scope presented in Section 3.5 of this thesis (GSA, 2023).

1.3. Mesoscopic Simulation and DynusT

Traffic simulation is a traffic engineering approach to studying the transportation network by utilizing models in order to be able to plan or simply just observe and operate the transportation systems. Usually, specialized software is being used to create and run the model. There are several levels of traffic simulations, namely microscopic, mesoscopic, and macroscopic.

Macrosimulation utilizes a macro-model of the given relatively broad area to observe and analyze relationships between basic traffic parameters such as traffic flow, which measures the number of vehicles passing a certain point; traffic density, which represents the number of vehicles per given length and the speed of traffic flow which measures the distance covered in a certain time. Macrosimulation generates traffic flows, which can be fed as inputs to the microscopic models. Microscopic simulation, on the other hand, observes the individual vehicles in the network and their interactions. This is enabled by the car-following model, which describes the relationship between the leading vehicle and the following vehicle, whose behavior is dependent on the leader. To make the simulations more realistic, a lane-changing model is employed to account for the lateral movement as well. The mesoscopic model uses traits of both the macro and microscopic models and would stand in between them (Cheu, 2021).

DynusT, which stands for Dynamic Urban Systems for Transportation, is a simulation-based dynamic traffic assignment model. If it had to be categorized into one of the above-mentioned groups, it would fall under the mesoscopic models as it can generate traffic volumes based on travel demand and route assignment, but it can also provide measures for evaluating the interactions of individual vehicles and operation effectiveness. It can be used to assess the impacts of alternate traffic operations and control strategies, to evaluate strategies for work zones or incidents, to study the impacts of intelligent transportation systems, or to evaluate congestion-pricing schemes for tolling or air quality analyses. DynusT utilizes dynamic traffic assignment (DTA), which considers varying demand and route choice behavior reflecting the current network conditions and characteristics, to take into consideration the behavior caused by unexpected delays and congestion (Metropia Inc., 2017).

1.4. Research Questions and Hypotheses

This thesis followed three main steps, all leading towards the objective of providing an overview of the traffic patterns, mainly at the border crossings between El Paso and Ciudad Juarez and the surrounding area. As the main tool supporting the analysis, dynamic assignment simulation software DynusT has been selected. Other platforms have been considered, such as TransCAD. However, DTA is ideal for vehicle routing problems as the vehicles find the most optimal route based on the immediate conditions of the network by evaluating the current costs, not solely on the macroscopic parameters, which is the trait of the macroscopic simulation such as TransCAD. DynusT is a mesoscopic level of simulation. Therefore, it enables the evaluation of the whole bi-national area in one model with a sufficient level of detail. Microscopic simulation would provide more precise results for one port of entry; however, it would not help much in reaching the outlined objectives.

Firstly, it was necessary to conduct research on the proposed design alternatives, mostly from websites, presentations, and other open sources. Attending the "A Better Border for a Better America" conference and Bridges Steering Committee public meetings was one of the other ways of gathering more insight into the project. Secondly, the mesoscopic model of the area had to be prepared and calibrated using the most recent available traffic flow data. The second step aimed to use the data and information gathered to select and model alternatives, based on which the final evaluation was made. The last step was to run the model in order to obtain and analyze the results.

The main underlying question was how the traffic flows at the other ports of entry would be affected if the BOTA reconstruction alternative 4, which proposes removing commercial traffic from this bridge entirely, was to be realized. An extensive change like rerouting commercial vehicles out of the downtown area would have significant impacts on the traffic movements in the region. This impact study should serve as a basis for decision-making in this regard, discuss the feasibility of such a proposal, and outline some measures to minimize the risks of potential implementation. As a side objective, the modeling and calibration process has been described in detail to serve as a guide for other students or researchers who would like to utilize DynusT to fulfill their research objectives since the amount of publicly available information on the use of this software is very limited.

1.5. Contents

This chapter is followed by the Literature Review highlighting the most significant pieces referenced throughout this thesis. The subsequent section describes the border crossings, their significance, limitations, and how those could be addressed by using technology. Chapters 4 and 5 provide documentation of the actual modeling, calibration, and analysis efforts, which led to the final discussion and feasibility evaluation. The whole work is concluded in Chapter 6.

2. LITERATURE REVIEW

In this chapter, the most significant documents, which have been referenced and serve as a research basis for the thesis, are presented. An in-depth literature review has been conducted in order to understand the context, the crossing process, and the local and national significance. The literature has been divided into several subtopics covering different aspects of the outlined problematics.

The following subtopics were identified:

- Border crossing and its local significance,
- International trade and logistics,
- Border crossing process,
- Technology.

Border crossing and its local significance is clearly demonstrated in the 2023 document "Shedding Light on the U.S.-Mexico Border Definition" by Jesus Cañas, which showcases the interconnectedness of the communities on each side of the border and the increasing significance with increasing proximity. It emphasizes the need to address the area as a whole, not as two separate entities. Sener et al. then shed light on what motivates individuals to cross from one side of the wall to another, supporting the narrative of interconnected communities.

International trade and logistics are naturally associated topics with any border discussions. The three-part study published by the University of Texas at El Paso (UTEP) Hunt Institute thoroughly mapped the commercial ties between the USA and Mexico, quantified them, and provided an estimate of monetary savings associated with border wait times reduction. They also provided a brief overview of the border crossing process and proposed several solutions to the identified challenges. The border crossing process is also described in the 2014 publication by the U.S. Customs and Border Protection, which focused on importing to the USA, and in the 2022 master's thesis of Katerina Pithartova, whose objective was to map the border crossing processes thoroughly and put together an ontology describing it.

Last but not least, the supporting technology has been researched, ranging from the Intelligent Transportation Systems, discussed mainly in the 2012 work published by the Texas A&M on Border-Wide Assessment of Intelligent Transportation System (ITS), to concepts such as Smart Border management elaborated on in a 2019 paper by Svitek et al.

This is not an exhaustive list of all the literature used in this document; it only highlights the crucial pieces used to build upon. Numerous other resources have been reviewed and presented to support the whole picture. All are properly referenced and can be found in the references chapter of this document.

3. BORDER CROSSINGS

3.1. Cross-Border Transportation in the El Paso–Juarez Region

Mexico and the USA are undeniably strong partners when it comes to both non-monetary and monetary capital and material flows, tourism, and especially cultural influence and exchange. This is inherently more evident in places such as El Paso, where the Hispanic population prevails. According to the last data from the U.S. Census Bureau, 81.6 % of the El Paso inhabitants are of Hispanic or Latino origin, with a great share of them being bilingual (U.S. Census Bureau, 2022a). Additionally, this data does not account for the people commuting on a daily basis from Mexico to participate in activities such as work or education, which, to a great extent, shape the sentiment of the community.

Bearing this in mind means addressing the whole El Paso – Juarez agglomeration as one whole, considering the needs of the citizens on both sides of the wall conjointly, and studying the impacts on both communities with the same level of emphasis. A study conducted jointly by the Banco de México, Federal Reserve Bank of Dallas, and Universidad the Guadalajara, presented in September 2023 as part of the conference "A Better Border for a Better America" supports this statement by emphasizing that there is statistical evidence the USA and Mexican cross-border metropolises are economically integrated. They took it even further by claiming that border cities on the Mexican side are linked to the American economy to a greater extent than to the Mexican (Cañas, 2023).

It is important to realize that while this thesis focuses on commercial movements, the reality is that all of the POEs mentioned above also serve passenger vehicles or pedestrians, and some of them even have non-commercial purposes exclusively. That means it is not possible to omit this traffic completely, and it has to be addressed as part of the problem. There is a wide variety of reasons why people cross the border, from tourism, including shopping and health services, social visits, and work, to education access (Sener et al., 2015). These trips boldly contribute to the overall capacity utilization, making the POEs a major bottleneck on the network, which challenges the feasibility of further economic and social integration.

3.2. Implications for International Trade and Logistics

As already mentioned, the USA-Mexico border spans around 2,000 miles, of which approximately 1,250 miles belong to Texas, accounting for more than 60 % of the total length. Of the 29 currently operating border crossings in Texas, 14 process commercial traffic (TxDOT, 2022). The state of Texas not only accommodates the longest portion of the border, but it is also the biggest importer of Mexican goods. The data provided by the U.S. Census Bureau from the year 2022 shows that out of the total $454.8 billion in imports, Texas ranks number one with more than 31 % of the total share (U.S. Census Bureau, 2022b).

A study conducted by the UTEP Hunt Institute suggests that the physical proximity yields interdependency, resulting in five million jobs in the USA being tied to trade with Mexico. On the Mexican side, the benefits are even more profound since more than 5.5 million direct and indirect jobs are tied to the USA-Mexican partnership in the automotive industry alone. The interdependency can be observed not just in terms of the labor market but throughout the whole supply chain, which can be illustrated by the example from 2020 when border movement was disrupted as a result of the COVID-19 pandemic. The sugar exports from Mexico to the USA decreased by almost 18 %, and the disruption in avocado supply, which makes up for about 90 % of avocados being sold on the USA market, almost caused a national shortage. These disruptions may occur more frequently, with increasing levels of volume and traffic posing a major threat to the supply chain. The waiting times were identified as the main factor hindering the efficiency. The long wait times could be caused mainly by inconsistent federal policies, outdated technologies, and a lack of coordination between the US and Mexican sides. The researchers estimated that a 10-minute reduction in border wait times might translate into an additional $312 million of cargo flows annually, as well as the potential to create thousands of new jobs, having positive impacts on both economies (Rodríguez et al., 2022).

The 10-minute reduction goal is not randomly chosen, as explained in the second report out of the three-part series, but rather, it reflects a baseline that could be theoretically achieved with different operational provisions. It is the biggest time frame that can be perceived as statistically reliable, though they indicate that the regression analysis they conducted provided mostly linear results; therefore, it might be valid even for greater time reductions. The second report also takes the findings from the first part and presents them more granularly. The concrete monthly estimates in millions of US dollars per state can be observed in the last column of Table 1 (Rodríguez et al., 2023).

When it comes to the trip destinations, almost half of the movements coming to the USA through El Paso end within Texas. Although it is a significant portion of the overall trips, it also means that the rest terminate out of state, mainly in Michigan, California, Ohio, and Illinois. The study also uncovered that many of the imported commodities are intermediate products, meaning they are being used to produce the final goods in the USA, which again shows how interconnected the economies are, how fragile the supply chain may be, and how aiming to make it resilient should be the top priority (Alfaro et al., 2023).

Table 1: Impacts of 10-minute Wait Times Reduction, source: Hunt Institute, Rodríguez et al., 2023

State	Loaded Containers 2019	% of Total State Crossings	Total Import Value (Million USD) 2019	% of Total Import Value	Average Value per Loaded Container (Import) (Million USD)	Additional Loaded Containers*	Additional Cargo Value** (Million USD)
Arizona	344,191	7.2%	$17,663.2	5.5%	$0.05	28	$1.4
California	1,056,457	22.2%	$43,567.8	13.7%	$0.04	86	$3.5
New Mexico	632,973	13.3%	$39,983.7	12.6%	$0.06	52	$3.3
Texas	2,732,531	57.3%	$217,153.6	68.2%	$0.08	222	$17.7
US Total	**4,766,152**	**100.0%**	**$318,368.3**	**100.0%**	**$0.07**	**388**	**$25.9**

3.3. BOTA Operations

Bridge of the Americas was originally built in 1967 as part of the Chamizal Treaty work and was subsequently replaced in 1998 with two bridges for northbound and southbound commercial traffic and two bridges for northbound and southbound passenger vehicles, with sidewalks for both directions. It offers toll-free crossing for pedestrians as well as personal and commercial vehicles. The personal crossings are available 24/7, and the commercial section has established times of operation. The bridge itself measures 506 feet, but the overall land usage is much broader, as it also accommodates the adjacent infrastructure of the GSA. Unlike all other El Paso bridges, which are owned by the City of El Paso, the ownership is split between the USA Section, International Boundary and Water Commission, and Mexican Section, International Boundary and Water Commission, and is jointly operated by USA and Mexican Customs (TxDOT, 2015).

In the southbound direction, BOTA is easily accessible from Interstate 10 (I-10), which is one of the most important freeways in the southern part of the USA, spanning from the west to the east coast. Between 2021 and 2023, the connection has been made more efficient by separating the traffic bound from I-10 to Juárez and traffic bound from I-10 to Loop 375 to different ramps as part of the I-10 Connect project. The new configuration can be observed in Figure 2 (TxDOT, n.d.-a). On the Mexican side, the bridge is connected directly to the Mexican Federal Highway 45.

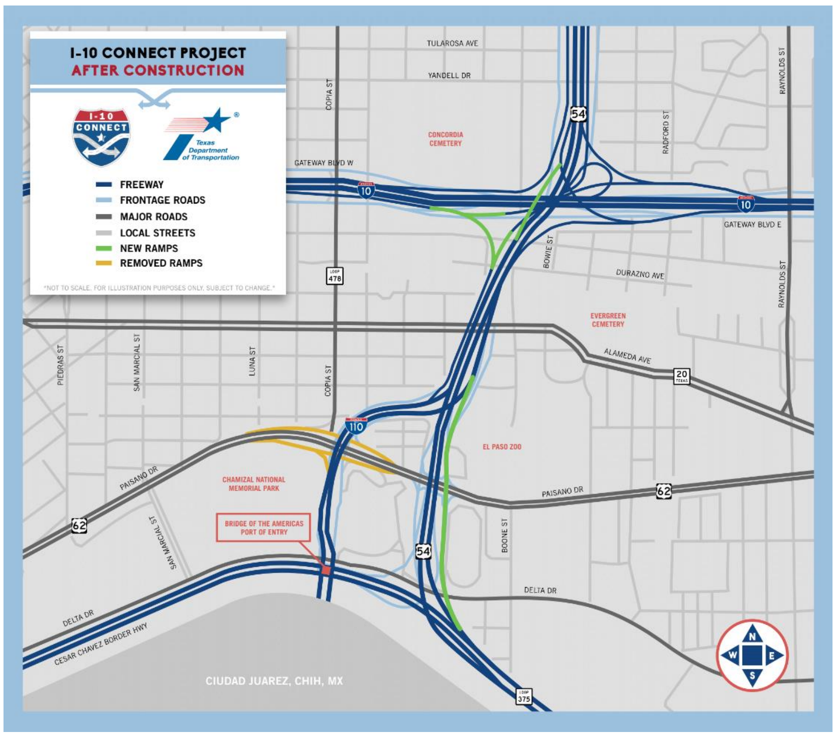


Figure 2: I-10 Connect After Reconstruction, source: TxDOT, I-10 Connect

Aside from standard border crossing procedures, BOTA also offers several programs for frequent personal and commercial travelers, enabling better efficiency and convenience. Being part of the program entitles the member to use one of the dedicated lanes for faster processing. There are two programs targeting personal vehicles and one targeting commercial vehicles. Personal vehicles can take advantage of the SENTRI (Secure Electronic Network for Travelers

Rapid Inspection) and Ready lanes. Commercial vehicles can use the FAST (Free and Secure Trade) lane.

The Ready lane is the least demanding and does not require any registration prior to arriving at the border. The only requirement is to possess a Ready Lane-eligible card that contains RFID (Radio Frequency Identification) technology. The documents that could be used are USA Passport Cards, Enhanced Driver's Licenses, and many more. By scanning the document prior to arriving at the booth, the U.S. Customs and Border Protection (CBP) officer is spared doing this step, which makes the overall process more efficient (U.S. Customs and Border Protection, 2023).

Both the SENTRI and FAST lanes are based on the Trusted Traveler Program, which enables private and commercial entities to get pre-approved based on background checks, delivered documentation, and an in-person meeting with the CBP officer. In the event that everything is in order and the administrative fee is paid, travelers can utilize expedited customs processing and the FAST lanes to transport goods more quickly into the USA. Non-commercial entities can use the SENTRI lanes. However, all occupants need to have their own valid membership to benefit from it. The validity for both types of membership is limited to five years (Department of Homeland Security, n.d.).

There is also another way to use the FAST lanes, and that is the Customs Trade Partnership Against Terrorism (CTPAT). Membership in this initiative is free, and it brings many more benefits to the user than the Trusted Traveler Program. However, it requires much tighter communication and relationship with the CBP, as indicated on the CBP website:

"When an entity joins CTPAT, an agreement is made to work with CBP to protect the supply chain, identify security gaps, and implement specific security measures and best practices. Applicants must address a broad range of security topics and present security profiles that list action plans to align security throughout the supply chain." (U.S. Customs and Border Protection, n.d.)

In return, the member can take advantage of many benefits listed on the website, one of which is access to the FAST lane.

3.4. Commercial Crossing Process

The border crossing process differs based on the type of vehicle that is being utilized. Different procedures are designed for privately owned vehicles (POV), buses, pedestrians, and commercial vehicles. Differences occur between northbound and southbound trips. Except for pedestrians, the process for all other types of travelers commences by locating the appropriate lane, which leads to one of the inspection booths. The traveler is directed by digital variable message signs, which are placed above the individual lanes. The different types of lanes are described in Section 3.3 (Pithartova, 2022).

In order to enter the USA as part of the commercial crossing, necessary documentation has to be prepared in advance. There are all sorts of different documents applicable based on the type of shipment, with the following being the most important:

- Entry Manifest (CBP Form 7533) or Application and Special Permit for Immediate Delivery (CBP Form 3461) or other form of merchandise release required by the port director,
- Evidence of right to make entry (e.g., bill of lading),
- Commercial invoice or a pro forma invoice when the commercial invoice cannot be produced,
- Packing lists, if appropriate,
- Other documents are necessary to determine merchandise admissibility.

Presently, the process is simplified both for the carriers doing their paperwork themselves and for the broker companies. The brokers have the possibility to use the Automated Broker Interface, which enables them to digitally file most of the documentation ahead of the shipment, effectively eliminating the need for lengthy paperwork at the POE. Analogously, the carriers can submit the documentation using the Automated Commercial System.

After the shipment has arrived at the POE and the initial documentation has been submitted, the two-phase inspection may take place. If the inspection is passed or waived, and no violations have been found, the goods are released alongside the entry summary documentation and estimated duties (U.S. Customs and Border Protection, 2014).

Before entering the USA, the Mexican border control officers check the export documentation. If everything is in order, the truck is sent to the side operated by the USA CBP. Firstly, the CBP measures the weight and compares it to the declared vehicle class and shipment size. If there are no discrepancies, the truck is released. If not, it is sent to a secondary inspection booth for further investigation. If any of the above-mentioned steps fail, the shipment may be denied entry to the USA and can be sent back to Mexico (Pithartova, 2022). A flowchart describing the process can be observed in Figure 3.

Figure 4 then provides a different view of the same process. Although it was created almost 20 years ago, it is in line with what is presented in the flow chart from 2022, meaning it is still current. There is a total of three steps, one on the Mexican and two on the USA side. The first step involves verifying the documentation on the Mexican side and potential cargo inspection in case of any suspicions or discrepancies.

In the second step, the CBP primary inspection is carried out, similar to the Mexican side, with the possibility of sending the shipment for a secondary, more thorough inspection. Additionally, what is not displayed in Figure 3 is the visual vehicle safety inspection, which aims to check the compliance of the entering vehicles with the safety requirements of the state.

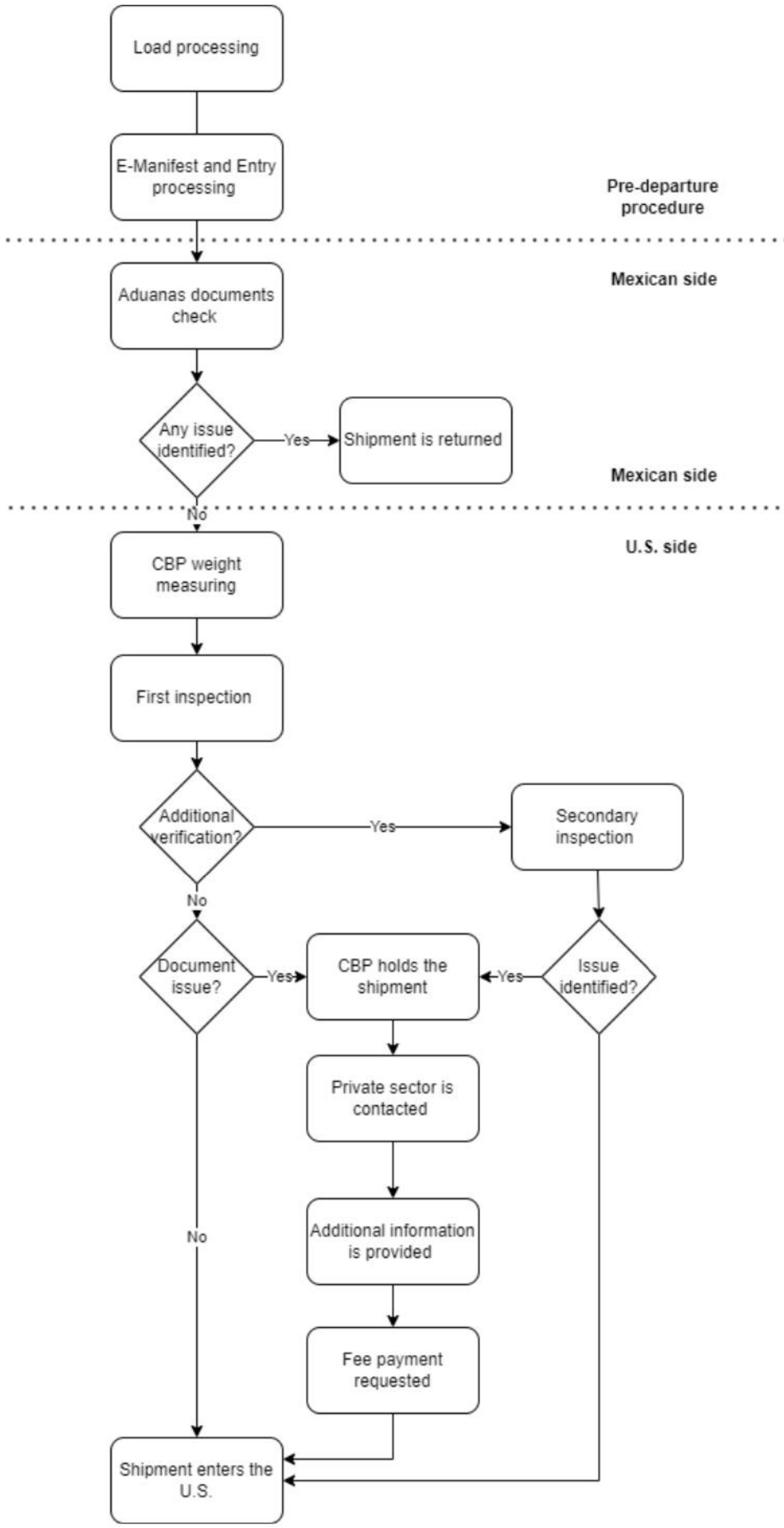


Figure 3: Commercial Vehicle Border Crossing Flowchart, source: Pithartova, 2022

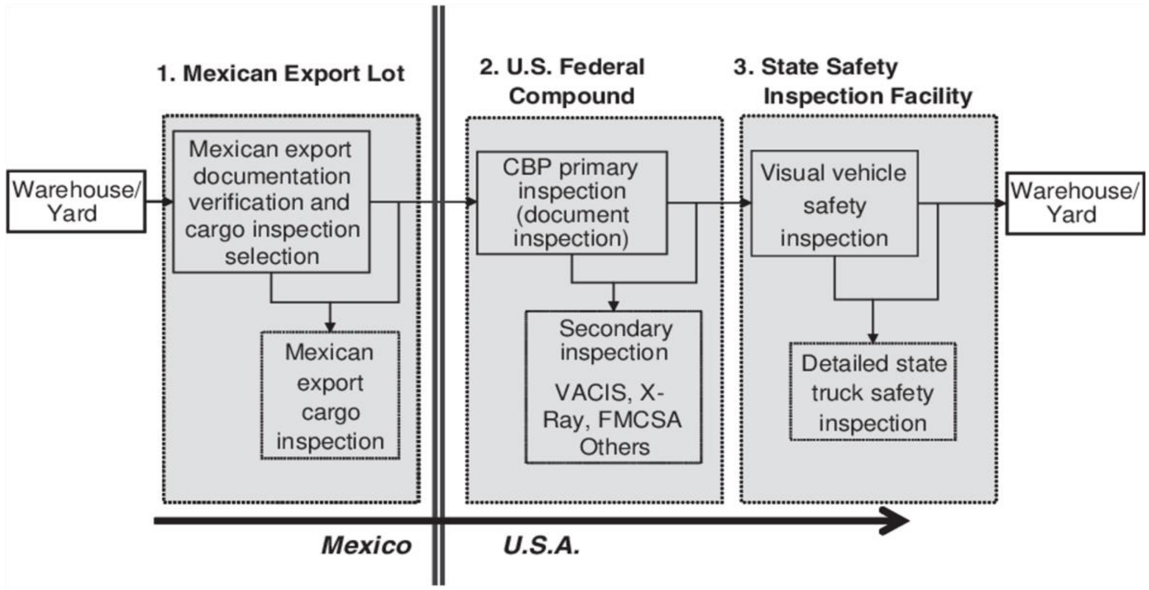


Figure 4: Commercial Inspection Process, source: Juan Carlos Villa, 2006

3.5. BOTA Reconstruction Scenarios

As mentioned in the previous chapters, the GSA is planning on expanding and renovating the current BOTA facilities to improve the CBP operations and reduce wait times. They also pledged to minimize the impact on the community, meaning they presented several options for the reconstruction and are currently in the process of community engagement and eliciting comments and requirements from the citizens affected by the proposed changes. One of the goals of the project is to also promote pedestrian crossings by changing the layout and creating ties to the different modes of transport, potentially calling for a mobility hub solution (Partida, 2023). The projected timeline of the project is to award the design by April 2026 and start the construction in August 2026, with the tentative completion date by mid-2031 (GSA, 2023).

To provide context, the current BOTA POE facility is at its limit, with little to no room for expansion in the vicinity. Although there is a possibility to acquire the land of the El Paso County Coliseum and Events Center, there is very little public support for such a decision as it houses the only ice rink arena in the area, making it a significant landmark of El Paso (Golden, 2023). The four alternative scenarios consider the following approaches:

- Use existing site with no expansion,
- Acquire land to accommodate future growth, retain the ice rink,
- Acquire land to enable complete segregation of commercial vehicle inspection from other activities,
- Remove commercial traffic from the BOTA bridge entirely.

Alternative 1 can be observed in Figure 5. Alongside Alternative 4, it is the least invasive as it keeps the Paisano Green Community, El Paso County Coliseum, and the ice rink, also known as El Paso County Coliseum Events Center. The proposed land acquisition is highlighted in red. The operations should be carried out on two levels. The ground level would support the non-commercial movements, as well as the secondary commercial traffic. The primary commercial inspection would be offset to the upper level. The Federal Motor Carrier Safety Administration (FMCSA) and TxDOT inspection facilities would be jointly located in place of the current Commercial Vehicle Enforcement facility of the Texas Department of Public Safety, to the left of the Paisano Green Community.

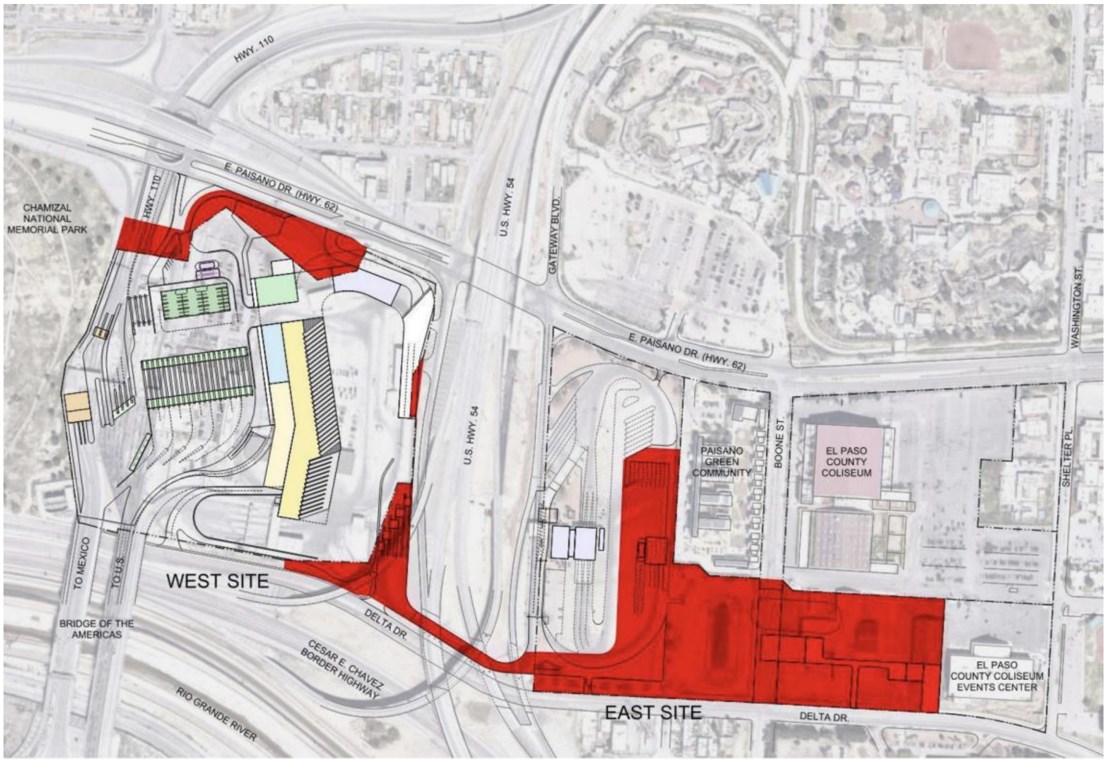


Figure 5: BOTA Reconstruction: Alternative 1, source: GSA, 2023

Alternative 2, which can be observed in Figure 6, extends the needed land acquisition further east, seizing the land of the El Paso County Coliseum Centre. The ice rink placed on the premises would have to be removed in order to realize this option. As mentioned earlier, in the eyes of the public, this is a highly unpopular option. The advantages of this design are that the current facilities would still house the inspection for non-commercial vehicles, pedestrians, buses, and commercial primary, while the commercial secondary and FMCSA truck inspections would be moved to the newly built east site, providing more capacity for the routine operations.

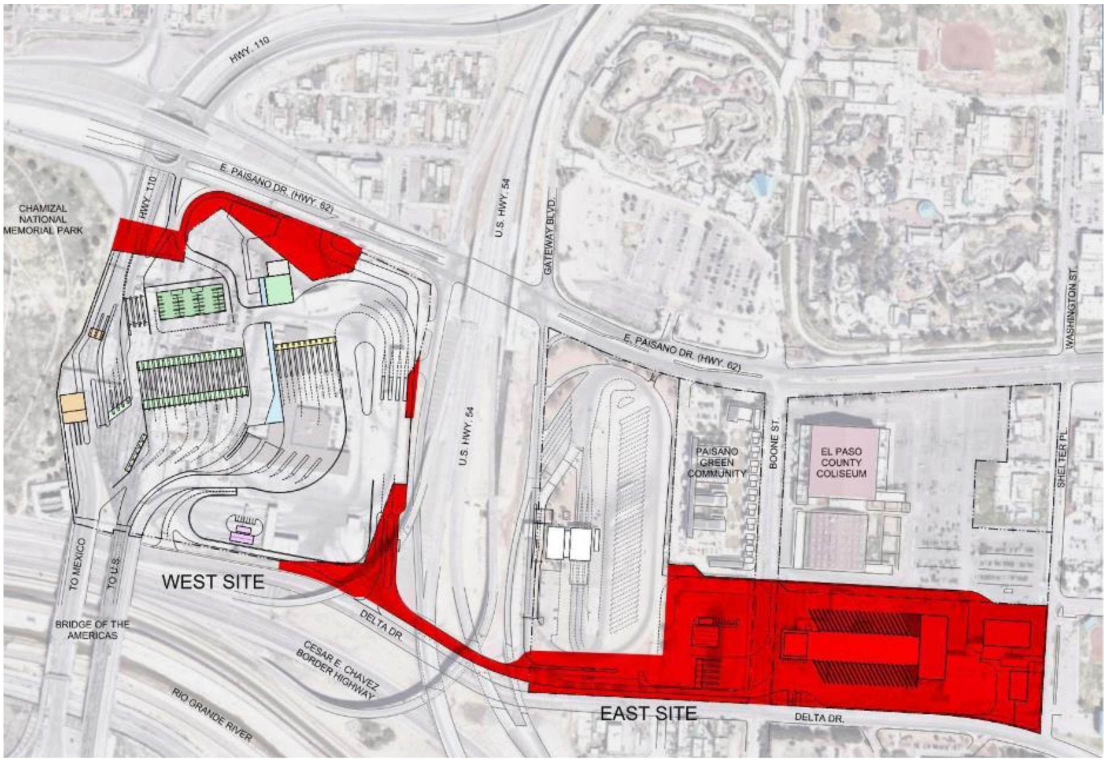


Figure 6: BOTA Reconstruction: Alternative 2, source: GSA, 2023

Alternative 3, which can be seen in Figure 7 requires more significant land acquisition, effectively replacing the community area in its entirety. The current facility in the west site would be used solely for non-commercial purposes, whereas new infrastructure would be built in the east site to completely support the commercial vehicle inspection, both the primary and secondary, as well as FMCSA. Such a solution might significantly increase the capacity for both commercial and non-commercial movements. The premises of the Paisano Green Community would remain untouched; however, the proximity of the potentially busy commercial terminal could be harmful, considering its residential nature.

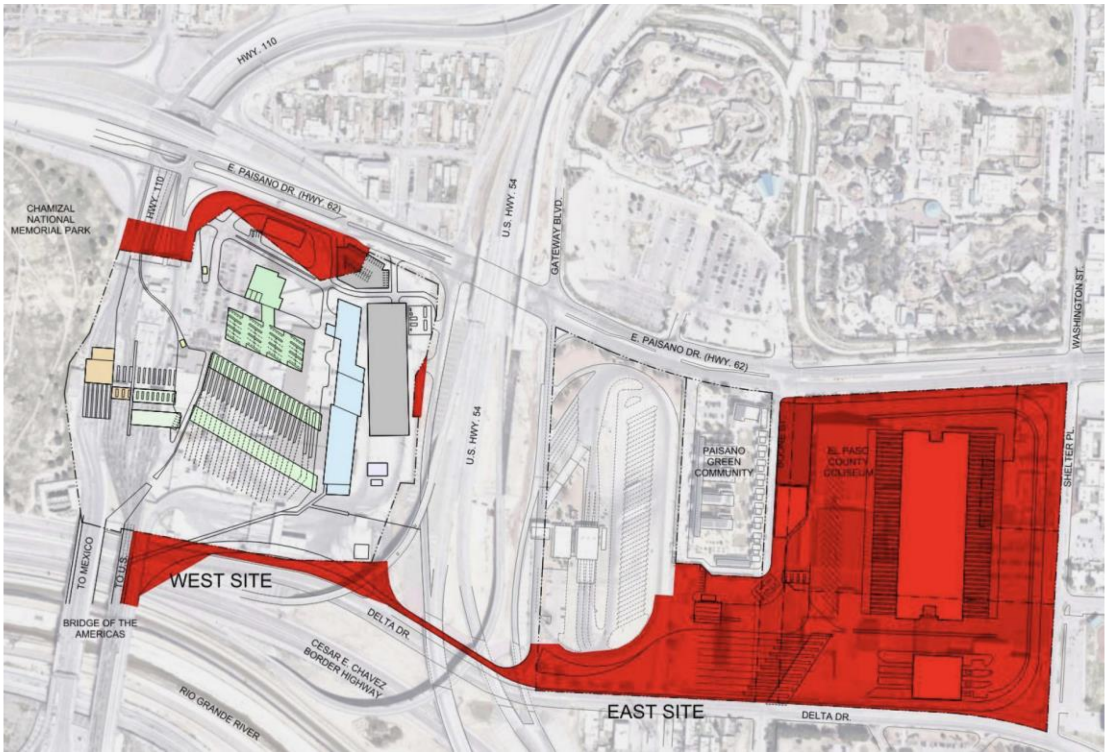


Figure 7: BOTA Reconstruction: Alternative 3, source: GSA, 2023

Alternative 4 is to be seen in Figure 8. In this scenario, commercial traffic is removed from BOTA entirely, and the commercial flows shall be redistributed to other POEs in the area, meaning Ysleta-Zaragoza, Tornillo, and Santa Teresa. Minimum land acquisition is required. The implications of this variant might be crucial for traffic patterns in the area as well as the lives of El Paso citizens; therefore, it became the main concern of this thesis. The simulation provided answers about the feasibility of such a design and what could be done to minimize the risks and ensure the project has a chance of succeeding. Chapter 5 onwards deals with the topic in detail.

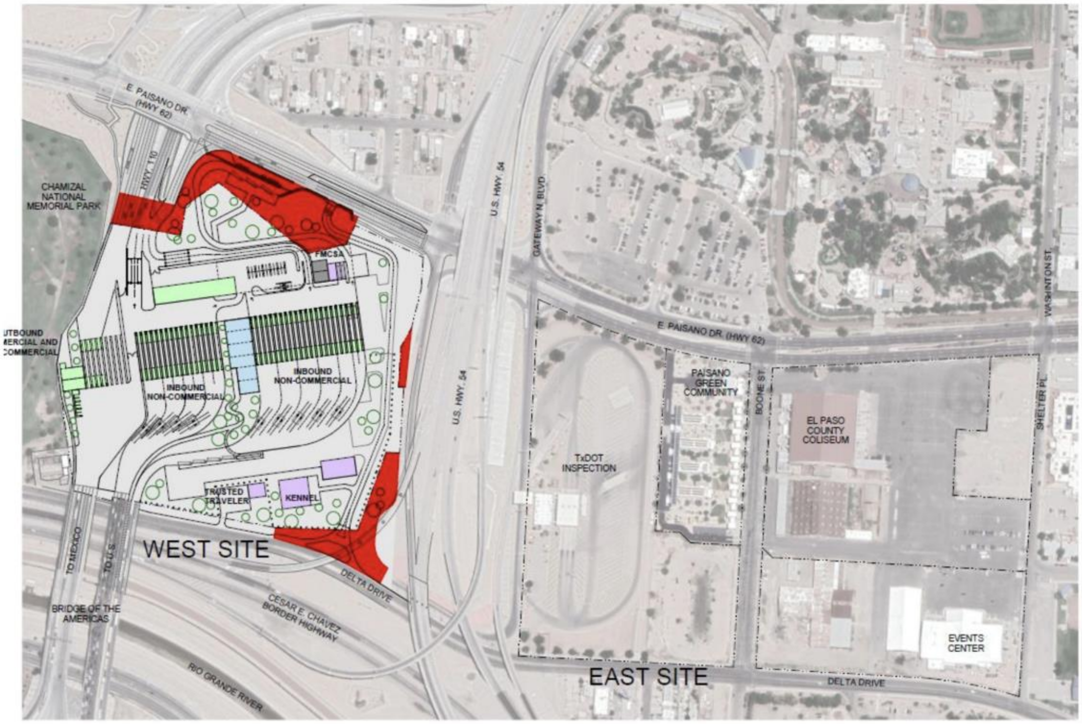


Figure 8: BOTA Reconstruction: Alternative 4, source: Karla R. Carmichael, 2023

To be complete, the National Environmental Policy Act (NEPA) process considers two additional variants that have not yet been described. One of them is **Alternative 1a,** which is basically Alternative 1 but with the condition that the facilities will be eventually transformed into a non-commercial solution, placing it somewhere in the middle between Alternative 1 and Alternative 4. As with any NEPA process, the last considered alternative is the no-action option (Karla R. Carmichael, 2023).

3.6. Smart City Initiatives and Intelligent Transportation Systems

Smart City is a term that is defined in many different ways based on the needs or goals of the organization, that formed the definition. What remains the same, though, is the focus on using the technology and, most importantly, the data that is being gathered to build resilient and sustainable communities, increase the quality of life of the individuals within them, and preserve resources for generations to come.

One of the terms that might emerge in relation to Smart Cities is the Intelligent Transportation Systems (ITS). ITS aims to utilize the data gathered by sensors and detectors along the road network to maximize its capacity while making the traffic safer by keeping the drivers informed, optimizing the traffic flow using actors, and utilizing advanced traffic management methods. ITS can be found in all areas of transportation and mobility – personal vehicles, traffic and highway management, public transportation or even parking, and many more. In the context of border management, ITS plays a crucial role as it may help harmonize the traffic flow before reaching the border as well as within the terminal itself.

A research team under the Texas Transportation Institute from the Texas A&M University has, in their 2012 report, identified four areas where ITS are utilized (Rajbhandari et al., 2012):

- Cross-border Processes,
- Tolling,
- Traffic Management and Enforcement,
- Traveler Information and Data Management.

Cross-border processes are mentioned in the context of the actual crossing of the border by commercial as well as non-commercial entities. The role of ITS lies predominantly in the RFID technology used in frequent traveler programs such as SENTRI or Ready Lane (see 3.3). The system utilizes a sticker transponder mounted on a windshield, an RFID card that carries the necessary information, and two roadside units. Additionally, FMCSA considered other technologies to expedite the inspection process.

Tolling is another area supported by the use of Intelligent Transportation Systems. They must support the money collection and tolling operations such as account management and customer service. The tolling can be realized in the form of manual collection, automatic toll collection using automatic coin machines, or an ITS solution called electronic toll collection (ETC). ETC has to be able to automatically identify and classify the vehicles, enforce violations, and process transactions. The actual implementation may vary and can be realized as an RFID transponder mounted in the vehicle and a roadside unit to read it, automatic license plate recognition, or other technologies based on budget, availability, and other limitations.

Traffic Management and Enforcement aims to optimize the traffic flows in order to maximize safety and the capacity for crossing. This can be achieved in several ways, either at the border or in the proximity. It encompasses technologies such as weigh-in-motion, video surveillance, and thermal imaging, as well as more complex systems such as real-time incident management or traffic management systems.

Traveler Information and Data Management encompasses the use of variable traffic signs, dashboards, and applications to provide traffic information to the drivers and help them make better routing decisions, which helps to moderate the traffic flow. The huge amounts of data collected by ITS can be stored and archived for further use for planning and operations in the future.

ITS not only helps safety and capacity but subsequently also reduces border wait times, which has huge economic impacts (see 3.2). The second part of the Hunt Institute study from 2023 specifically mentions which technologies might help to fulfill the reduction in wait times. Besides the already existing programs for trusted travelers, which do not necessarily affect the majority of the crossing movements, they emphasize the need to adopt technologies capable of starting the inspection process well before reaching the POE, employing self-reporting supported by license plate and facial recognition. They also suggest investing in smart infrastructure, which will speed up the crossing process and increase overall safety. They mention separating the commercial and non-commercial crossings into separate POEs, or at least separate lanes within each POE, suggesting lanes for commercial trucks with empty containers or retractable barriers as some of the viable options to achieve this. Last but not least, improvements in management practices and staffing should be considered to ensure policy consistency and avoid issues connected to the lack of workforce (Rodríguez et al., 2023).

3.7. Smart Border

The use of informatics systems in the context of effective borders can be found in the literature under the collective name “Smart Border”. There are several slightly differing ideas of what the actual Smart Border should encompass in terms of technologies and tools, but they all overlap in the ultimate purpose, which is to make the border area sustainable, safe, and as efficient as possible.

Svitek et al., in the 2019 paper, present their idea of a Smart Border solution in the El Paso – Juarez area. They base the proposal on a systems theory approach, effectively decomposing the whole border system into its components and mapping the relationships among them. They also set the border system into an environment, both near, which represents the area adjacent to the border, and distant, which is in the form of remote Border Patrol checkpoints located on major roadways in several sectors along the border. The system boundary of the actual border system is comprised of the wall equipped with different technologies and the area above and beneath it. The boundary itself has numerous subsystems, making it serve its purpose. By applying these principles, they came up with a high-level concept that can be observed in Figure 9.

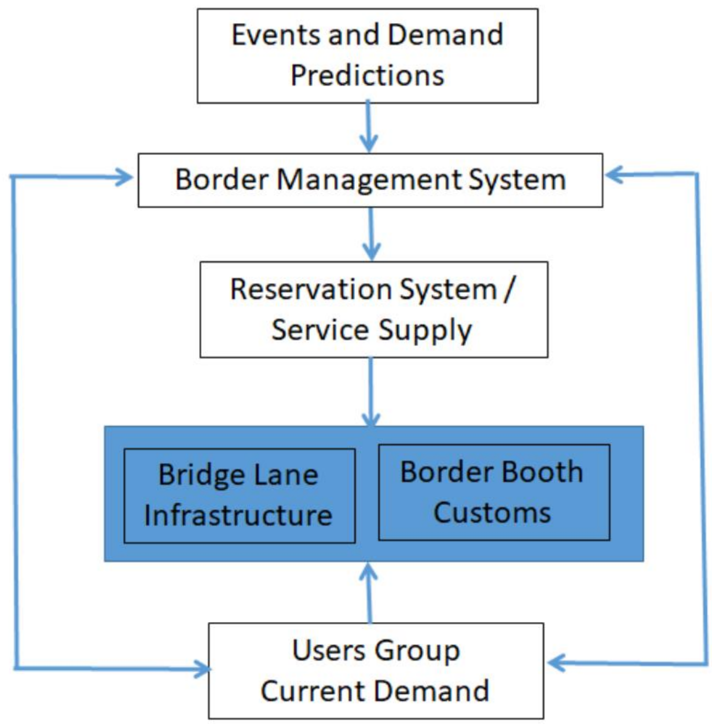


Figure 9: Example of a Smart Border Concept, source: Svitek et al., 2019

The whole concept lies predominantly in identifying the current demand by monitoring the border area, utilizing the shared data, and employing smart border management processes. The demand has to be categorized into different user groups and predicted using a model for each of the groups. The demand has to be met with supply while taking the predictions into consideration. The "supply" could be in the form of slot bookings, priority check-in, or other ways of allocating capacity. The border management component is there to propose optimal time-scheduling and the handling of different scenarios with the ability to learn from the historical data. When it comes to the actual technology that could fulfill this vision, the authors mention queue theory in coordination with ITS, implementing containerized goods transportation to relieve the POEs from commercial vehicle crossings, employing reservation systems, or introducing more efficient mobility solutions such as railway or car sharing (Svitek et al., 2019).

This aligns with a report published by Deloitte in 2014, which aims to provide guidance to governments on how to make the borders more cost-effective and secure without sacrificing mobility and negatively affecting the local communities. The report presents four different steps in transforming the ordinary border into a smart platform (Morris et al., 2014):

- **Risk-based decision-making**: Understanding that the vast majority of goods crossing the border do not pose a risk and introducing inspection and scanning technologies to detect and prevent the entry of unsuitable goods, ideally before leaving the origin. Selectivity for thorough inspections.
- **Standardization of data requirements**: Promoting cross-border cooperation and data sharing to limit the individual data collection efforts, e.g., Schengen Area. Adopting international standards for data collection.
- **Consolidate functions at the border**: Consolidating agencies to be able to address the issue of border security together with trade and immigration, e.g. CBP. Doing so will also be the step in joint use of collected data.
- **Open to commercial and community solutions**: Opening to concepts such as public-private partnership (PPP), e.g., in the form of trusted travel programs, where the government enables the private entities to undergo an initial audit and get verified in

exchange for smoother processing of shipments. Introducing these concepts on a global scale.

The first point can be further elaborated on, as the total time lost in the border inspection processes can be reduced not only by selectivity and pre-inspections but also by reducing the overall number of unknown arrivals that need to be dealt with at the POE by enabling, e.g., self-check-in. The unwanted travelers could then be moved away from the actual border to leave capacity for the wanted verified travelers (Broeders & Hampshire, 2013).

While certain critical voices arise regarding the topic of Smart Borders, engineering should inherently provide solutions, solve problems, and make it in the most efficient manner possible. Smart Borders are not just surveillance, data sharing, and policing. They can encompass many other topics and tools not yet mentioned. Examples of such may include the use of electric vehicles (EVs) for hauling the cargo across the actual border terminals, the use of truck appointment systems, or offsetting the truck traffic to the railroad using a freight shuttle system. Some of these topics are discussed in the context of the El Paso – Juarez area as part of Section 5.4.

4. METHODOLOGY

As stated earlier, the main goal of this thesis was to evaluate the impacts of closing off the BOTA POE for commercial traffic and rerouting commercial vehicles out of the El Paso downtown area. Two alternative approaches have been considered to evaluate such a scenario. The first, subsequently not used, counted on utilizing open data, i.e., datasets not bounded by any licenses which can be used and shared freely, from several sources such as the City of El Paso Open Data Portal, TxDOT, and USDOT Open Data Portal or Census or Bureau of Transportation Statistics. Each dataset was carefully evaluated and processed using the most appropriate method, e.g., Python, Microsoft Excel, or GIS for geospatial data. To be able to achieve the goal, the following framework has been established:

1. Obtain and analyze the number of commercial crossings per given period, including the trends.
2. Estimate the ratio of the state/out-of-state imports and determine the percentage of trips terminating in El Paso County.
3. Locate and pick distribution centers and warehouse areas in the vicinity of El Paso to be used as potential destinations.
4. Perform network analysis.
5. Draw conclusions.

However, there were several challenges that have been believed to have a nonnegligible impact on the results of the analysis. The main challenges were the inability to estimate the proportion of trucks heading to the adjacent warehouse facilities and out-of-state on a sufficient level of reliability and the influence of traffic patterns in Ciudad Juarez, which are not easily obtainable.

In light of the identified challenges, an alternative approach has been adopted with the help of Dr. Jeff Shelton from the Texas Transportation Institute by Texas A&M, who kindly provided an older bi-national DynusT model of the El Paso – Juárez area. This model served as the cornerstone for the analysis. The model was first developed in 2013 to support a project for the Juarez municipality (Texas A&M Transportation Institute, 2015). The following methodology has been developed:

1. Update the network.
2. Conduct O-D calibration.
3. Set up the scenario.
4. Run the simulation.
5. Perform analysis and draw conclusions.

During the research, it turned out that a similar topic has already been explored by Alfredo Sanchez in his master's thesis on the network effect of dynamic routing of commercial traffic through Ports of Entry (Sanchez, 2010). While the methodology is similar, the motivation and the desired outputs differ. The model used was not bi-national and, therefore, omitted the significance of the location of origin zones within the Juárez reason for POE choice. This thesis aims to follow up with updated data while addressing the region as one whole. The location of warehouses and maquiladoras on the Mexican side is a crucial factor in determining the demand for each POE, as the longer trip to the more distant port of entry, such as Santa Teresa, may be the prevailing factor in avoiding this crossing despite more favorable waiting times or tolling conditions (Hernandez et al., 2013).

4.1. Traffic Network

The model is built upon a network (see Figure 10) of sufficient level for mesoscopic simulation covering the vast majority of El Paso and Ciudad Juárez area. The following updates had to be made to bring the model up to date:

- Paisano Intersection can no longer be used to access BOTA,
- Northbound personal vehicle connection to Ysleta-Zaragoza POE,
- Southbound connection from Ysleta-Zaragoza to Blvd. Independencia (Juárez),
- Border West Express Way (Loop 375),
- Liberty Expressway (Texas State Highway Spur 601),
- New Canutillo Neighborhood,
- Tornillo-Guadalupe POE has been added,
- Mexican Federal Highway 2 has been extended to connect the newly added Tornillo POE,
- Loop connecting Highway 2 with Tornillo and Lib. De Cd. Juárez has been added,
- New direct connect configuration at the spaghetti bowl (I-10 connect and other updates),
- Numerous minor updates.

Additionally, the following parameters have been checked and revised on the major links to ensure alignment with the current network settings to bring the model as close to reality as possible:

- Road type,
- Traffic flow model,
- Number of lanes,
- Free flow speed (speed limit).

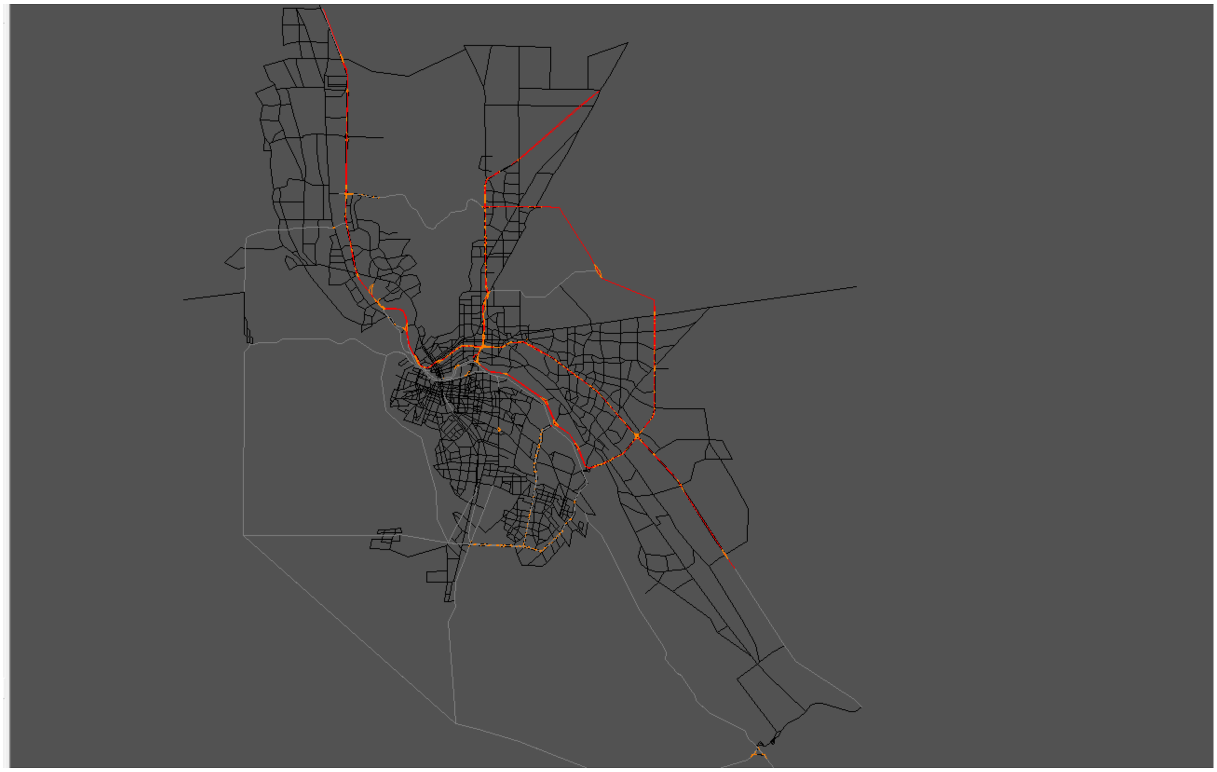


Figure 10: DynusT Modelled Network, source: DynuStudio Software

Tools such as Google Maps, Google Earth, and OpenStreet Map have been used to code the network geography and check parameters, including the number of lanes and speed limit. A more detailed view of modeled POEs is presented in Figure 11.

Each node is described by several parameters, which can be seen in Figure 12. The most important ones are the #TAZ, which signifies to which traffic analysis zones the said node pertains, and the #CTRLTYPE, which enables choosing between different modes of control, e.g., no control, four-way stop sign, two-way sign, actuated traffic control, etc. If the node poses as a potential destination, it should have the #DZONE parameter filled in, which assigns it to a certain destination zone. One node can belong to up to five destination zones or to none. Last but not least, the traffic plan shall be assigned if the actuated traffic control type is selected.

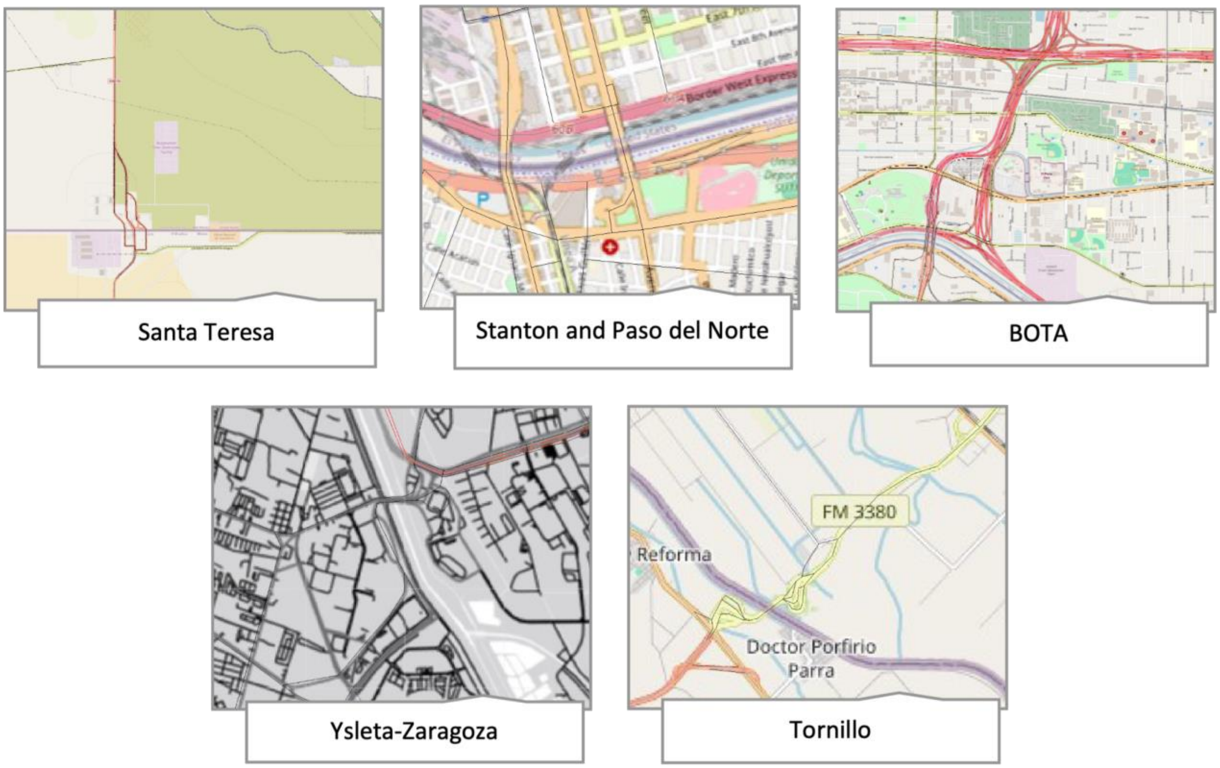


Figure 11: Modelled Ports of Entry, source: DynuStudio Software, captions created by the author

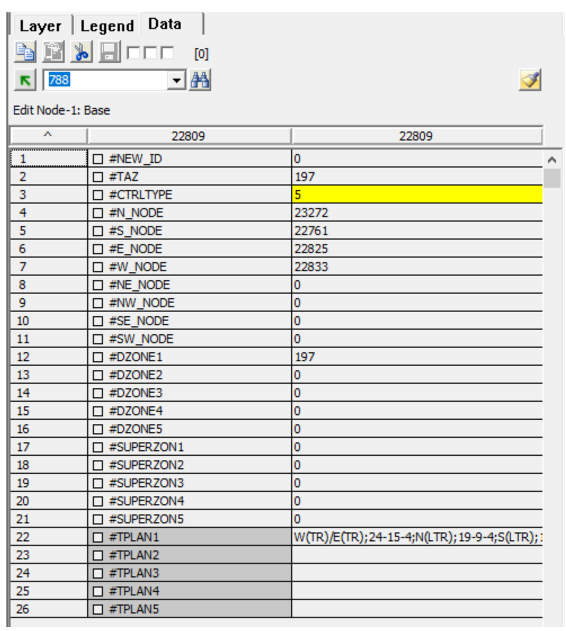
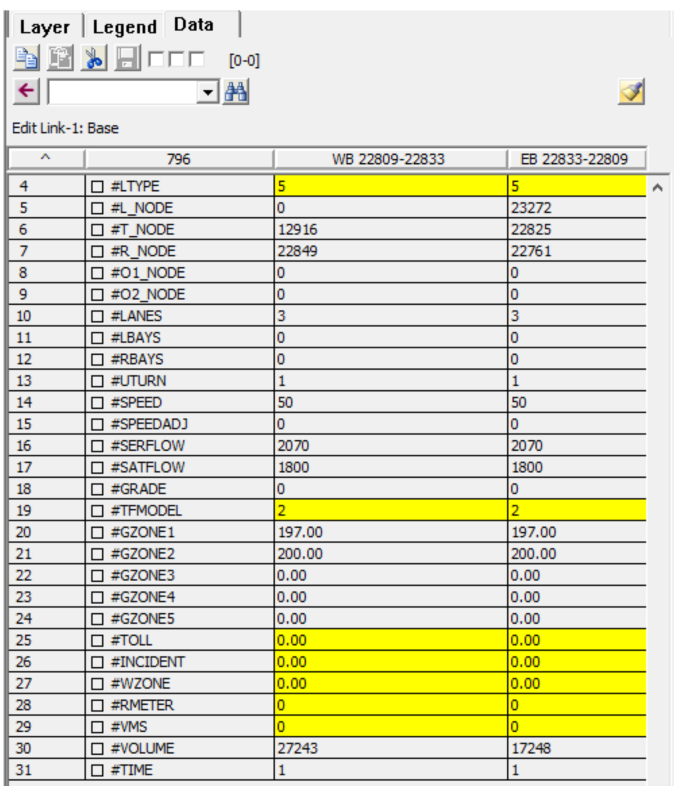


Figure 12: Node Set-up Interface, source: DynuStudio Software

The first link parameter is #LTYPE, which enables specifying what type of road is represented, e.g., highway, freeway, or arterial. This parameter does not affect the behavior of the vehicles on the network. Then, the number of lanes must be specified, including left-turn and right-turn bays, if applicable. Another important parameter to set up is the speed, which would equal the free flow speed, in this case, the speed limit for the certain link. Saturation flow of 1,800 pc/h/lane, the default value, was used throughout the model. The parameter #TFMODEL has to be selected correctly. For this model, there are three predefined models: freeway, arterial, and bridge. The #GZONE parameter enables assigning the node to a generation zone in case it falls under an area that generates trips. Links serve as trip generations, while nodes serve as the destinations. Optionally, incidents or tolls may be set up. Volume and time shall remain blank. These get populated after calibration and run. All fields can be observed in Figure 13.



^	796	WB 22809-22833	EB 22833-22809
4	#LTYPE	5	5
5	#L_NODE	0	23272
6	#T_NODE	12916	22825
7	#R_NODE	22849	22761
8	#O1_NODE	0	0
9	#O2_NODE	0	0
10	#LANES	3	3
11	#LBAYS	0	0
12	#RBAYS	0	0
13	#UTURN	1	1
14	#SPEED	50	50
15	#SPEEDADJ	0	0
16	#SERFLOW	2070	2070
17	#SATFLOW	1800	1800
18	#GRADE	0	0
19	#TFMODEL	2	2
20	#GZONE1	197.00	197.00
21	#GZONE2	200.00	200.00
22	#GZONE3	0.00	0.00
23	#GZONE4	0.00	0.00
24	#GZONE5	0.00	0.00
25	#TOLL	0.00	0.00
26	#INCIDENT	0.00	0.00
27	#WZONE	0.00	0.00
28	#RMETER	0	0
29	#VMS	0	0
30	#VOLUME	27243	17248
31	#TIME	1	1

Figure 13: Link Set-up Interface, source: DynuStudio Software

Additionally, traffic signals had to be coded. For this, the Traffic Signal Timing Sheets for El Paso intersections have been provided by Dr. Shelton. These contain information about the different signal plans, phase sequencing, cycle lengths, etc. For the purpose of the simulation, the traffic plan, which is active for most of the time, usually weekday off-peak hours, has been used.

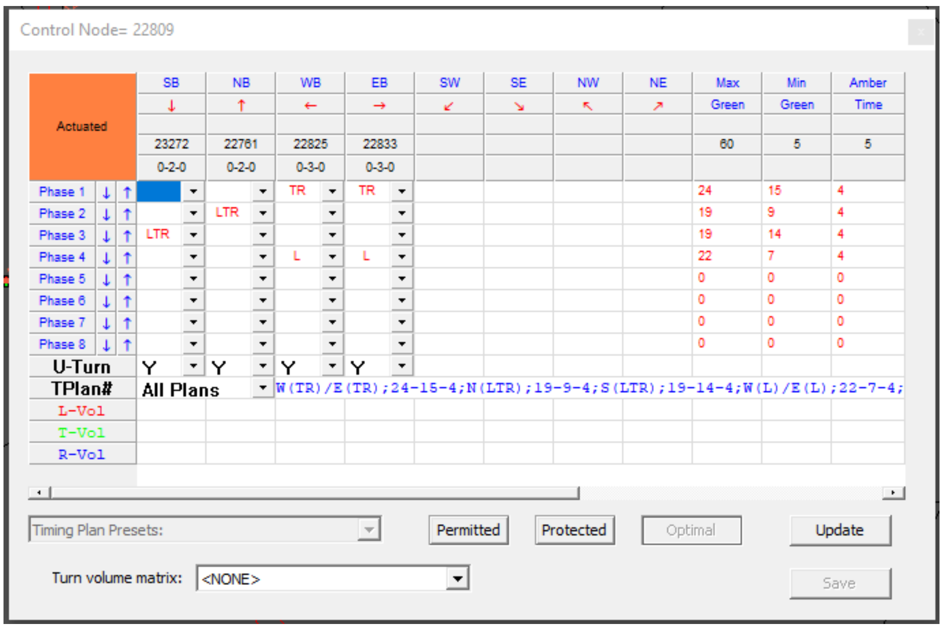


Figure 14: Signal Plan Set-up Interface, source: DynuStudio Software

Figure 14 displays the interface that is used to set up the traffic signal for a certain node, in this case, node number 22809. Based on the intersection geometry, the adjacent nodes are displayed as SB (southbound), NB (northbound), WB (westbound), and EB (eastbound). Each phase of the traffic plan is signified by a row. In each phase, for a certain direction, the L (left), T (thru), R (right), or their combination is selected to signify the current right of way. Each phase has defined maximum and minimum green times, as well as amber time. For each node, up to five plans can be predefined, but since this model covers a wide area, only one plan for each intersection has been used for this specific model.

4.2. Tolling

Although the toll rates seem to be relatively low, many of the travelers cross the border repeatedly, even several times a week. Therefore, the compound effect of these payments needs to be taken into consideration as it may have a non-negligible impact on the decision process behind which POE to use. Though this behavior cannot be directly projected into the model, it appears indirectly through the calibration process as the utilization of each POE. The tolls at the current network can be observed in Table 2.

Table 2: Toll Rates, source: created by the author in MS Excel

POE	SB Toll (USD)		NB Toll (USD)	
	POV	Truck	POV	Truck
Santa Teresa	0.0	0.0	0.0	0.0
Paso del Norte	-	-	2.2	-
Stanton	3.5	-	0.0	-
BOTA	0.0	0.0	0.0	0.0
Ysleta-Zaragoza	3.5	5.5 - 9 (+4.5 / axle)	2.2	7 - 23.4
Tornillo	0.0	0.0	2.2	7 - 23.4
Data Source	https://pdnuno.com/border-crossings			
	https://puentesfronterizos.gob.mx			

This table presents the individual ports of entry and their toll rate in both the southbound and northbound directions. The provided values represent a range rather than a standalone value based on the crossing vehicle type. Additional details on toll rates can be found on the websites listed in the data source field. For POVs, when crossing from the USA to Mexico, Stanton, and Ysleta bridges are tolled. In the opposite direction, toll is not collected at Stanton; instead, it is collected at Paso del Norte and Tornillo. For the trucks, it is analogical, except for Stanton and Paso del Norte, where trucks are not allowed to enter. For commercial vehicles, the toll varies with the type of vehicle, load, and number of axles. For the simulation, all trucks are considered to be three-axle trucks (one single axle and two tandem axles), which corresponds to the toll of $13.50 calculated as $9.00 for a two-axle commercial truck and an additional $4.50 per the third axle in the southbound direction and $7.00 in the northbound respectively. To be able to dynamically evaluate whether the drivers prefer a longer drive with no toll or whether they are going to be paying for their trip, the value of time needs to be assigned. According to the annually updated calculation of road user costs provided by TxDOT (TxDOT, 2024b), the road user cost per vehicle hour for POVs is $37.20. For trucks, it is $52.75. Additional adjustments should be made based on wages or the cost of living in the El Paso area. However, to simplify the process, the values were just rounded down to $35.00 and $50.00.

4.3. O-D Calibration

In the standard four-step traffic model, the following steps need to be conducted:

- Trip generation (zones with origins and destinations),
- Trip distribution (trips distributed between O-D pairs),
- Mode choice (trips splits into different transport types),
- Assignment.

The network already has predefined Traffic Analysis Zones (TAZs) and the pertaining demand, which were set up based on the data available at the initial creation of the model in 2013. To account for the change over the years, the Origin-Destination (O-D) calibration had to be conducted. The inputs for the calibration are the actual Annual Average Daily Traffic (AADT) flows for each link of the network based on 2022 data. For El Paso, the data is obtainable from the TxDOT Traffic Count Database System (see Figure 15).

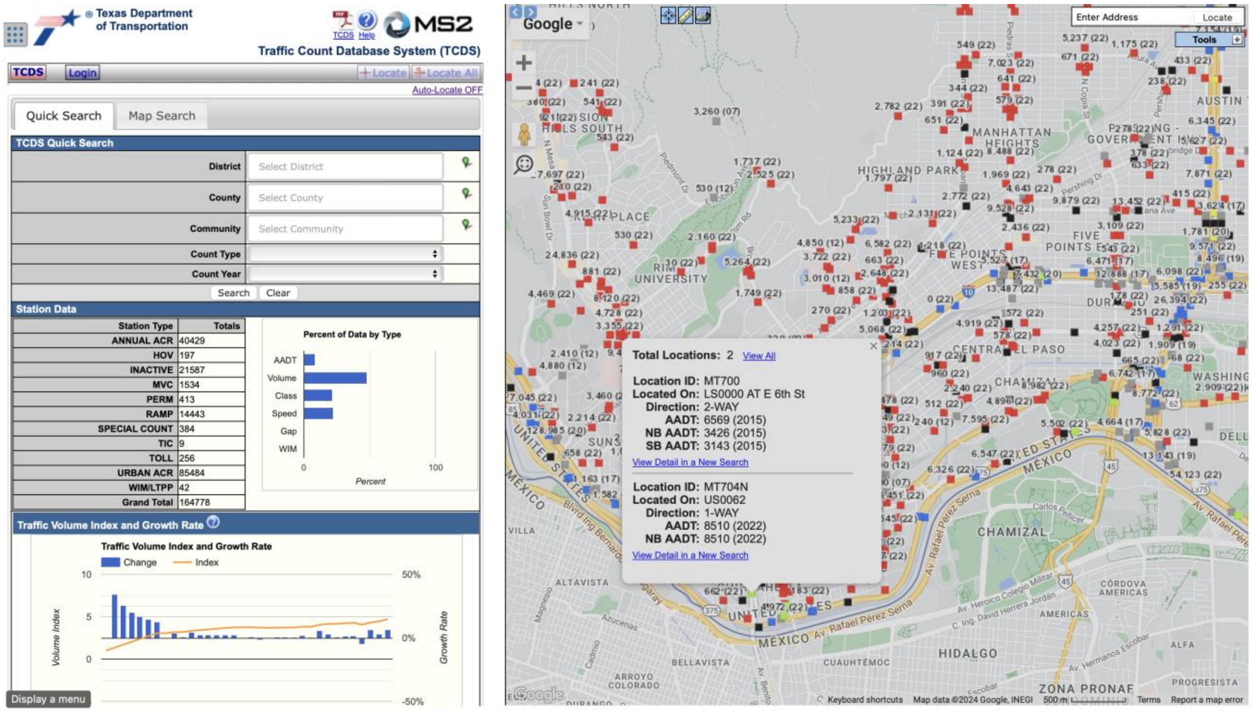


Figure 15: Traffic Count Database System, source: https://txdot.ms2soft.com

For Juárez, the AADT for each link has not been published. However, there are counts from 2023 available for each highway coming to the perimeter of the city, which, together with the border crossing data, can provide sufficient estimates. The Mexican highway traffic counts are available through the Datos Viales platform under the Dirección General de Servicios Técnicos of the Mexican government (see Figure 16). More granular data was requested from this organization unsuccessfully.

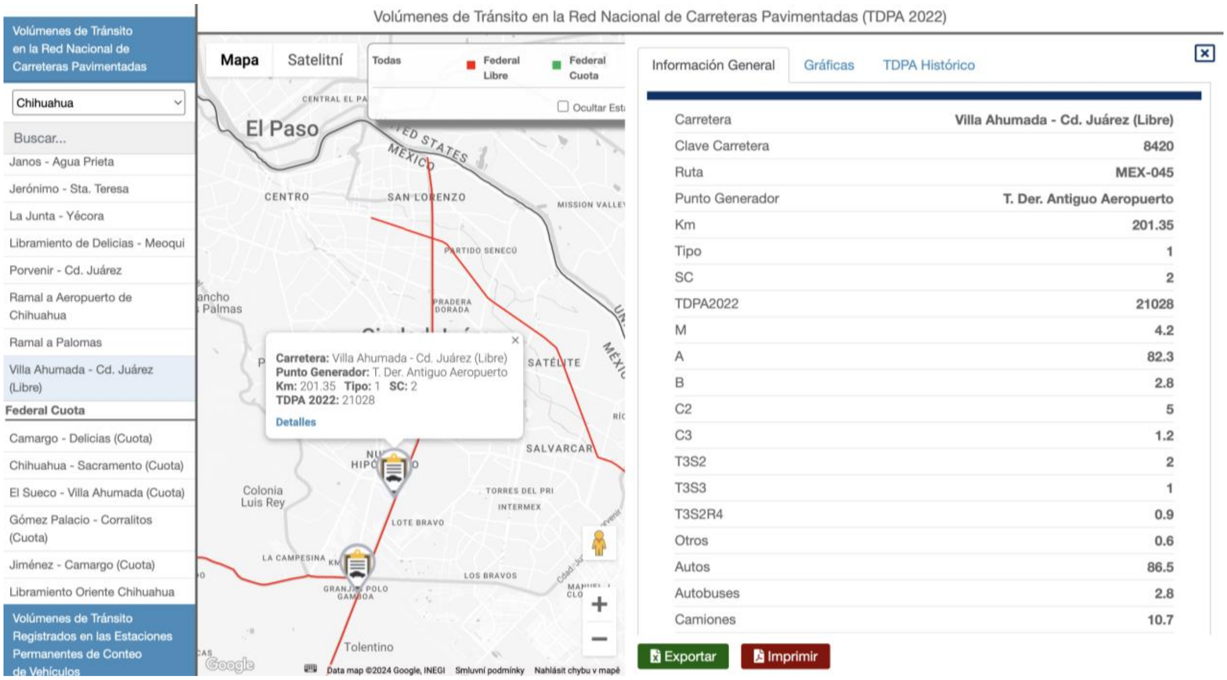


Figure 16: Datos Viales Platform, source: http://datosviales2020.routedev.mx

The border crossing data is not available as a complete dataset. However, it could be retrieved and integrated from several sources. The main source of data is the PDN Uno website (Available: https://pdnuno.com/data/crossings), which is an initiative of the International Bridges Department. They provide crossing counts for personal vehicles and trucks by aggregating data from CBP and the City of El Paso International Bridges Department. At the time of calibrating the model, the yearly figures for northbound crossings were available for the whole year of 2022 and a part of the year 2023. For southbound crossings, the data was available for the full year of 2023; however, it was only available for selected crossings. The missing flows have been estimated based on data available from the TxDOT Traffic Count Database System. The final values can be observed in Table 3 and Table 4, with the 2023 flows marked with an asterisk. The estimated values are colored blue to distinguish them from the directly available data. The yearly data has been averaged to daily crossings based on the number of opened days per year, which differs for commercial and personal vehicles. This approach is in line with USDOT's AADT simple average method (USDOT, 2018).

Table 3: Personal Vehicles Crossing Counts, source: created by the author in MS Excel

Personal Vehicles						
POE	Days per Week	Days Opened	Yearly (2022)		Daily	
			SB	NB	SB	NB
Santa Teresa	7	365	N/A	645,430	1,612	1,768
Paso del Norte	7	365	-	4,164,585	-	11,410
Stanton	7	365	1,894,578	1,510,077	5,191	4,137
BOTA	7	365	N/A	4,191,354	18,197	11,483
Ysleta-Zaragoza	7	365	2,656,023	3,129,903	7,277	8,575
Tornillo	7	365	N/A	352,370	972	965
Data Source	cbp.gov/about/contacts/ports					
	https://pdnuno.com/data/crossings/personal-vehicles					
	https://txdot.ms2soft.com					

Table 4: Truck Crossing Counts, source: created by the author in MS Excel

Trucks							
POE	Days per Week	Days Opened	Dataset Months	Yearly 2022 (*2023)		Daily	
				SB	NB	SB	NB
Santa Teresa	5	260	12	N/A	159,570	846	614
BOTA	6	312	12	N/A	161,405	820	517
Ysleta-Zaragoza	6	312	12	*636,421	649,561	2,040	2,082
Tornillo	7	365	2	N/A	*6,208	108	102
Data Source	cbp.gov/about/contacts/ports						
	https://pdnuno.com/data/crossings/cargo-trucks						
	https://txdot.ms2soft.com						

The final demand for crossing in the southbound direction differs slightly from the demand in the northbound direction. For trucks, there is approximately 13 % more traffic crossing from the USA to Mexico. For POVs, it is the other way around. While the flows, in reality, do not have to equal precisely, it is probable that there is some bias introduced into the traffic counts due to the fact that a uniform ratio between POVs and trucks has been selected as 90/10, even for the border crossings for which other data than AADT's was not available. For example, to match the truck volumes in the southbound direction to the northbound, the flows through Santa Teresa, BOTA, and Tornillo would each need to be lower by around 39 % since all northbound flows, as well as Ysleta southbound flows, are given. While this makes sense in terms of flow conservation, El Paso is not a closed system. Considering there is no publicly available data to validate the southbound figures, the AADT method has been used to approximate the traffic flows and to calibrate the network.

The actual calibration is done automatically by provided Python and MATLAB scripts. It takes the initial O-D matrix and, based on the actual input flows, adjusts the input demand for a specified number of iterations, aiming to reduce the error between the input traffic flows on the selected links and the outputs of the simulation. The workflow of the calibration software, as pictured in the provided documentation, can be observed in Figure 17.

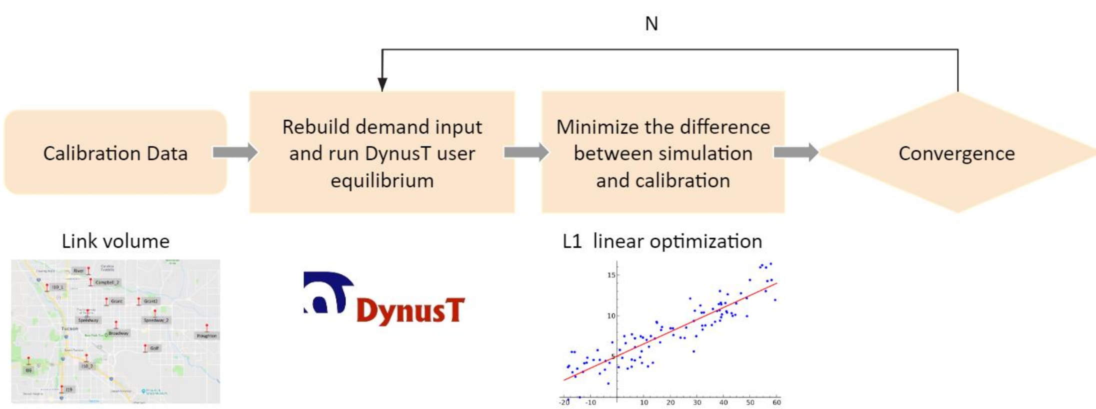
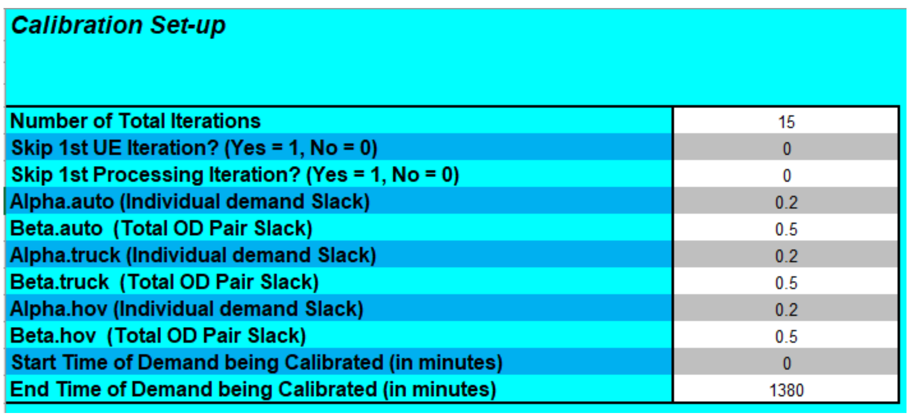


Figure 17: Calibration Methodology, source: Metropia Inc., 2020

The desired settings for the calibration process are set up in an Excel spreadsheet, which contains several sheets and is one of the inputs for the calibration workflow. The first sheet enables the changing of several parameters of the calibration process. The form can be observed in Figure

18. It is possible to select the number of iterations. Naturally, the higher the number, the higher the possibility of getting more accurate results. However, it is a good practice to continuously observe the error in each iteration as, at some point, it may not be getting any smaller due to limitations in the network. The other settings include skipping first iterations if the calibration or simulation has been previously run, the percentage that the O-D pairs for each vehicle type can change, and the run time of the simulation. For further information on the parameter values, the user guide shall be consulted (Metropia Inc., 2020).



Calibration Set-up

Number of Total Iterations	15
Skip 1st UE Iteration? (Yes = 1, No = 0)	0
Skip 1st Processing Iteration? (Yes = 1, No = 0)	0
Alpha.auto (Individual demand Slack)	0.2
Beta.auto (Total OD Pair Slack)	0.5
Alpha.truck (Individual demand Slack)	0.2
Beta.truck (Total OD Pair Slack)	0.5
Alpha.hov (Individual demand Slack)	0.2
Beta.hov (Total OD Pair Slack)	0.5
Start Time of Demand being Calibrated (in minutes)	0
End Time of Demand being Calibrated (in minutes)	1380

Figure 18: Calibration Set-up Form, source: DynusT Matrices Estimation Software Package

The actual calibration values are then entered into three separate sheets (see Figure 19), each for a different vehicle class. The three available classes are low-occupancy personal vehicles (autos), trucks, and high-occupancy vehicles (HOV). Each row has a unique value that does not correspond to the link ID from the network. The links are matched based on a start and an end node. Each direction has to be listed separately. For each node pair, the average daily traffic flow based on the above-mentioned sources has been entered. Most of the flows have been separated by direction. For the few which have not, the counts have been split 50/50. This division does not introduce any significant inaccuracy. Based on the sample used for calibration, the values tend to be, on average, within the 10 % band of the mean value, which, considering the number of these links, does not have a major impact on the simulation. The Mexican data provided a distinction between trucks and personal vehicles, while the data from the USA provided only the total counts. Based on consultation with Dr. Shelton, the split between personal vehicles and trucks was calculated to be 90/10, which represents the usual observed distribution on the El Paso Network. The HOVs have not been considered since El Paso does not have any infrastructure, such as HOV lanes, which would distinguish them from low occupancy vehicles. The POEs have been calibrated to allow only the appropriate vehicle type for the appropriate link, if separated.

	A	B	C	D	E	F	G
1	SL ID	From Node	To Node	Traffic Counts	Start Time	End Time	Data ID
2	1	95582	10322	249	0	1380	
3	2	10322	95582	233	0	1380	
4	3	95699	94969	163	0	1380	
5	4	94969	95699	150	0	1380	
6	5	60263	91572	809	0	1380	
7	6	91572	60263	809	0	1380	
8	7	10410	10378	138	0	1380	
9	8	10378	10410	19	0	1380	
10	9	63885	63829	1468	0	1380	
11	10	63789	63877	1762	0	1380	
12	11	63805	63877	1501	0	1380	
13	12	63885	63813	1579	0	1380	
14	13	58256	61992	2932	0	1380	
15	14	61992	58256	2834	0	1380	
16	15	60979	61019	1861	0	1380	
17	16	61019	60979	1938	0	1380	
18	17	61570	60987	2365	0	1380	
19	18	60987	61570	2365	0	1380	
20	19	58088	57661	2856	0	1380	
21	20	57661	58088	2409	0	1380	
22	21	58152	93065	5473	0	1380	
23	22	58176	93062	4501	0	1380	
24	23	92545	92466	4158	0	1380	
25	24	92465	92546	4886	0	1380	
26	25	92540	64348	711	0	1380	
27	26	64348	92540	711	0	1380	
28	27	93084	93083	2798	0	1380	
29	28	93083	93084	2798	0	1380	
30	29	92431	89380	2047	0	1380	
31	30	89380	92431	2185	0	1380	
32	31	92567	92568	11468	0	1380	
33	32	92583	92584	11020	0	1380	
34	33	92385	92387	2051	0	1380	
35	34	92388	92386	2056	0	1380	
36	35	92414	84365	6654	0	1380	
37	36	84365	92414	6344	0	1380	
38	37	95703	95701	3511	0	1380	

Calibration_Setup | Auto_Calibration_Links | Truck_Calibration_Links | HOV_Calibration_Links

Figure 19: Sample Calibration Sheet, source: DynusT Matrices Estimation Software Package

For calibration, 135 links have been chosen. The focus has been to match the flows most closely on the interstates and highways, which serve as important freight corridors. Additionally, all the ports of entry and their arterials have been included in the calibration files to make sure the volume coming through each of the crossings represents the reality as truly as possible. The selected calibration points (links) can be seen in Figure 20. The data obtained from the USA is colored red, and the Mexican data is colored green. The calibration has been run approximately 170 times. However, as the model was continuously changed and improved, the results are the output of the final 40 iterations of the calibration process. The O-D matrices produced in this run were used in the final simulation.

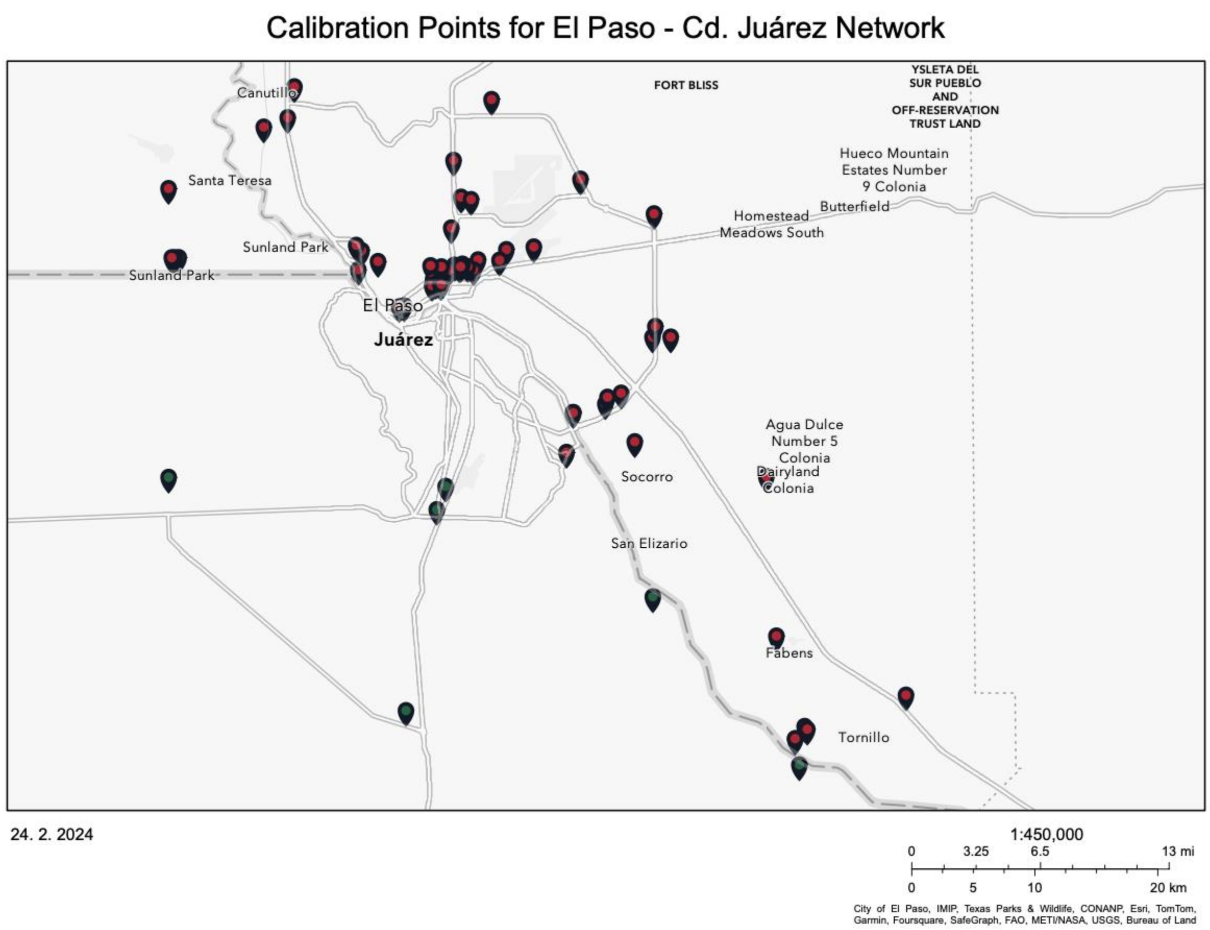


Figure 20: Calibration Points, source: created by the author in ArcGIS

The results of the calibration process can be observed in the tables and figures below. Table *5* provides the observed (AADT) and calibrated flows and their difference as an absolute value.

The error is reasonable for most of the southbound and northbound crossings. The only major outlier is the exaggerated number of northbound crossings through Stanton. Its position directly in the downtown area makes it very attractive, and although it houses only one lane in the USA-bound direction, it is available for SENTRI cardholders only, which explains the high throughput despite relatively low theoretical capacity. However, this unusual setting is not projected into the simulated network, which partially contributes to the difference. Another more influential factor is the limited amount of calibration data points on the Mexican side, as these additional 2,000-2,500 vehicles have been generated in each iteration. However, they were moving between BOTA and Stanton due to dynamic routing decisions. For the purpose of this research, the impact is not as crucial, as the closure for commercial trucks will increase rather than decrease the capacity for the POVs. The difference has been considered in the final discussion. The deviation at Tornillo is a limitation of the model as this POE is situated at the periphery of the modeled network, which limits the demand for using this crossing.

Table 5: Calibration Results for POVs, source: created by the author in MS Excel

Calibration Results / Personal Vehicles						
POE	Observed		Calibrated		Error	
	SB	NB	SB	NB	SB	NB
Santa Teresa	1,612	1,768	1,540	1,765	72	3
Paso del Norte	0	11,410	0	11,410	0	0
Stanton	5,191	4,137	5,191	6,780	0	2,643
BOTA	18,197	11,483	18,188	11,941	9	458
Ysleta-Zaragoza	7,277	8,575	7,277	8,549	0	26
Tornillo	972	965	614	1,036	358	71

The statistics summary for POVs can be observed in Table 6 and covers all calibration links, not just the POEs. It shows that the total % difference between observed and simulated vehicles is 1.24%, which is reasonable. The achieved mean error, positive or negative, was 224 vehicles.

Table 6: Calibration Statistics for POVs, source: created by the author in MS Excel

Calibration Statistics / POVs	
Metric	**Value**
Total Observed	1,751,203
Total Simulated	1,729,446
Mean Error	224
Abs. Difference	21,757
% Difference	1.24%

A graphical representation of the results can be seen in Figure 21, where the difference between the first and the last iteration can be observed. The horizontal axis displays the observed AADT values, which are plotted against the calibrated flows, which are the outputs of the calibration. It shows that the vast majority of calibration points are within the 10 % band of the red lines. There are a few outliers. Two of them are the Stanton and Tornillo POEs mentioned above. The rest are at links situated outside of the border crossing area. The green points represent the flows before calibration, and the purple points show the final iteration used in the simulation.

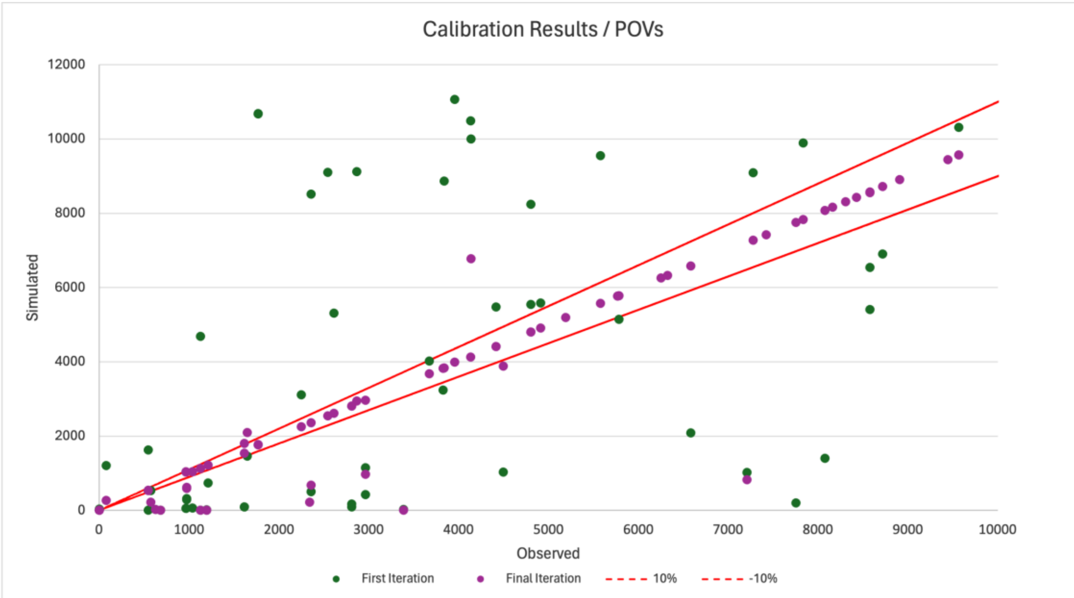


Figure 21: Calibration Results for POVs, source: created by the author in MS Excel

The truck results can be observed in Table 7. Most links at the POEs are calibrated nearly perfectly for both southbound and northbound crossings. Similarly, as with the POVs, the Tornillo POE shows slightly weaker demand in the southbound direction. While this difference is outside of the 10 % band and, therefore, is significant in terms of this port of entry, it does not substantially affect the overall results. Tornillo does not operate near its designed capacity, and 17 trucks, from the macro point of view, are not influential. Also, the discrepancy is in the southbound direction, which usually is not the major issue. The delay tends to be in the northbound direction, crossing from Mexico to the USA. The statistics summary in Table 8 uncovers a 3.97 % difference between overall observed and simulated flows, slightly worse than for the POVs but still very accurate. The mean error totaled 66 trucks. Figure 22 supports the statistics, with most of the values being in line and just a few outliers.

Table 7: Calibration Results for Trucks, source: created by the author in MS Excel

Calibration Results / Trucks						
POE	Observed		Calibrated		Error	
	SB	NB	SB	NB	SB	NB
Santa Teresa	846	614	846	611	0	3
Paso del Norte	0	0	0	0	0	0
Stanton	0	0	0	1	0	1
BOTA	820	517	820	517	0	0
Ysleta-Zaragoza	2,040	2,082	2,040	2,082	0	0
Tornillo	108	102	91	101	17	1

Table 8: Calibration Statistics for Trucks, source: created by the author in MS Excel

Calibration Statistics / Trucks	
Metric	Value
Total Observed	194,956
Total Simulated	187,209
Mean Error	66
Difference	7,747
% Difference	3.97%

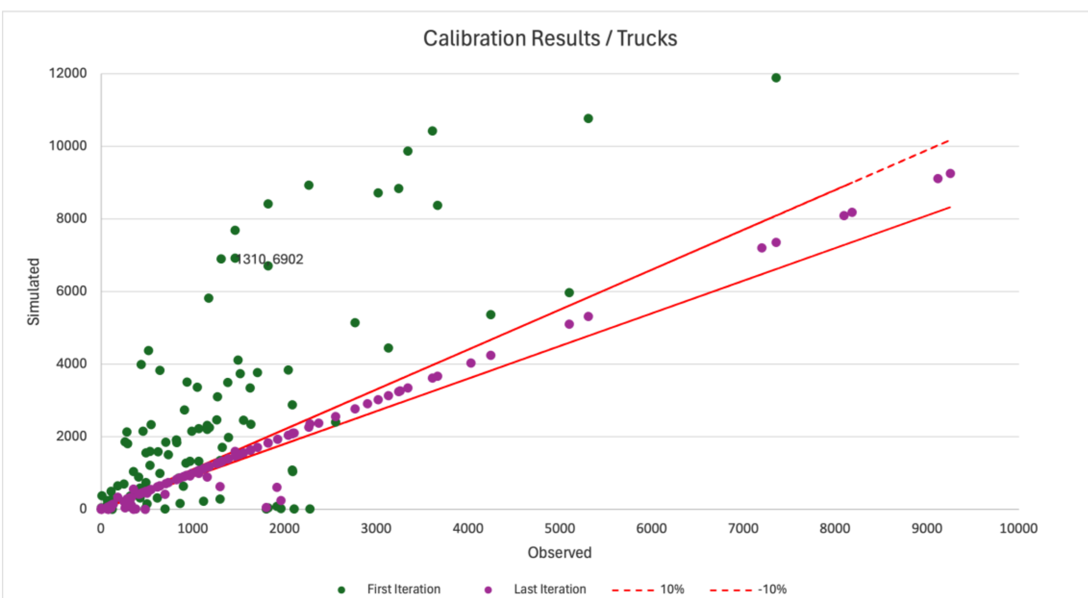


Figure 22: Calibration Results for Trucks, source: created by the author in MS Excel

4.4. Traffic Flow Models

Traffic flow models use equations to describe the relationship between the standard traffic flow measures, which are speed, density, and flow. There are different approaches. The simplest and most common is the Greenshields model, which assumes a linear relationship between speed and density under uninterrupted flow. This can be simply described as $\mathrm{V} = \mathrm{D} \times \mathrm{S}$, where V is the flow, D is the density, and S is the speed, which means that speed is a linear function of traffic density $\mathrm{S} = \mathrm{f(D)}$ with a negative slope. This behavior can be easily observed, as whenever the density increases, the cars get closer together and, influenced by each other, start slowing down. If further elaborated, a relationship between flow and density can be established, which is called the fundamental diagram.

For the simulation, three traffic flow models have been utilized, each for different link types. Traffic flow model number one should describe the behavior on a freeway. It has also been used for highways and other similar types of links. The second and the most used is for the arterials, which describes behavior on all the different roads in the neighborhoods and connectors that are not of highway or freeway type. The last traffic flow model has been used for the ports of entry at the roads coming to the bridges as well as the bridges themselves. They are set up for all the links before the inspection booths. Beyond them, type 1 and type 2 links are employed. After consultation with Dr. Cheu, the parameters for each traffic flow model were adjusted to match the traffic behavior of the respective road type. The final traffic flow model curve for each vehicle class can be observed in Figure 23 and Figure 24. For the bridge model, the maximum speed of 25 mph has been selected. The jam density was selected as quite high at 220 pc/mi/ln. On one mile of a road, approximately 230 cars can be accommodated per lane, at five meters a car and one meter space behind and in front of each vehicle. It can be expected that the vehicles are driving closer to each other than on a standard road, thus fully using the whole capacity. Additionally, the density breakpoint has been moved to 20 vehicles per mile, and the curve has been made steeper, as it can be expected that the jam will start forming quite quickly. The shape of the curve can be adjusted by changing the Alpha and Beta parameters.

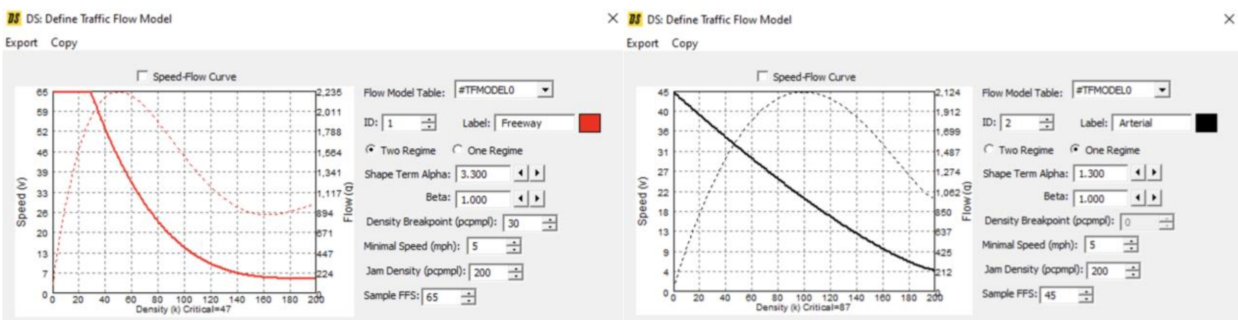


Figure 23: Traffic Flow Models for Freeway and Arterial, source: DynuStudio Software

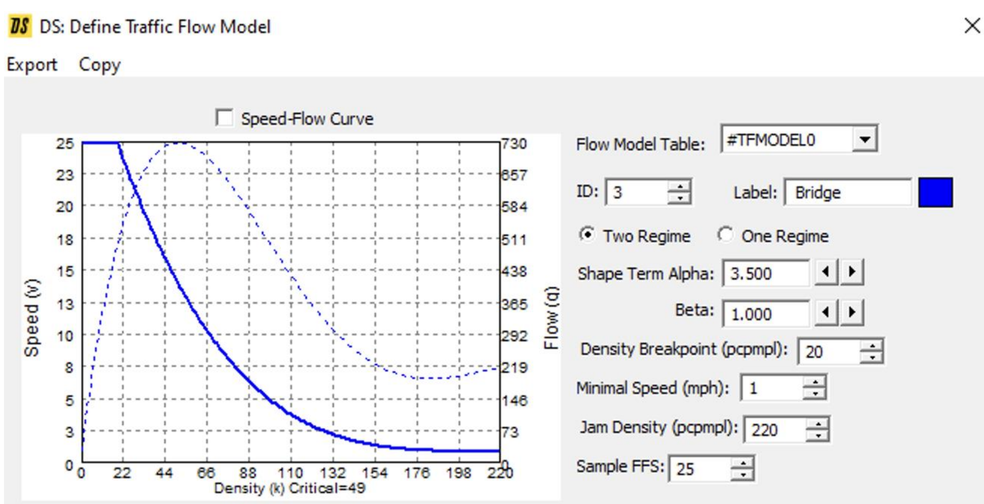


Figure 24: Traffic Flow Model for Freeway, source: DynuStudio Software

To get closer to the actual behavior at the port of entry, inspection booths have been emulated by placing stop signs at places where they should be in the network. Additionally, links adjacent to these nodes have been assigned a maximum speed of five miles per hour, wherever appropriate. Although these provisions do not enable modeling the queuing precisely, they introduce at least some form of delay, which would otherwise not be present, as the theoretical capacity at the bridges is rather high due to the high number of lanes and relatively low traffic flows. Of course, in reality, the throughput is very limited. However, the simulation covers a full 24 hours, and the model is calibrated with AADTs, so it spreads the demand throughout the whole day, which results in a relatively lower delay than in reality.

4.5. Simulation Parameters

The run of the calibrated model has been simulated in 15 runs using the parameters discussed in the previous sections. The simulation time has been one average day (24 hours / 1,440 minutes) as per the AADTs used for calibration. The simulation step has been set up to six seconds. Other parameters can be observed in Figure 25.

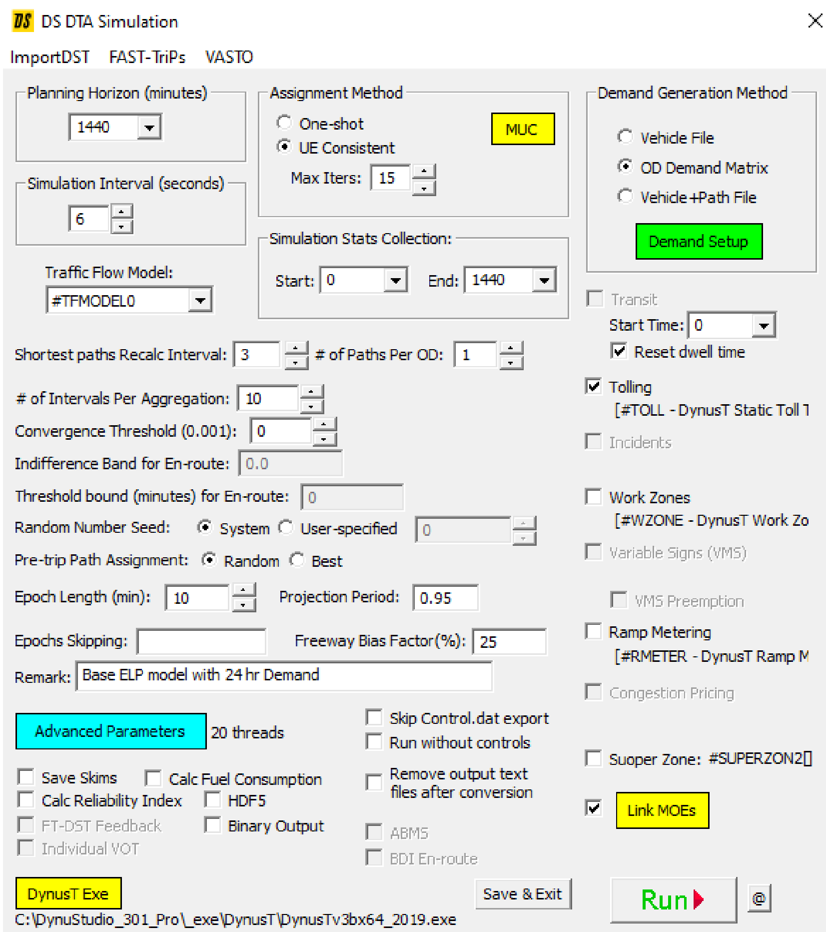


Figure 25: DTA Simulation Set-up Prompt, source: DynuStudio Software

4.6. Simulation Scenarios

Two alternative scenarios were simulated and observed in addition to the base scenario, which corresponds to the current network calibrated with 2022 values. The first observed alternative scenario was the closure of the BOTA bridge for commercial vehicles, with no other changes to the network. The links that are currently used by trucks were closed off, and the links for personal vehicles have been extended accordingly. The commercial vehicles had to find an alternative route to their destination through one of the available ports of entry – Santa Teresa, Ysleta-Zaragoza, or Tornillo. Technically, the closure was achieved by setting a toll value of $1,001 for trucks on the BOTA bridge, which prevents them from choosing this route. Although the available reconstruction plans are only in the form of a preliminary design study, the plan in Figure 8 uncovers the potential number of lanes to be used. The BOTA bridge currently offers four lanes for POVs and two for trucks in each direction. In both alternative scenarios, all 12 lanes have been made available for POVs. On top of that, in the northbound direction, the links connecting the bridge with the nodes acting as inspection booths have been extended to 16 and 22 lanes, respectively.

The second alternative scenario is a derivative of the first one, with the slight difference of removing tolling fees from the Tornillo bridge to attract more traffic, both commercial and personal. The fees at the Ysleta bridge have been considered doubled for commercial vehicles, and for POVs, the rate remained unchanged.

One aspect which has been omitted is the hours of operation of the different POEs. All crossings except for Ysleta-Zaragoza have published hours at which they operate and cannot be used outside of this time window. For the commercial crossings, the most restricting are Tornillo and BOTA, which operate between 10 a.m. to 4 p.m. and 6 a.m. to 6 p.m., respectively. In the current network arrangement, if the trucks were to be removed from BOTA after 6 p.m., they would have to go either to Ysleta or Santa Teresa, which would still operate at this time. However, the simulation uses AADTs for the calibration and not hourly values. Therefore, it would be difficult to emulate the current network closely. What is more, the opening hours could be adjusted based on demand or other operational parameters such as the number of available officers. Therefore, this aspect has been left out. It could, however, be one of the other areas worth exploring further, and it carries certain limitations mentioned in Section 5.5.

5. RESULTS DISCUSSION

This chapter contains the results of all the simulation runs. Some time has been taken to validate the base scenario to prevent the situation of using an unreliable basis for the derived alternative scenarios, which would negatively impact the validity of the results. Based on the data obtained from the simulation, the feasibility of the proposed changes has been evaluated, and several recommendations have been presented to ensure that the potential implemented scenario has the highest possible chance of success in the long term.

5.1. Base Scenario Analysis and Validation

The base scenario shows a relatively high demand for crossing in the city center area, both for commercial as well as personal vehicles. Bridge of the Americas is the most utilized for non-commercial crossings in the southbound direction, presumably because of the direct connection to the Spaghetti Bowl and, thus, the I-10 interstate, while still being reasonably close to the downtown area. It also provides the highest capacity and is free of toll, which plays a role in the routing decision-making of private individuals.

For trucks, the most utilized is the Ysleta-Zaragoza POE, despite being tolled. One of the reasons is the strong demand on the Mexican side due to the high concentration of Maquiladoras (see Figure 26), which serve both as origins as well as destinations. To validate this claim, a very rough idea of potential commercial and industry destinations north of the border can be observed in Figure 27. The zoning Plan of El Paso from the El Paso Open Data Portal (Available: https://city-of-el-paso-open-data-coepgis.hub.arcgis.com) has been loaded into ArcGIS and selected zones have been plotted onto the map, as per the provided legend.

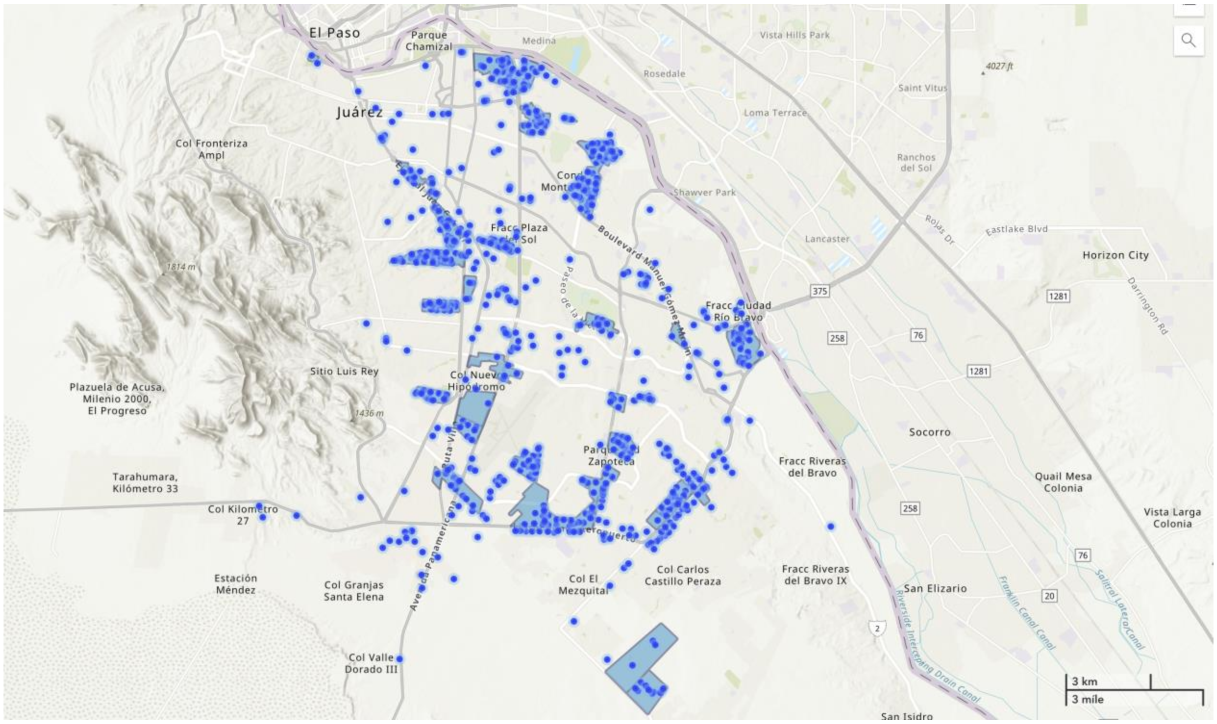


Figure 26: Maquiladoras in Cd. Juárez, source: https://www.imip.org.mx/imip/files/mapas/industria

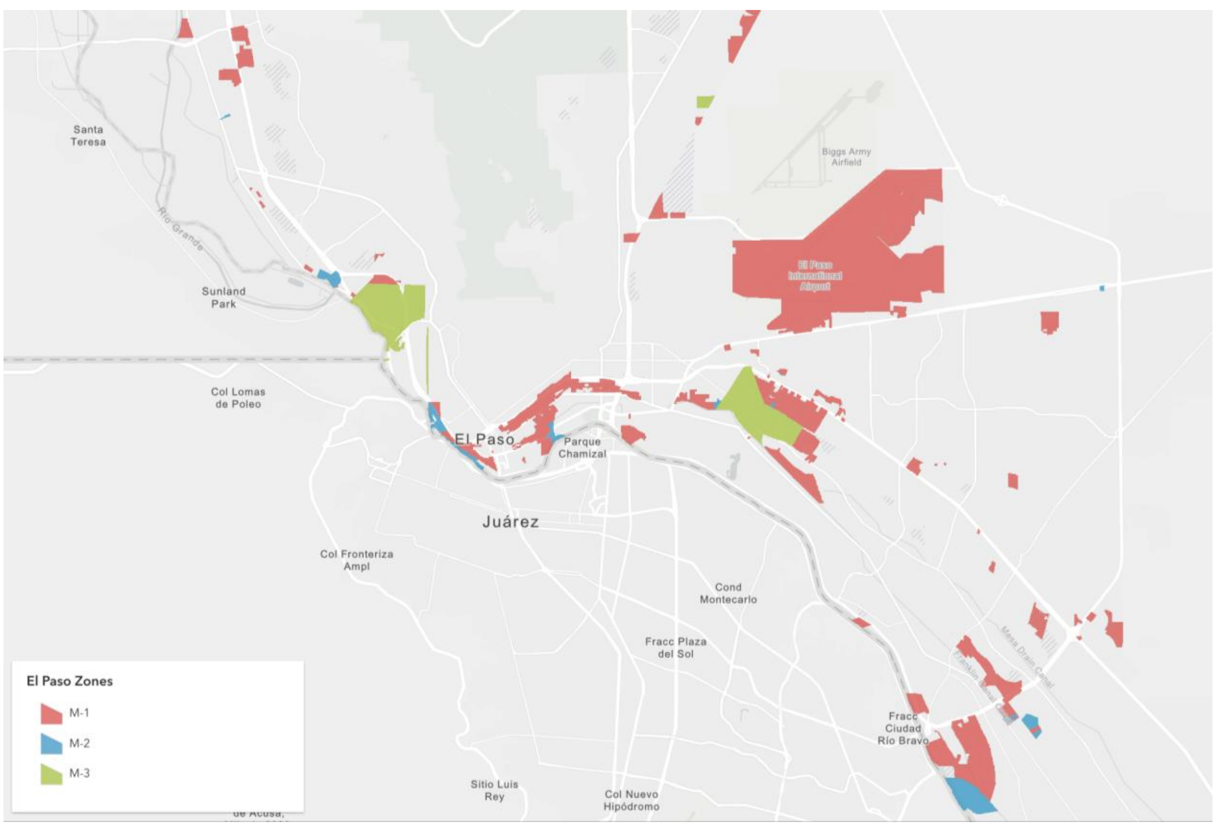


Figure 27: El Paso Manufacturing Zones, source: created by the author in ArcGIS using El Paso Open Data Portal

Zones accommodating manufacturing and warehousing are the M-1 Light Manufacturing, M-2 Heavy Manufacturing, and M-3 Unrestricted Manufacturing. The vast majority of the zones are situated around the downtown area, the area in the vicinity of the Ysleta-Zaragoza POE, along the I-10 and the airport.

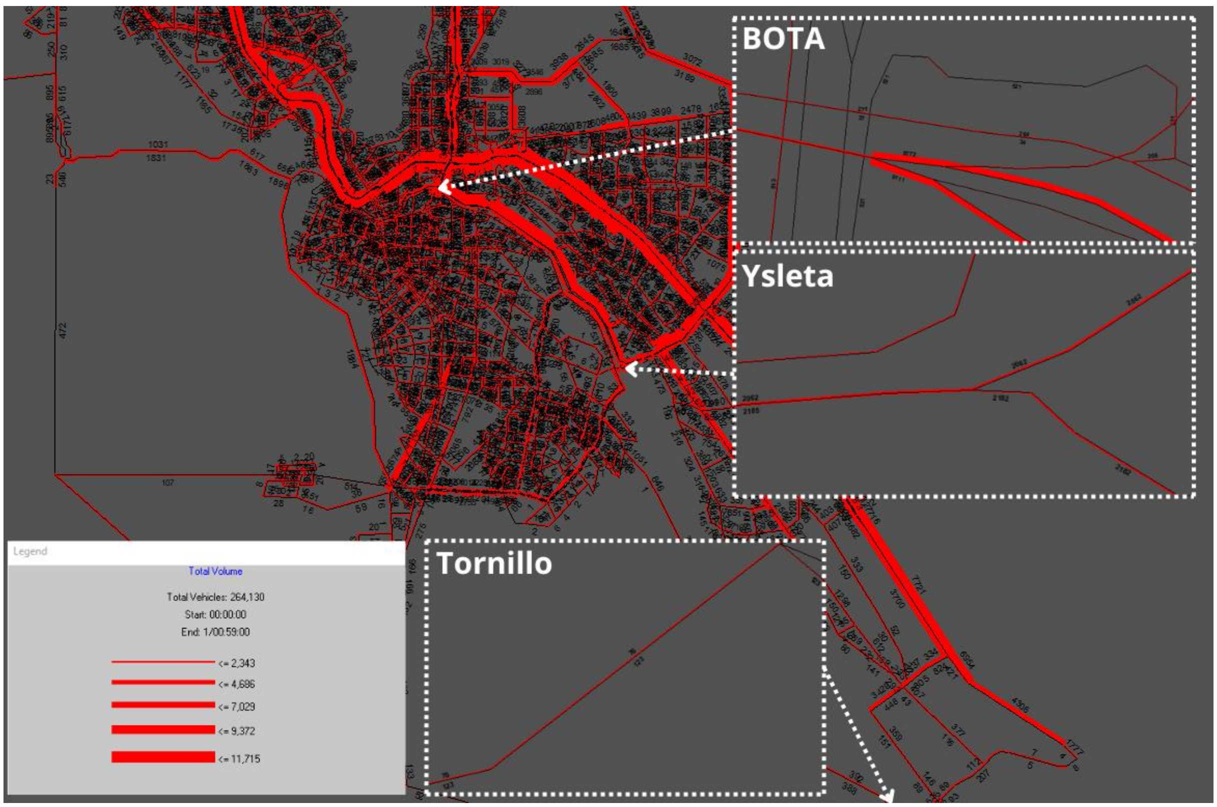


Figure 28: Truck Traffic Flows in the Simulated Network, source: DynuStudio Software, captions created by the author

Figure 28 shows the 24-hour simulated truck traffic flows of the base scenario with a detailed view of BOTA, Ysleta, and Tornillo border crossings. The highest flows, i.e., the links where the line is the thickest, can be observed along the whole I-10 and Loop 375, naturally, as those are the roadways with the highest capacity. However, other areas, such as the intersection of Alameda Ave with Loop 375 leading towards southeast and Tornillo and the adjacent commercial and industrial districts or Sunland Park in the northwestern part of El Paso, in accordance with the presented locations of manufacturing and warehousing, also show a higher concentration of trucks and trip origins and destinations, which confirms a decent level of calibration and approximation of the actual network by the model. There is a certain imbalance between northbound and southbound flows, as acknowledged earlier in the report. For more information, see Section 4.3.

5.2. Implications of Commercial Traffic Diversion from BOTA

Table 9 and Table 10 show the actual difference between the base scenario and the Scenario 1, with BOTA closed off to the commercial traffic and unchanged tolling. There are small fluctuations between the two scenarios, which occurred due to the model using dynamic assignment. Therefore, for each run, the flows might slightly differ despite being run in 15 iterations. It shows that as a result of the increased capacity of BOTA due to truck removal, a surge of 6.3 % in the southbound direction and 9.1 % in the northbound direction, respectively, has been recorded. Most of the vehicles were rerouted from the Stanton bridge. Some portion also chose BOTA instead of Ysleta. However, this capacity has been filled in by vehicles rerouting from Tornillo, therefore no major change in the northbound flows through Ysleta appeared. The total sum of rerouted flows is almost zero; therefore, no major losses occurred. Such a high number of flows was attracted mainly because of the exaggerated number of vehicles crossing at Stanton. However, in reality, some traffic would be attracted up to a point when the quality of service, meaning delay, would start deteriorating before reaching a certain level of stability. Higher capacity and throughput could be expected along with smaller delays, at least initially.

Table 9: Simulation Results for POVs (Scenario 1), source: created by the author in MS Excel

Simulation Results / Personal Vehicles								
POE	Base Scenario		Scenario 1		Difference		Change %	
	SB	NB	SB	NB	SB	NB	SB	NB
Santa Teresa	1,695	1,752	1,640	1,752	-55	0	-3.2%	0.0%
Paso del Norte	0	10,920	0	10,952	0	32	0.0%	0.3%
Stanton	5,171	7,164	4,308	6,251	-863	-913	-16.7%	-12.7%
BOTA	18,419	12,502	19,581	13,643	1,162	1,141	6.3%	9.1%
Ysleta-Zaragoza	7,240	8,420	6,977	8,431	-263	11	-3.6%	0.1%
Tornillo	611	1,071	613	894	2	-177	0.3%	-16.5%

As for the trucks, the vast majority of them picked Ysleta-Zaragoza POE for their crossing. There is a small increase at Santa Teresa, though some of the new traffic might be fluctuations between the simulation runs, as explained earlier. Although Ysleta is only slightly closer than Santa Teresa, it offers a direct connection to Loop 375 and, subsequently, I-10. It is also located in an area with a high concentration of potential destinations on both sides of the border, and the relatively small toll is not significant enough to change the drivers' routing decisions. There is also a relatively big surge of crossings through Tornillo despite being tolled in the northbound direction, over 50 %. However, it needs to be kept in mind that it translates to only 69 additional trucks coming through. What needs to be noted is that considering the current network conditions, the role of Ysleta could be stronger than indicated by the outputs of the simulation due to limited operating hours at Tornillo and Santa Teresa. After a certain hour, Ysleta is currently the only POE available for use.

Table 10: Simulation Results for Trucks (Scenario 1), source: created by the author in MS Excel

Simulation Results / Trucks								
POE	Base Scenario		Scenario 1		Difference		Change %	
	SB	NB	SB	NB	SB	NB	SB	NB
Santa Teresa	895	615	928	640	33	25	3.7%	4.1%
Paso del Norte	0	0	0	0	0	0	0.0%	0.0%
Stanton	0	0	0	0	0	0	0.0%	0.0%
BOTA	813	521	0	0	-813	-521	-100.0%	-100.0%
Ysleta-Zaragoza	2,062	2,185	2,854	2,578	792	393	38.4%	18.0%
Tornillo	76	123	57	192	-19	69	-25.0%	56.1%

If Ysleta-Zaragoza Bridge was supposed to accept all these trucks from BOTA, its throughput would have to increase by around 38 % in the southbound direction and 18 % in the northbound direction to sustain the same level of service. That is hardly sustainable considering the overall growth outlook of the cross-border traffic.

A second alternative scenario has been set up to investigate the possibility of using tolls to control the flows through individual POEs. The network is identical to Scenario 1, which means the BOTA bridge does not accept any commercial traffic. However, the toll rates at Ysleta and Tornillo have been changed to favor the choice of Tornillo over Ysleta and bring in more traffic. In Scenario 2, the toll for commercial vehicles has been doubled from \$7.00 to \$14.00 in the northbound direction and from \$13.50 to \$27.00 heading south. Tolling at Tornillo has been removed for both commercial and personal vehicles. The results for personal vehicles are to be seen in Table 11, and they uncover that the measures had little to no effect. There have been some shifts between PDN, Stanton, and BOTA, but flows have not changed drastically. The volume, which shifted from Tornillo to Ysleta in the northbound direction in Scenario 1, has returned, aligning personal vehicle flows with the current network settings, i.e., the base scenario.

Table 11: Simulation Results for POVs (Scenario 2), source: created by the author in MS Excel

Simulation Results / Personal Vehicles								
POE	Base Scenario		Scenario 2		Difference		Change %	
	SB	NB	SB	NB	SB	NB	SB	NB
Santa Teresa	1,695	1,752	1,671	1,673	-24	-79	-1.4%	-4.5%
Paso del Norte	0	10,920	0	11,356	0	436	0.0%	4.0%
Stanton	5,171	7,164	4,319	6,056	-852	-1,108	-16.5%	-15.5%
BOTA	18,419	12,502	19,588	13,364	1,169	862	6.3%	6.9%
Ysleta-Zaragoza	7,240	8,420	6,966	8,282	-274	-138	-3.8%	-1.6%
Tornillo	611	1,071	631	1,077	20	6	3.3%	0.6%

Table 12 compares truck flows between the base scenario and Scenario 2. In this scenario, the vast majority of trucks originally crossing southbound at BOTA rerouted to Tornillo because the new toll at Ysleta was already too high for them to accept, considering the predetermined value of time of $50.00. In the northbound direction, the shift has not occurred, as the doubled toll is still relatively low, though it could be prompted by increasing it enough.

Table 12: Simulation Results for Trucks (Scenario 2), source: created by the author in MS Excel

Simulation Results / Trucks								
POE	Base Scenario		Scenario 2		Difference		Change %	
	SB	NB	SB	NB	SB	NB	SB	NB
Santa Teresa	895	615	958	635	63	20	7.0%	3.3%
Paso del Norte	0	0	0	0	0	0	0.0%	0.0%
Stanton	0	0	0	0	0	0	0.0%	0.0%
BOTA	813	521	0	0	-813	-521	-100.0%	-100.0%
Ysleta-Zaragoza	2,062	2,185	2,189	2,564	127	379	6.2%	17.3%
Tornillo	76	123	750	235	674	112	886.8%	91.1%

These results have two really important implications. Firstly, it shows that simply removing the toll from Tornillo has some effect. However, it is not strong enough to attract major volumes, as is apparent from the simulation statistics. Secondly and more importantly, it unveils that by increasing the toll enough, the demand for certain crossings can be regulated by changing the toll fee. So, the best description is that the trucks have not been attracted to Tornillo because they do not have to pay tolls; rather, they were pushed out by excessively high tolls at Ysleta in the Mexico-bound direction.

The routing of the trucks followed the initial hypothesis that many of the origins and destinations are located near Ysleta on both sides of the border. Therefore, there are increased flows on Mexican Highway 2 in the direction from Tornillo towards Ciudad Juarez, and similarly, increased flows can be observed on I-10, Alameda Avenue, and Socorro Road from Ysleta towards Tornillo, meaning a relatively high number of trips pertain to the area around Ysleta and relatively low number begins or terminates in the vicinity of Tornillo itself. The traffic patterns change between the base scenario and Scenario 2 is visible in Figure 29 where the current state is displayed on the left and the theoretical simulated state with trucks using Tornillo to cross on the right. As apparent from the results, Santa Teresa POE has not been significantly affected by the changes. Using Santa Teresa to relieve Ysleta seems less likely than using Tornillo.

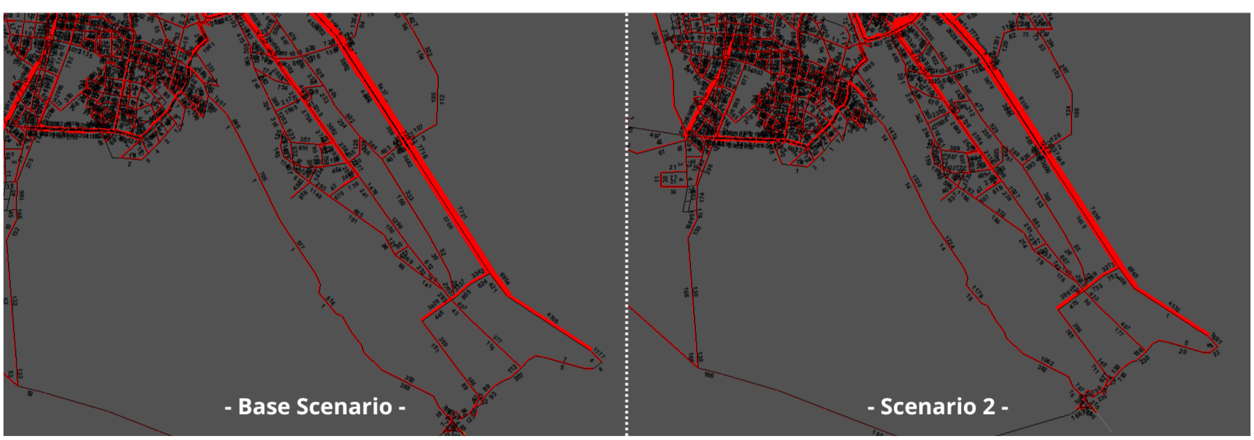


Figure 29: Commercial Traffic Patterns Change, source: DynusT Software, captions created by the author

5.3. Proposal Feasibility Evaluation

As per the previous section, if no other changes in the network were considered, the simulation suggests that the Ysleta-Zaragoza bridge would require to significantly increase throughput to keep the same level of effectiveness, meaning to at least maintain the current average delay, as it would need to accommodate all the traffic currently crossing at BOTA. While the infrastructure should be sufficient to take the additional flows, it does not address the issue of increasing demand for cross-border trade and related movements. Another potential issue might lie in the capacity of the roads leading toward the ports of entry on the Mexican side. Though their capacity has been continuously increasing, its close proximity to the city center makes only certain provisions possible. Figure 30 displays node delays of the base scenario in the morning peak hours. Obviously, the POEs are the most significant bottlenecks with black circles around them. However, many locations in downtown Juarez suffer from lower to intermediate delays as well.

While the proposal appears to be technically feasible, it needs to be coordinated with many other provisions that would help distribute the flows more evenly across the network, as expecting Ysleta to bear all the additional burden would not be sustainable. Any potential issue or system malfunction could quickly lead to a major gridlock, creating long queues and long waiting hours before being able to cross. The concrete measures that could be accepted to minimize these risks and to help the project succeed in the long term are outlined in the following section.

Figure 30: Network Delays; source: DynuStudio Software

5.4. Recommendations for Implementation

There are several provisions that could be considered in order to make this impactful change in routing possible. Based on the presented results, it became evident that while there is still some remaining capacity on the POEs, the arterials, mainly around BOTA and Ysleta, start to suffer from delays and congestion even in the current state. Considering the growing demand for crossing due to reshoring and the overall positive growth outlook as outlined in Section 1.1, the situation is not sustainable in the long term, especially because the roadway capacity cannot be increased indefinitely. Based on the results obtained and the research conducted, the following recommendations have been made. Each is then further described in more detail later in this section.

- Use the full potential of the periphery POEs in Santa Teresa and Tornillo,
- Introduce a control mechanism to drive the demand,
- Implement new organizational measures to increase throughput,
- Implement new solutions to bypass the current infrastructure limitations.

The first recommendation aims to direct the focus on the two periphery POEs in Santa Teresa and Tornillo, which currently operate well below their design capacity, especially the latter one. They both provide decent connections to highways or interstates on both sides of the border. Santa Teresa is located between Mexican Federal Highway 2 and New Mexico State Road 136, and it has a direct connection to I-10. Likewise, at Tornillo, there is a connection to I-10 on the USA side, and there is a newly built junction that enables the driver to take Highway 2 to Juarez or bypass it and head south on Highway 45 or west on Highway 2 without the need to ever enter the city of Juarez. While their remote location is the main reason for a lower demand, if used right, it could be turned into a benefit. One such idea is using this location at the edge of the city to house city logistics solutions such as Urban Fulfillment Centers. These specialized facilities aim to reduce the number of big trucks entering the inner city by providing highly automated warehousing and fulfillment and a last-mile delivery using more sustainable means of transport, such as electrically powered vehicles, thus reducing the local emissions and footprint. The semi-trailers and big trucks could cross either at Tornillo or Santa Teresa, where they would unload in one of the Urban Fulfillment Centers, and the delivery to the inner town would be carried out by smaller, more compact trucks or cars. Such arrangement enables highly optimized delivery schedules, resulting in less traffic and all related externalities. Trips not terminating in the El Paso area could still utilize I-10 to travel west or east based on their final destination. Several retailers, including big players such as Amazon, already use this area for their logistics centers.

Additionally, the North American Free Trade Agreement (NAFTA) restricts the movement of certain Mexican trucks within the outlined commercial zones, usually spanning 25 or 75 miles from the border. Therefore, it is not unusual that the trailers are picked up on either side of the border by an American-registered vehicle, which then carries the trailer through the USA (Rajbhandari et al., 2012). There are two main methods that deal with this limitation: transloading and through-trailer. However, both rely on using facilities within a narrow band on each side of the border to either cross using one trailer and transload the cargo onto another trailer after crossing from Mexico to the USA or alternatively using the same trailer all along and switching only the trucks and drivers. The short movement of trailers from the border warehouses is also called drayage to be able to distinguish it from long-haul trips. Both Urban Fulfillment Centers and NAFTA required warehouses present a great opportunity for utilizing the mostly available land around Tornillo and Santa Teresa POEs and how to increase demand for the crossing at these areas. The municipality or county should ensure there are no policies restricting such use and take necessary steps to attract public investors. The current operating hours of Tornillo would not enable such concepts to be successful. Therefore, it is essential to commit to making the crossings available for longer periods, taking into account the existing demand. The Urban Fulfillment Centers could also be financed in the Public-Private model, and while that might be difficult to achieve initially, it should be further investigated and discussed with all potential stakeholders.

The second recommendation is loosely connected to the first one as it suggests implementing some type of control mechanism that would be able to regulate the demand for certain crossings. Currently, the POEs are already equipped with RFID sensors that provide real-time traffic flow and delay data, which are, to some extent, utilized and made available through online dashboards managed directly by CBP and other entities. According to Smart City principles presented in Chapter 3, this data could be put into use by implementing a dynamic toll control algorithm that could regulate toll rates based on the current delay and demand for crossing at each POE. The simulation uncovered that increasing the toll rate plays a significant role in routing decisions and thus could be used accordingly. The road network would need to be equipped with information tables at all major roads and junctions and should display the current toll rate, waiting times, and possible recommendations for which crossing to use. The data could also be available online. Such implementations have been tested successfully in the USA as well as around the globe. One of the best-known examples is the London Congestion Charge, which penalizes drivers entering the city center at certain times by making them pay relatively high fees during peak hours (Leape, 2006).

The third recommendation is to use all available means to increase the throughput at the current crossings. While the infrastructure-based provisions might be limited, there are still organizational measures that could be introduced to optimize the flows. One such solution is the use of Truck Appointment Systems, which were originally designed for use in the maritime docks but might as well be used at border crossings. These enable booking an appointment at the port of entry for a certain time slot, effectively optimizing the flows and expediting the customs process. Certain pre-check procedures are already in use and enable truck drivers to expedite both the truck inspection and the customs process. These could be implemented concurrently, enabling better streamlined flows and supply chain.

Lastly, **the fourth recommendation** is to not be fixed on the road network, which can be extended only to a certain limit. One of the better alternatives would be to investigate the usage of rail infrastructure to conduct cross-border shipments. While the current settings make the use of trains for moving cargo from one side of the border to the other complicated and thus underused, in general, rail transportation is one of the most efficient means of transporting cargo, especially containers over medium to long distances. More effort should be directed towards possible ways of how to implement the already operating network more firmly into the cross-border cargo movements. One of the concepts specifically designed for border regions is the Freight Shuttle System, which aims to implement a privately owned and operated infrastructure to effectively transport containers through the border and to avoid the individual inspections targeted at each truck coming through the bridges. The public-private financing scheme should ensure the project is built and maintained despite the high initial costs, as the operation mode will be profit-driven. The operation would be ensured by numerous fully autonomous and electrified transporters, which would carry truck trailers or standard containers through the border. The whole customs process would be completed prior to reaching the depot on the other side, thus eliminating the unproductive time that drivers spend waiting in the queues. The concept counts on using a separated and elevated guideway, effectively minimizing the taken-up space. Such a solution could have non-negligible impacts on a number of aspects of the border crossings. Most importantly, major benefits could be expected in terms of air quality and the total time lost due to the current queues and delays.

Additionally, the current traffic patterns could be expected to change to further offset the trucks further from the city core and thus make the city more livable (S.S. Roop et al., 2011).

5.5. Limitations and Future Research

The presented results provide a reasonable idea of what would happen in the current network in case of commercial traffic diversion from BOTA to other POEs. Simulation and modeling are, from their definitions, some generalization of reality, and therefore, they provide only approximate results. The limitations have been mentioned continuously throughout the report. However, the most impactful generalization in this model is missing the exact calibration points for the Mexican links. Despite all efforts, getting this data was not possible as cooperation between the responsible organizations was required. Although it affects the accuracy of the model, it should be fairly easy to fix if the data were to become available. To this account, the El Paso MPO is currently developing a TransCAD-based Bi-National International Travel Demand Model, which should provide the most recent and accurate data on travel demand in this area. Outputs of this model could be used to update the O-D matrices, which could then be fed to the mesoscopic simulation, though it must be kept in mind that the number of TAZs will probably differ. Another less significant yet noteworthy limitation is that the operation hours of the ports have not been implemented. The reasons for that are twofold. Firstly, it is difficult to reasonably calibrate the model with certain hours of operation, considering the input for the calibration process are average daily values, not hourly. Secondly, the operation hours can change quite promptly based on the demand. Therefore, they could be considered demand-driven rather than the other way around. This limitation has impacts especially on the simulated waiting times at the border crossings as, in reality, the trucks would arrive at the border before the actual operation commences, creating a line that never really disperses throughout the day. In the model, the trucks are being let through continuously, so the queue forms in the peaks rather than being present for the whole simulation period.

As outlined in the previous section, one of the potentially promising tools to control demand for the currently underutilized Tornillo bridge might be dynamic tolling. Various control mechanisms utilizing live data could be employed and simulated to achieve better network capacity utilization and delay reduction. Such an example of data integration in Smart Cities could be a potentially very interesting topic to delve into and could be the primary focus of future research and modeling efforts. Concretely, investigating how high the toll should be to be able to control the demand is one of the potential directions. Another interesting point of view on the same topic, but more theoretical, might be investigating the ideal distribution of vehicles across all six POEs to achieve the most efficiently utilized network, or alternatively, what proportion of trucks would need to be rerouted from BOTA to other ports to achieve the highest throughput across the whole network. The model could also be adjusted to incorporate all the major planned updates to the network in the upcoming years, and using a scaled demand, the future traffic behavior could be simulated. Last but not least, DynusT provides instruments to study parameters such as node delays or travel times. These could be observed and evaluated alongside the traffic volumes observed in this thesis.

6. CONCLUSION

The GSA seeks to renovate the current BOTA port and considers several alternatives, from not introducing any changes to completely redesigning the whole area, including changing the purpose of use from mixed personal and commercial traffic to personal only. This research focused on utilizing one of the most commonly used transportation engineering methods when it comes to planning, which is simulation. For the selected scale, an opportunity presented itself, and the mesoscopic model in DynusT was updated, calibrated, and subsequently used to draw conclusions. All outlined goals have been met, including the effort to clearly document the workflow process of using DynusT for simulation to make it easier for future researchers or students to follow up on this work or to pursue their own research interests with the help of the DynusT platform. The obtained results uncovered several major insights. Firstly, it showed that if the BOTA bridge is closed off for trucks, without any other provisions, the vast majority of the flows will reroute to the nearby Ysleta port, causing a major level of service deterioration. Secondly, even though removing toll from Tornillo could have some effect, it would not be strong enough to attract traffic from BOTA. Last but not least, it unveiled that by increasing the toll sufficiently (the threshold is dependent on the value of time), the demand for certain crossings can be regulated by changing the toll, as the drivers would take a longer route to avoid paying the fee.

In the context of the long-term growing demand for cross-border transport in the Mexico-USA corridor, the El Paso region plays a crucial role as one of the most significant gateways for the cargo flows, and therefore, any changes made to the network could potentially impact the supply chains on a national scale. In light of this, each decision needs to be carefully evaluated while still retaining the ability to move forward and innovate, which are fairly opposite requirements. The idea of removing the commercial traffic from one of the most frequent crossings in the city is bold. However, when coordinated with other measures presented in Section 5.4, it could be feasible and a step in the right direction. Huge potential lies in the recently built Marcelino Serna crossing, better known as Tornillo, which is currently widely discussed, even amongst local politics, in regard to underutilization and very weak demand. Considering the demand could be shifted towards the area around Tornillo by incentivizing the sprawl of commercial and warehousing districts in the currently unused area in coordination with dynamic tolling could make the BOTA bridge commercial closure without any traffic collapses on the Ysleta-Zaragoza bridge possible. Without any additional provisions, it would need to accept all the additional load which could cause issues already in the near to intermediate future.

Considering the additional provisions, removing trucks from BOTA is a promising idea, as it would relieve the inner-city area of heavy commercial traffic and, thus, many of the externalities of transportation systems. When paired with the Urban Fulfilment Centers, all the emissions and noise associated with internal combustion engine-driven trucks would be offset to areas outside of the city, leaving the core with mainly personal and pedestrian traffic. In the long term, concepts such as the Freight Shuttle System should be explored to provide enough capacity to accommodate future growth. These might be the first in the series of steps towards a city with a modal split leaning towards public transport, which would be incentivized and positively accepted. The potentially unused area around BOTA, which is currently occupied by the truck facilities, could be transformed into a mobility hub type of solution, providing new opportunities for the El Pasoans as well as commuters and opening doors to a more sustainable, cleaner, safer, and smarter city.

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GLOSSARY

Abbreviation	Description
AADT	Annual Average Daily Traffic
BOTA	Bridge of the Americas
BTS	Bureau of Transportation Statistics
CBP	Customs and Border Protection
CTPAT	Customs Trade Partnership Against Terrorism
DTA	Dynamic Traffic Assignment
ETC	Electronic Toll Collection
EV	Electric Vehicle
FAF	Freight Analysis Framework
FAST	Free and Secure Trade
FMCSA	Federal Motor Carrier Safety Administration
GIS	Geographic Information System
GSA	General Services Administration
HOV	High Occupancy Vehicle
ITS	Intelligent Transportation Systems
MPO	Metropolitan Planning Organization
MX	Mexico
NAFTA	North American Free Trade Agreement
NEPA	National Environmental Policy Act
POE	Port of Entry
POV	Personally Owned Vehicle
PPP	Public-Private Partnership
RFID	Radio Frequency Identification
SENTRI	Secure Electronic Network for Travelers Rapid Inspection
TAZ	Traffic Analysis Zone
TX	Texas
TxDOT	Texas Department of Transportation
USDOT	U.S. Department of Transportation

VITA

Marek Musil, born in the Czech Republic, completed his bachelor's degree in Intelligent Transportation Systems at the Czech Technical University (CTU) in Prague, Faculty of Transportation Sciences. He is currently pursuing a dual degree master's program jointly at CTU and the University of Texas at El Paso (UTEP), focusing on Civil Engineering with a specialization in Smart Cities. His bachelor's thesis delved into the integration of advanced GNSS based landing systems into commercial airline operations, with a particular focus on Smartwings, the largest Czech national airline. As part of his ongoing master's research, he is exploring routing opportunities for commercial crossings between El Paso and Juarez, aiming to optimize transportation systems in urban environments utilizing traffic simulation.

In addition to his academic pursuits, Marek has been a private pilot since the age of 18, and is actively pursuing further qualifications, including the airline transport pilot license. Professionally, he has held roles in supply chain and finance controlling and reporting, specializing in reporting, data analysis, and process optimization. He has also cooperated with the Department of Air Transport at CTU, serving as an Air Operations Lab Administrator, where he gained valuable insights into aviation operations and simulations.

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