Dynamic Travel Demand Management for Non-Recurring Extreme Events

by

Jeff Shelton, Geza Pesti, Gabriel A. Valdez

Project performed by
Center for International Intelligent Transportation Research

Report No.
CIITR Project: Dynamic Travel Demand Management for Non-Recurring Extreme Events

August 2012

Report prepared by
Center for International Intelligent Transportation Research
Texas Transportation Institute
4050 Rio Bravo, Suite 151
El Paso, Texas 79902

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

TABLE OF CONTENTS

Page

LIST OF FIGURES

DISCLAIMER AND ACKNOWLEDGMENTS

This research was performed by the Center for International Intelligent Transportation Research, a part of the Texas Transportation Institute. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein.

EXECUTIVE SUMMARY

Currently, there is no bi-national travel demand model of the El Paso – Juarez region that incorporates dynamic traffic assignment. Instead, static models have been developed to evaluate the impact of future changes in demographics across the border. However, static models contain several limitations when analyzing traffic flow at higher detail (e.g. no representation of individual lanes, no vehicle overtaking, etc.). On the other hand, dynamic models provide the ability to analyze the temporal and spatial distribution of traffic during specific time periods, as opposed to static models that rely on average daily volumes. Therefore, the time-dependent impact of infrastructure changes across the border can be captured. In order to develop a dynamic bi-national travel demand model several integration tools (e.g. VISUM – DynusT converter) were necessary to go from a macroscopic to a dynamic mesoscopic level. The research team used a static bi-national model in TRANUS previously developed by the Texas Transportation Institute as the base to develop a DynusT (Dynamic Urban Systems for Transportation) dynamic traffic simulation model.

The dynamic bi-national travel demand model had a total of 264 traffic analysis zones, 8459 links, and a 24 hour time-dependent origin-destination matrix. The origin-destination matrix was calibrated until the convergence criterion was met. The newly developed bi-national model was utilized to simulate three non-recurring extreme events in the border region including a weather, hazmat, and catastrophic scenarios. The short and long term impact on the transportation system was determined for each model including critical regions and traffic pattern changes.

The simulation results showed that most of the vehicles traveling along I-10 looking for an alternative route chose Cesar E Chavez Border Highway since it provides connectivity between the East and West sides of El Paso. Furthermore, when connectivity was lost between I-10 and the Bridge of the Americas port-of-entry vehicles re-routed towards Paisano Dr through either downtown or the Paisano Dr / I-10 interchange. As a result the total vehicle volume going into Juarez got reduced by 50% approximately from the daily average when simulating the I-10 / US 54 interchange collapse. Vehicles experienced stop-and-go conditions upstream of the affected areas throughout the city. Most notably, during the afternoon peak hours.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The El Paso – Ciudad Juarez border region has a unique and complex transportation system due to the amount of commuters that routinely cross back and forth across the international ports-of-entry. Any disturbance to the transportation system can cause severe impacts to the traffic congestion and economic activity in the border region. For example, non-recurring extreme events like inclement weather, hazmat traffic incidents, or a catastrophic infrastructure collapse can compromise the capacity and reliability of the existing transportation system. In these types of situations, traffic management centers try to alleviate congestion with real time traffic diversion routes through the use of dynamic message signs. However, the ability to predict the traffic impact of an extreme event can be quite challenging. With the advances in modeling tools, an opportunity arises for transportation agencies to take a more proactive approach to better manage traffic with such large-scale disruption.

The El Paso Metropolitan Planning Organization (MPO) and the Instituto Municipal de Investigación y Planeación (IMIP) each have their own respective travel demand models which are used for long-ranged transportation planning and forecasting. Yet, each cities model (i.e. El Paso and Juarez) is truncated at border crossings and do not account for trips that originate on one side of the border and terminate on the other. Therefore, any attempts to analyze the transportation impacts of both cities that result from a non-recurring extreme event were not possible. Recently, the Center for International Intelligent Transportation Research (CIITR) developed a bi-national model using the TRANUS software between El Paso and Juarez. TRANUS facilitated this process since it is an integrated land use and transportation system and thus avoids the need of extensive household surveys to estimate O-D matrices. In such way, the two cities were incorporated into one bi-national model that resulted in a set of O-D matrices to help in the planning process of the border region.

1.2 OBJECTIVE

The objective of this project is to develop a mesoscopic bi-national (El Paso – Juarez) DTA based simulation model to simulate and determine the short and long term impact of several non-recurring extreme events in the border region. In addition, the simulation results will help identify the most critical regions that are most adversely impacted by traffic pattern changes. Researchers will pinpoint locations where existing traffic control may be needed as well as recommending alternative routes to divert traffic from affected areas.

1.3 METHODOLOGY

The first step in this research was the development of an integrated dynamic bi-national travel demand model which required various integration tools to go from a macroscopic to a mesoscopic level. The first phase consisted on converting the static bi-national TRANUS model previously developed by TTI to TransCAD format. This includes the conversion of the network infrastructure as well as exporting the O-D matrix from the TRANUS model. The next step was to import the TransCAD network into VISUM including all the required attributes for links, nodes, and zones using a TransCAD/CUBE to VISUM import tool developed by PTV America, Inc. Once the network was in VISUM format, a series of validation steps were conducted to ensure current conditions in the region. Researchers examined all existing major arterials and freeway corridors to confirm the correct lane numbers, speed limits, link geometry, etc. The VDC converter was then used to convert the static bi-national model to mesoscopic format in DynusT. The VDC tool takes the regional travel demand model (in VISUM format) and converts to a mesoscopic format where the dynamic traffic assignment algorithm is used to replicate driver behavioral travel patterns at a regional level. Once the bi-national model was in DynusT format, the demand was calibrated with the traffic count data available throughout both cities.

The next step was to model and simulate three non-recurring extreme events including: a hazmat incident, a flooding incident, and a catastrophic event with the developed bi-national DTA based model. The simulation results were then used to identify the critical links and alternative routes to adequately support traffic in the region. The observations, findings, and mitigation strategies identified were documented for each of the scenarios analyzed. Figure 1 shows the methodology just described.

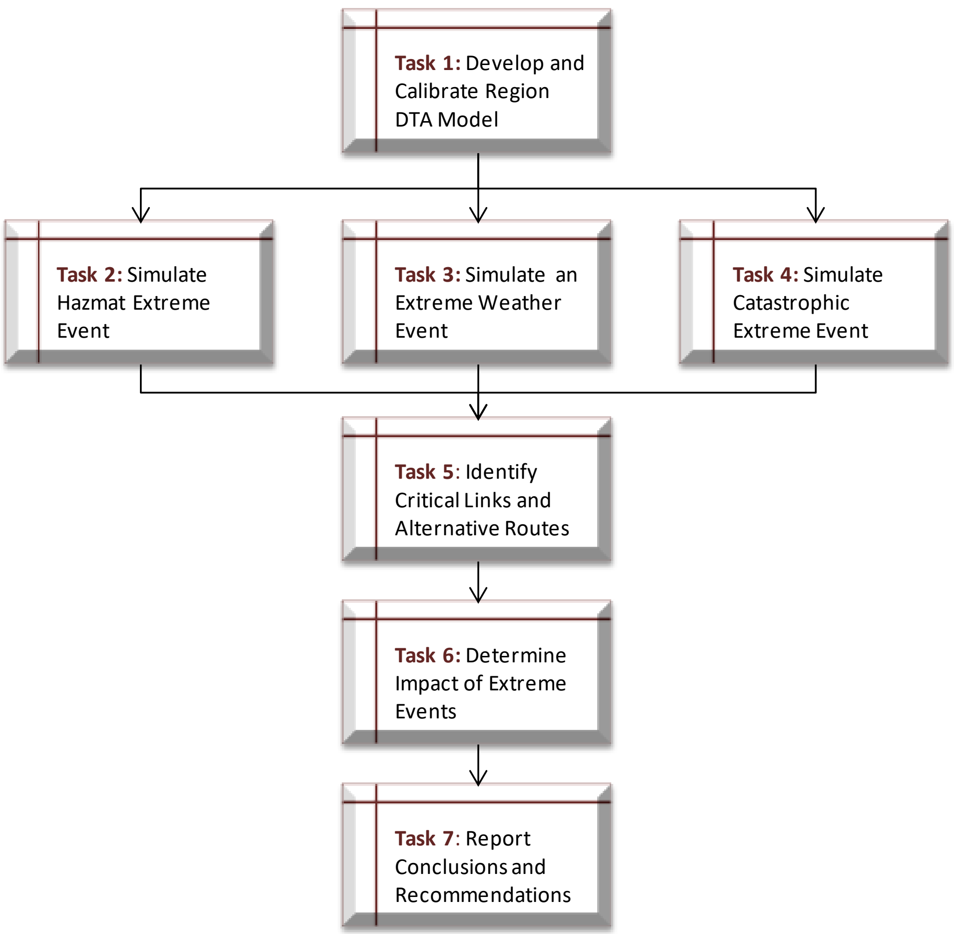

Figure 1: Research Methodology

CHAPTER 2: NETWORK MODEL INTEGRATION AND DEVELOPMENT

2.1 CONCEPT OF DYNAMIC TRAFFIC ASSIGNMENT

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

A simulation-based DTA model typically consists of two principal model components: a simulation model and a traffic assignment model. The simulation model is aimed at evaluating the quality of the assignment solution and the assignment model takes the inputs from the simulation to further generate more paths and assign vehicles to different paths in order to get close to the DUE/TDUE condition over the iterations.

2.1.1 Simulation Model

Most exiting DTA models adopt a "mesoscopic" traffic simulation approach in which individual vehicles' position and speed are calculated based on average traffic conditions on the link following either macroscopic speed-density relationship (1), headway distributions (2), or queuing processes (3). Mesoscopic simulation models generally have coarser simulation time resolutions (in the order of 5-10 seconds as oppose to 0.5-1 section resolution in microscopic models.) At times, some driver responses to roadway configurations (e.g., land-changing, roadside parking, etc.) are also simplified through changing the capacity of either links for intersections. With the simplified simulation logics and coarser time resolution, the mesoscopic models are able to accommodate a much larger network with more vehicles and longer simulation time period compared with microscopic models. In addition, all DTA models are path-based simulation, meaning that vehicles follow an assigned path from the origin to the destination. Diversion in response to roadway traffic condition changes or information provided to the drivers may also be modeled.

2.1.2 Traffic Assignment Model

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

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

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

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

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

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

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

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

Step 4. Check the convergence criterion that is based on the difference in numbers of vehicles assigned to various departure time intervals and paths over two successive iterations. Hence, assignments to the next iterations $r_{ihk}^{\tau,\iota+1}$ are compared with current path assignments $r_{ijk}^{\tau,\iota}$, $\forall$ i, j, τ, and k:

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

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

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

The integration of DTA allows dynamic control (i.e. time dependent) of the road network by representing variations in traffic flows and conditions such as vehicle overtaking, congestion spillback, etc in order to anticipate problems rather than just reacting to existing conditions. A dynamic bi-national travel demand model (TDM) would allow researchers to analyze the impact of proposed new port-of-entry infrastructure, analyze existing border crossing patterns during recurring and non-recurring events (e.g. bridge closure due to bomb threat, protesters, etc). In addition, variable tolling options allow for a more robust approach to analyzing proposed managed lanes in the region. Furthermore, a new dynamic planning model would be of interest to the El Paso Metropolitan Planning Organization who has shown interest in DTA-based analyses.

2.2 NETWORK DEVELOPMENT

2.2.1 TRANUS Bi-National Travel Demand Model

The development of the dynamic bi-national TDM was based on static model that was previously prepared by TTI to assess the viability of a cross-border mass transit service between El Paso and Ciudad Juarez (4). The static bi-national model was coded in TRANUS which is an integrated land use and transport modeling system developed by Modelistica. It combines state-of-the-art modeling of the activities locations, land use, and their interactions with a transportation system. In addition, TRANUS allows estimating O-D matrices for several traveler categories, modes, and trip purposes (5). The resulting TRANUS network from the cross-border project is depicted in Figure 2.

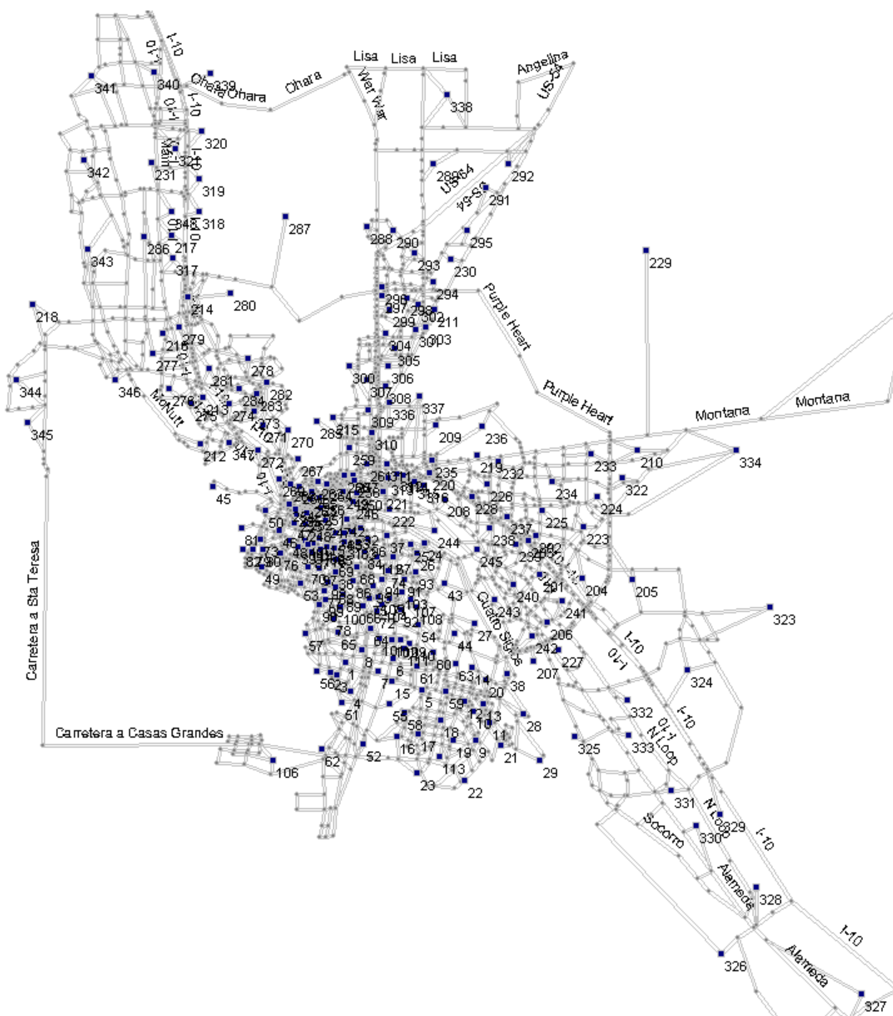

Figure 2: TRANUS Static Bi-National TDM

The model has a total of 264 Traffic Analysis Zones (TAZ) in which the El Paso and Ciudad Juarez region consist of 148 and 116 TAZ's respectively. However, the zone numbering was not 1 – 264, but 1-116 for Juarez TAZ's and 201-264 for El Paso for easier identification during the modeling process. The research team obtained the 24 hour matrix from a previously calibrated and validated bi-national model originally performed for mass transit purposes. This bi-national model was obtained from a 2009 base year scenario. The transportation model incorporates a simplified roadway network with the bi-national transit networks. The entire roadway network was composed of 9,084 links including the Ports-of-Entry (POEs) and Traffic Analysis Zone (TAZs) connectors. In addition, twenty individual link-types were used to define the free flow speed (km/h), penalizations, and tolls for each link, and to model each POE individually. It is important to remark that due to the complexity of the bi-national modeling area and the uniqueness of each POE (i.e. different capacities, volumes, delays, customs inspection times, etc), individual link-types were used to model each POE using certain parameters designed specifically for each given POE.

2.2.2 TRANUS Modeling Technique

The base year model was built using a set of matrices of economic flows from economic activities in the region and a land use model. All economic activities were group in three main categories; *Manufacturing*, *Commercial* and *Services*. Then the transportation model estimates travel demand and assigns traffic to a so called "transportation supply". When the final demand has been estimated for each zone, it must be distributed among production zones given that every sector requires inputs from other sectors. TRANUS estimates the locations of induced production using demand functions in combination with spatial distribution functions (5).

As mentioned in the preceding section of this chapter, the base-year conditions were obtained from a previous transit assignment included in the report "Application of an Integrated Land Use and Transport Model to the El Paso and Ciudad Juarez bi-national Area". This model was recalibrated for all POE links using pedestrian counts issued by the city of El Paso. Thus, the passenger cars O-D matrix obtained in TRANUS includes morning (7:00-8:00 am) peak-hour volumes with a final correlation coefficient (R^2) of 0.73 which is considered high for the a TRANUS travel demand model (4).

2.2.3 TRANUS 24-Hour Origin-Destination Matrix

After the analysis of total demand using TRANUS User Shell interface (TUS) was completed, an output file using the TRANUS IMPTRA application was needed to successfully generate the 24-hour matrix. This application/program program prints the results of the assignment from the transportation model in a number of optional formats.

Figure 3: IMPTRA Interface to Generate Origin- Destination Matrix

Since the final O-D matrix provided by TRANUS only covers the morning peak-hour, a final step was necessary to obtain the 24-hour matrix. This process involved the usage of a distribution of vehicle trips (auto driver) by time of the day that was estimated by El Paso Metropolitan Planning Organization in 1994 and is still in use by travel demand modelers in El Paso region (6). The research team used a single expansion hourly distribution factor (HD factor=0.187234) originally used to obtain the 7:00 to 8:00 matrix (4) was then divided by all elements of the O-D matrix.

$$\boldsymbol{O-D_{24-Hour\,(nm)}} = \frac{\begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{bmatrix}}{\boldsymbol{HD_{Factor}}} \qquad \textit{Eq1.}$$

where:

$\boldsymbol{O-D_{24-Hour}}$ = *24-hour Origin-Destination matrix*

$\boldsymbol{HD_{Factor}}$ = *Hourly Distribution Factor*

$\boldsymbol{x}$ = *element of the peak-hour matrix from the TRANUS assignment*

2.2.4 Exporting TDM from TRANUS to TransCAD

To transfer the network infrastructure into TransCAD the nodes, links, and TAZ polygons were exported as a shapefile from the TRANUS model. This includes the connectors as well as the zone centroids. The connectors connect the TAZs to the link network between the zone centroids and the connecting node (of the corresponding link). Each TAZ must be connected to at least one origin zone and one destination connector in order to run assignment. This allows vehicles to exit and enter the TAZs in the model (7). Therefore, a connector has two directions:

- Origin connector from zone to node and
- Destination connector from node to zone

Having a bi-national network in TransCAD was necessary to use the TransCAD to VISUM import tool[1] to later facilitate the process while maintaining accuracy.
Figure 4 illustrates the bi-national network in TransCAD platform. The total number of links in this network is 5,344 while the total number of nodes reached 3,851. As mentioned in section 3.1 of this chapter, the total number of TAZs was 264 as shown in Figure 5.

[1] Developed by PTV America, Inc.

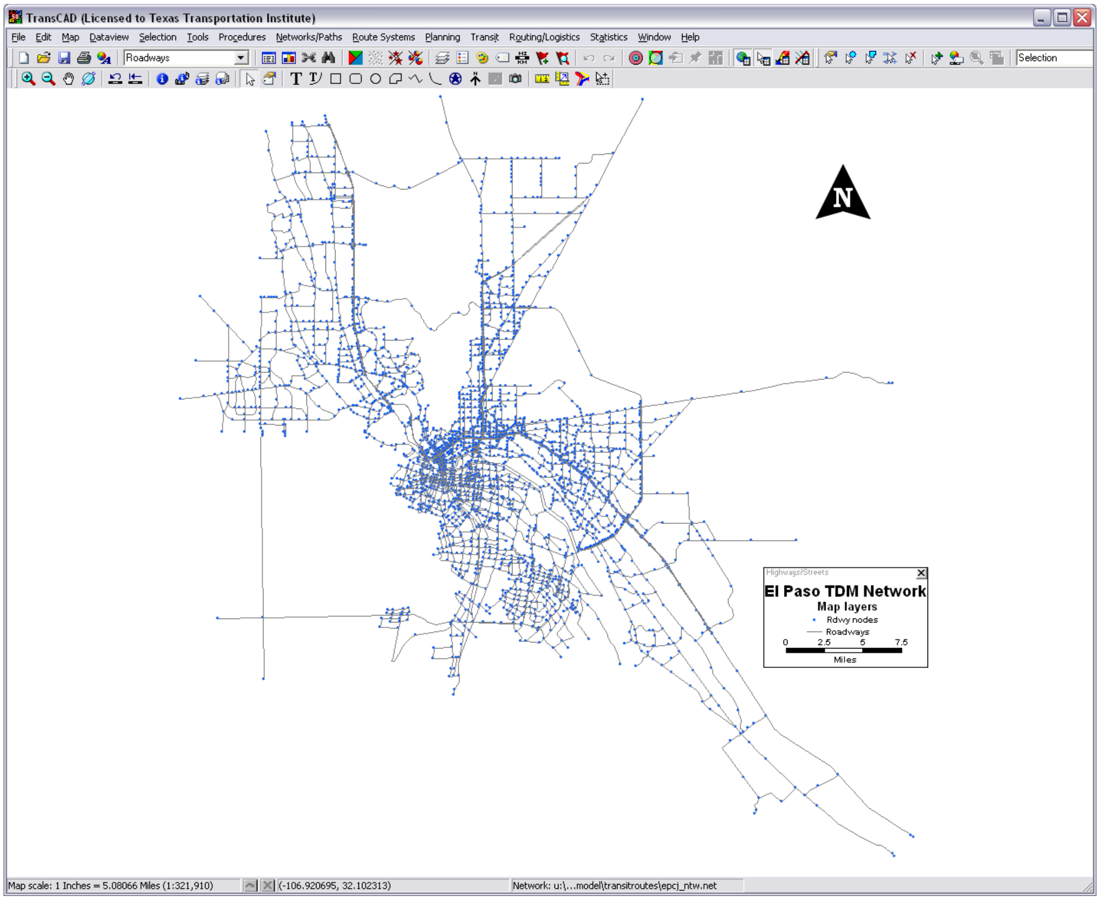

Figure 4: Bi-national Node-Link Network Configuration in TransCAD

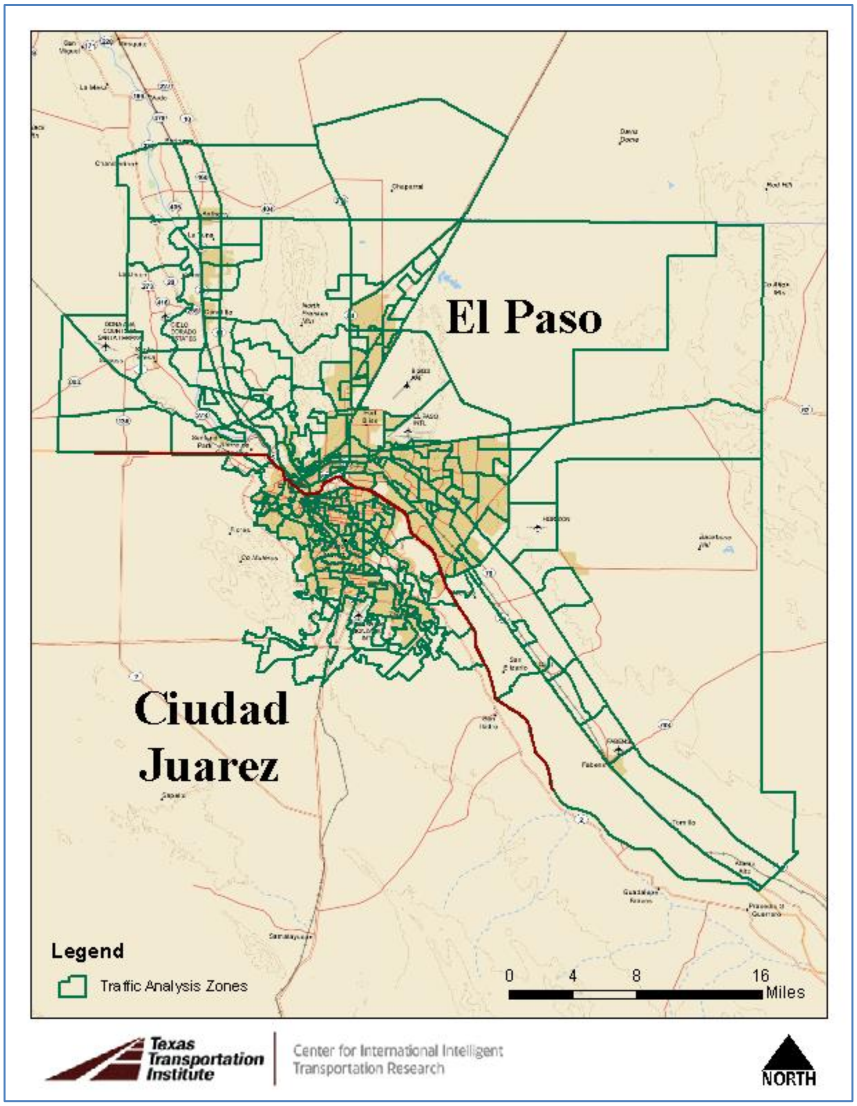

Figure 5: Transportation Analysis Zones in the Area of Study

2.2.5 TransCAD Conversion to VISUM

Once the bi-national model was imported into TransCAD, a conversion tool was utilized to have the network in VISUM format. Figure 6 shows the user interface for the TransCAD/CUBE import add-in for VISUM. As seen on the figure below, this tool required a shapefile for nodes, links (including connectors), and the number of TAZ's. In addition, the tool allows the user to import transit infrastructure such as stops and line routes, however, public transportation was not considered in this research due to DynusT limitations.[2] The resulting VISUM network is shown in Figure 7.

[2] DynusT transit assignment under development

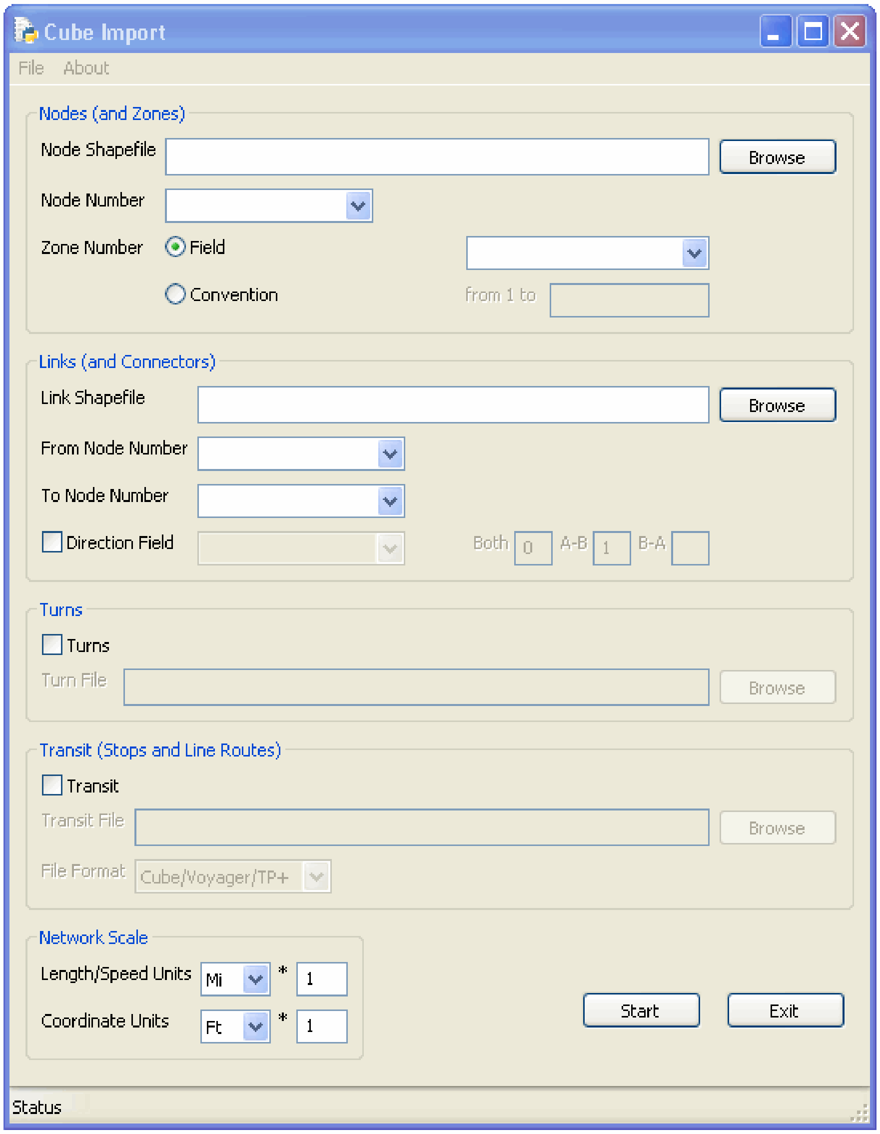

Figure 6: TransCAD/CUBE Import Add-in for VISUM

Figure 7: Resulting VISUM Bi-National Network

2.2.6 VISUM Network Validation

The validation process was performed to ensure that VISUM bi-national model represents current infrastructure conditions and verify that no coding errors exist. The first step was to conduct a “Check Network” via the VISUM software. This calculation informs the user of any possible errors within the model such as isolated nodes, zones not connected for private transport, links with zero capacity, etc. Once this was performed, the research team proceeded to perform a manual check of the following link attributes:

- Free flow speed for private transport
- Link capacity
  - The model includes a link capacity per hour and for 24 hours (daily capacity was added as a user-defined attribute)
- Number of lanes

In VISUM, a classification of four link types was created to differentiate between arterial, freeway, highway, and on (off)-ramp. The link types were based on the link classification that DynusT currently utilizes. As part of the validation effort, the on (off)-ramp infrastructure and geometry of mayor corridors in El Paso (e.g. I-10, Cesar Chavez Border Highway, Loop 375, U.S. 54) was double checked to ensure current conditions. The Juarez region required the coding of additional links to represent the frontage road for two mayor corridors in the Southeast area (e.g. Boulevard Independencia and Avenida de las Torres).

2.2.7 Mesoscopic DTA Based Bi-National Model

The final step to develop the mesoscopic DTA based bi-national model was to export the VISUM model to DynusT via the VDC tool. Figure 8 shows the user interface of the conversion tool. However, prior to using this tool, a user-defined attribute was created in VISUM for the Traffic Flow Model (TFM) of each link since it is required by DynusT. A TFM describes the relationship between speed and density of vehicles depending on the capacity of the link. Dual-regime (e.g. TFM attribute = 2) models were applied to freeways and single-regime models to arterials and on (off)-ramps. The conversion was performed and the resulting DynusT network is shown in Figure 9.**Error! Reference source not found.** Traffic control was not exported from VISUM since none was previously coded in the model. Instead, traffic control was input to the DynusT network based on signal timing sheets provided by the City of El Paso. The traffic control information for the city of Juarez was obtained from previous data collection efforts done by TTI on mayor intersections in Juarez. The study included registering the cycle length and phase movements. It is important to note that all Juarez traffic signals were coded as pre-timed in DynusT, whereas the El Paso signals are coded as actuated.

The dynamic bi-national travel demand model developed through the phase of this project consists of 264 zones. In addition, a twenty-four hour O-D matrix divided into one hour segments was created to conduct DTA. The developed DTA model overcomes the limitations of static models such as having volume/capacity ratios greater than 1.0, no vehicle overtaking, no congestion spillback, etc. Therefore, a more a more detailed analysis can be performed in the overall network due to infrastructure changes across the border. Furthermore, a DTA based planning model can be of interest to local transportation agencies (e.g. El Paso MPO, TxDOT) for future projects in the border region.

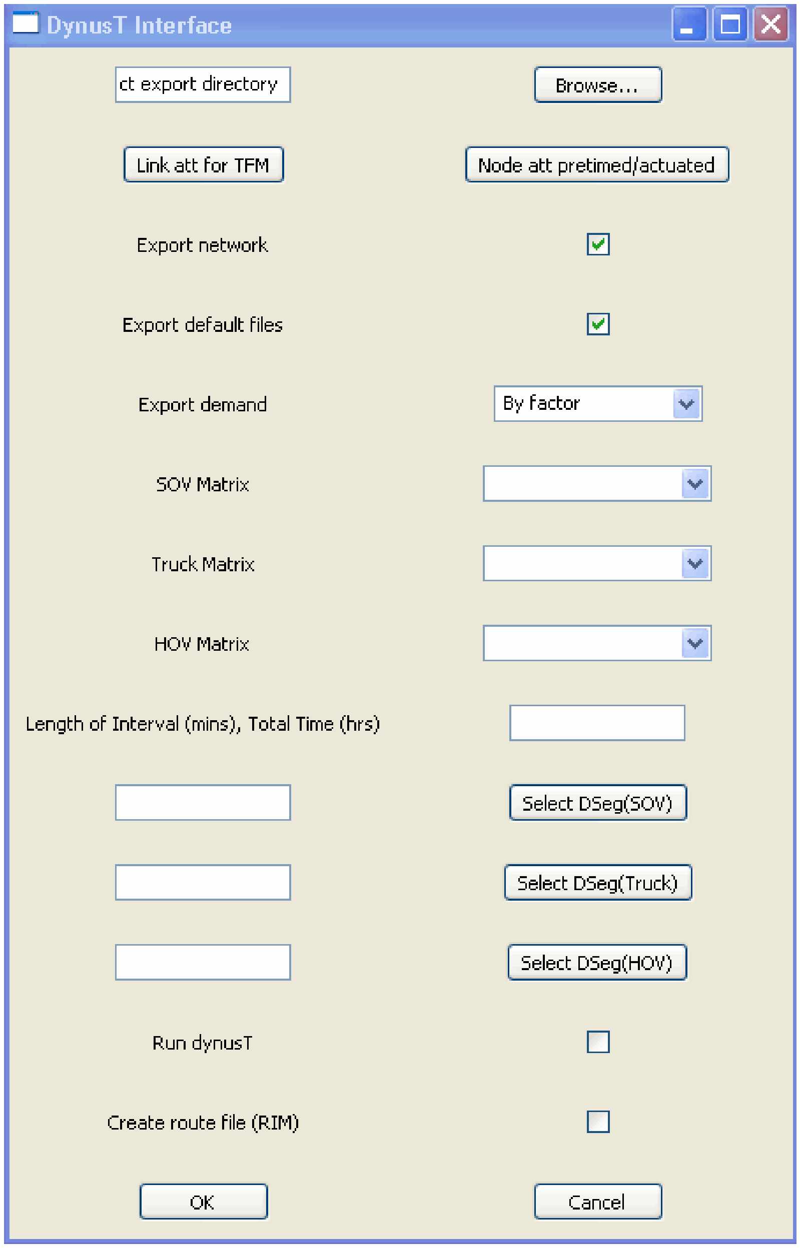

Figure 8: DVC Tool User Interface

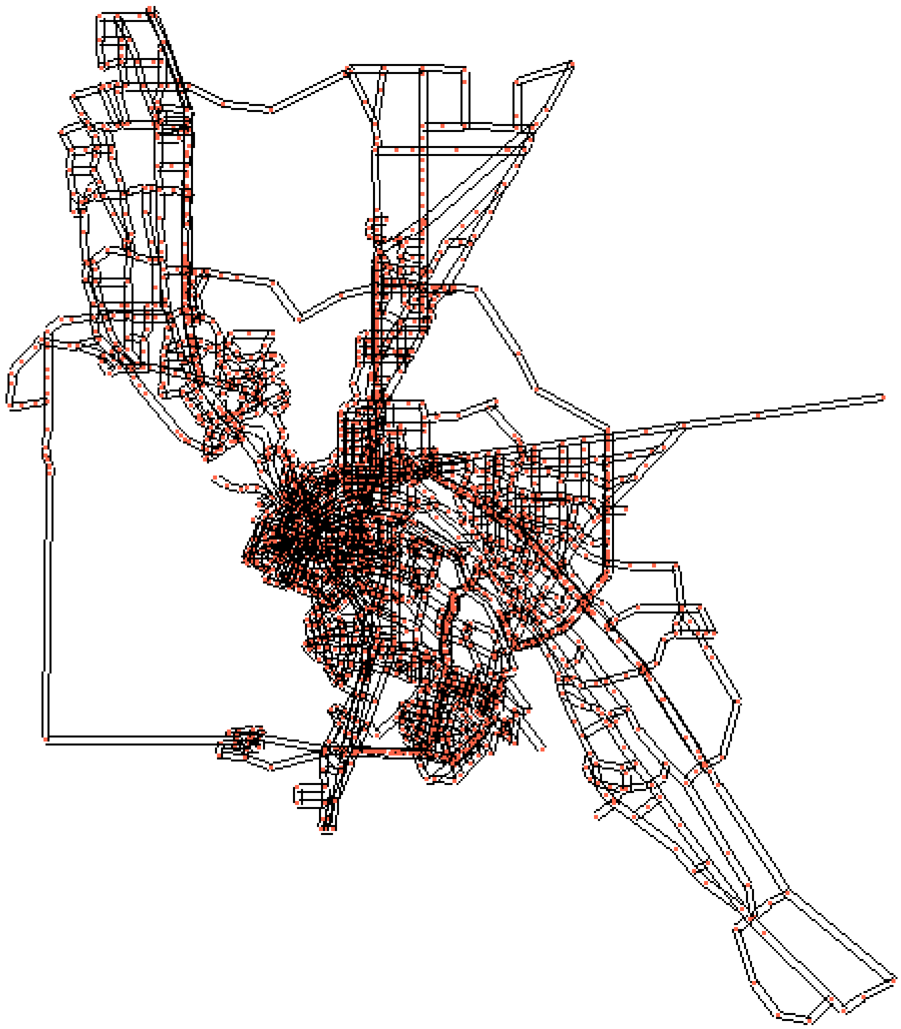

Figure 9: Mesoscopic DTA Based Bi-National Model

2.3 O-D MATRIX CALIBRATION

The O-D matrix calibration was performed by an iterative methodology developed by The University of Arizona's DynusT Laboratory (Figure 10). The O-D tool attempts to match the simulated time-varying volumes with the actual link volumes counts collected from the field. This is achieved by a linearized quadratic minimization process that reduces the deviation between simulated and observed counts. TTI utilized a total of 136 screen line counts for calibration throughout El Paso and Juarez including all the ports-of-entry located along the border.

The matrix calibration process was divided into two periods due to the amount of memory and time required to run the O-D tool for one twenty-four hour period. The iterative process was performed until the simulated and actual counts were within a ±10% absolute error range. The a.m. period reached convergence after 19 iterations as shown in Figure 11. On the other hand, the p.m. period was within the ±10% error after 14 iterations (see Figure 12).

O-D Matrix Calibration Periods:

- Morning Period (12:00 a.m. to 11:59 a.m.)
- Afternoon Period (12:00 p.m. to 11:59 p.m.)

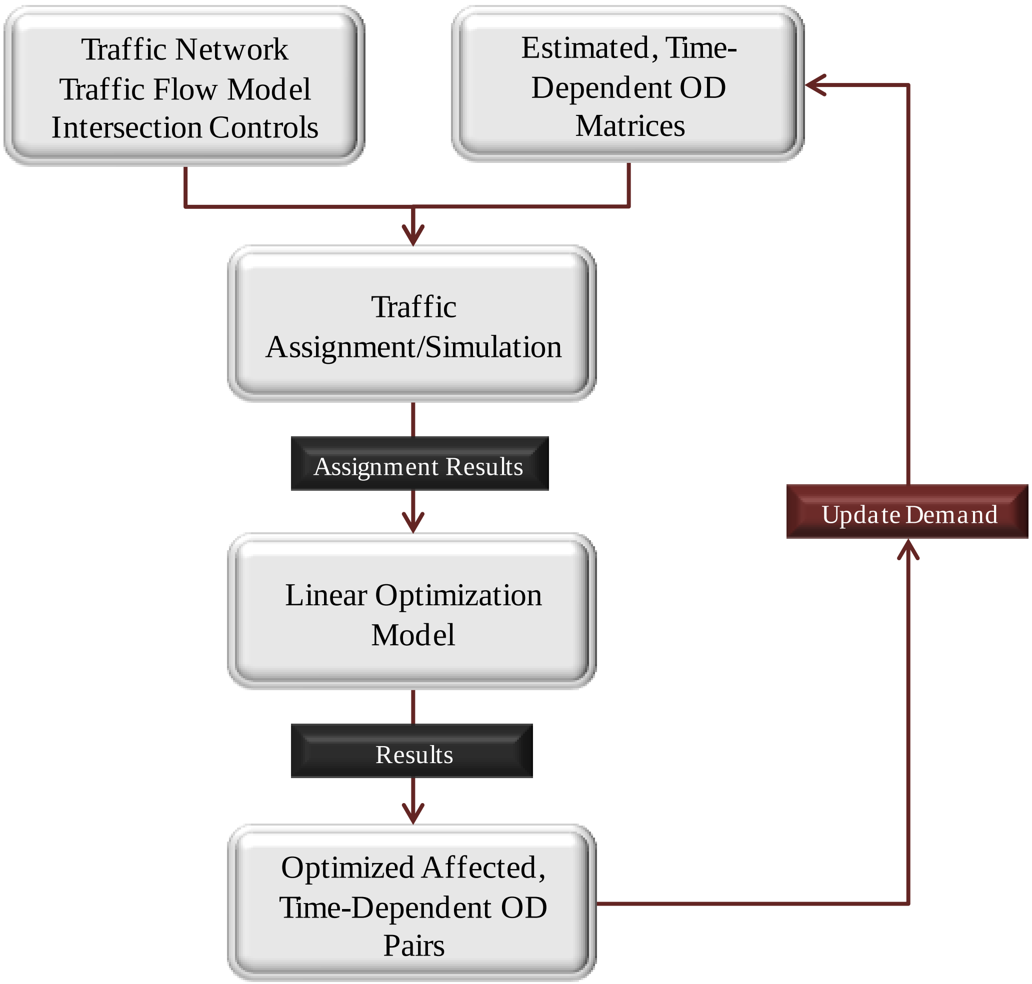

Figure 10: O-D Demand Calibration Framework

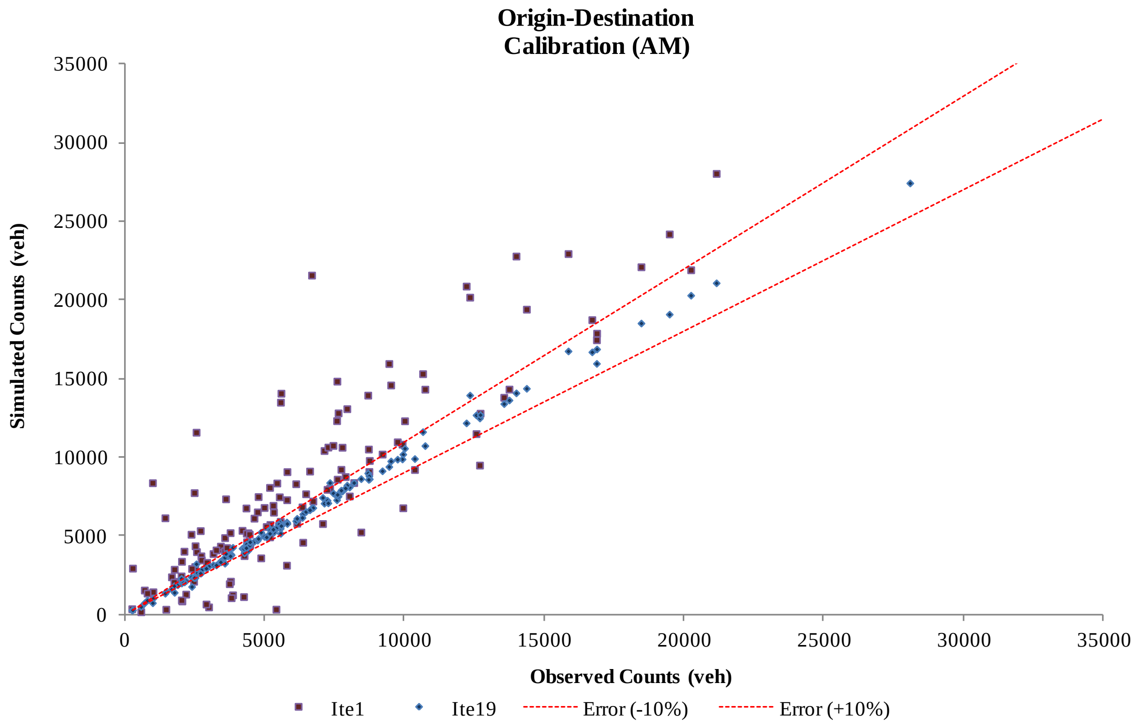

Figure 11: O-D Matrix Calibration Results – A.M. Period

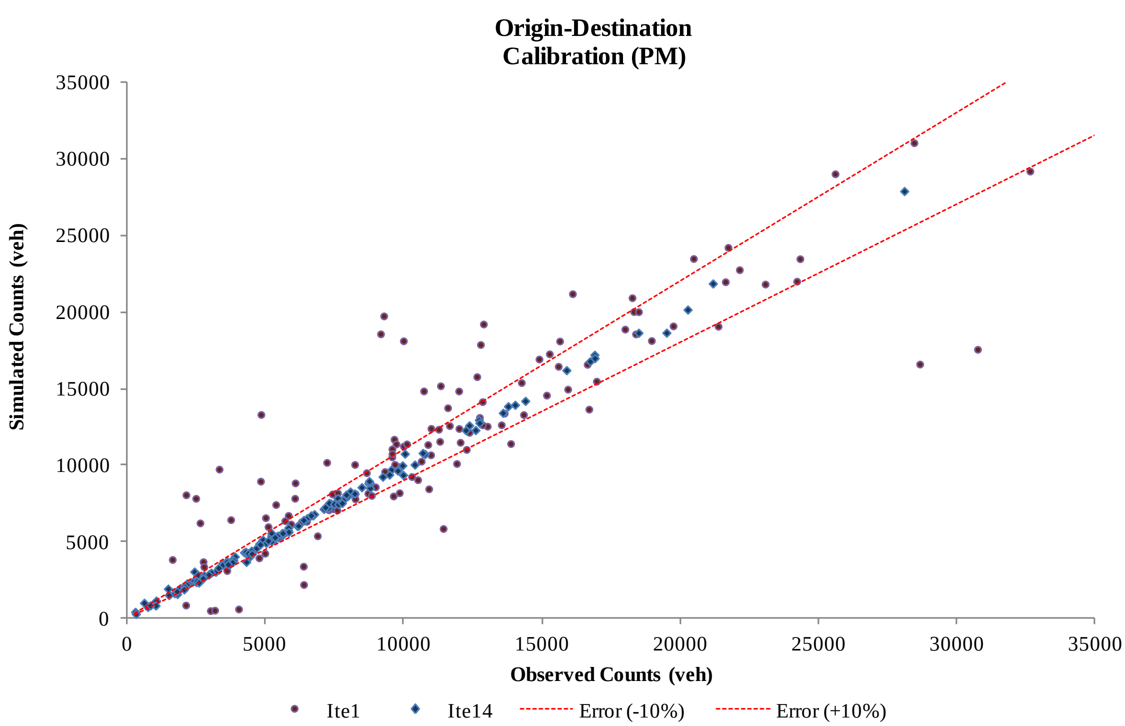

Figure 12: O-D Matrix Calibration Results – P.M. Period

CHAPTER 3: MODEL SCENARIOS

After vehicle demand was calibrated, the research team proceeded to code the three extreme event scenarios to be compared with the base case (i.e. do-nothing). The following sections describe each simulation model in further detail.

3.1 EXTREME CATASTROPHIC EVENT

In order to simulate the effects of a catastrophic event in the El Paso region, a scenario was created to replicate the collapse of a major piece of transportation infrastructure. As a result, the researchers chose to close down the I-10 / US 54 interchange which connects two major freeways as well as providing direct access to the most congested port-of-entry between El Paso and Juarez. The interchange closure was simulated for the whole 24 hours of simulation.

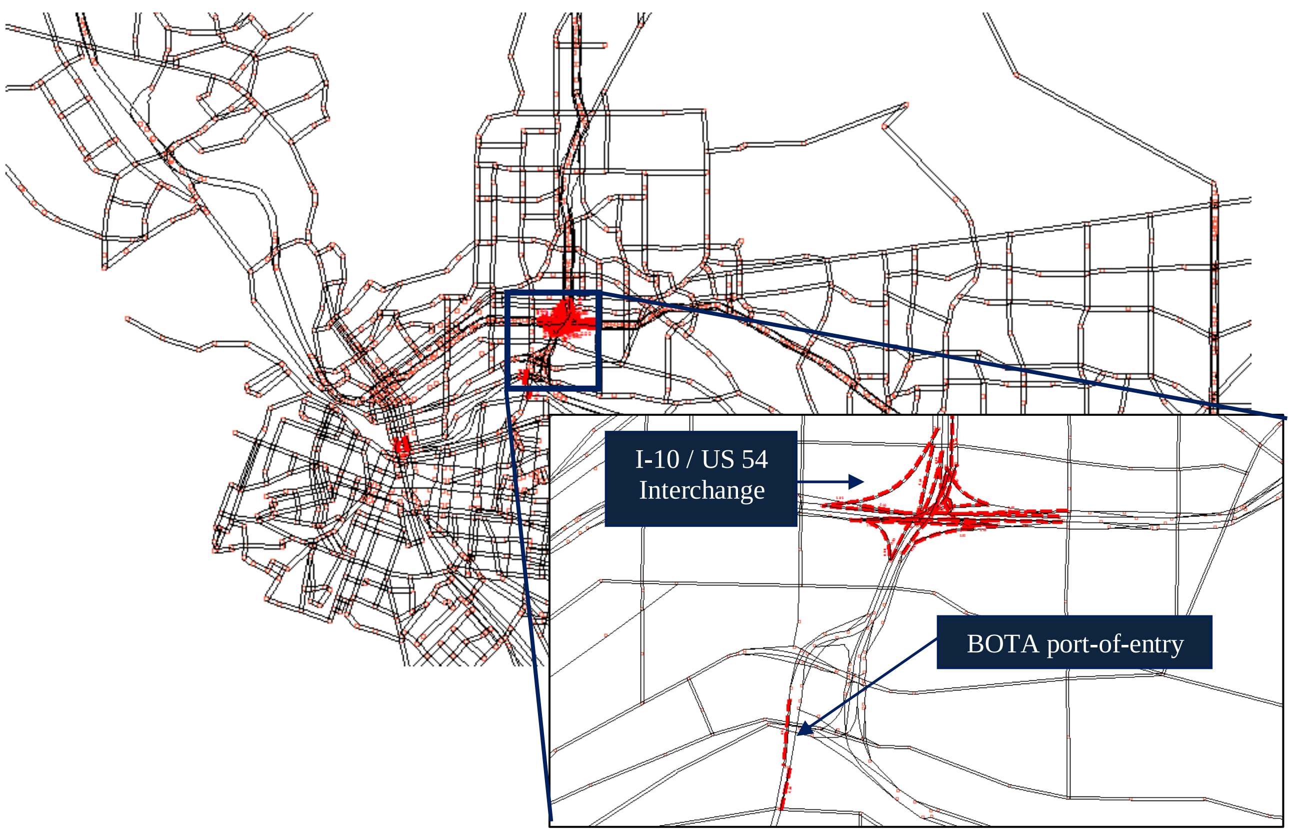

Figure 13: Extreme Catastrophic Event Simulation Model

3.2 EXTREME WEATHER EVENT

During the summer of 2006, the city of El Paso experienced severe amounts of precipitation that caused destructive flash floods within the border region. Furthermore, parts of the city transportation infrastructure were closed to all traffic thus making vehicles looking for alternative routes to reach their destination. Interstate 10 which serves as the main freeway in El Paso was partially closed near the central business district. In addition, parts of the southwest and northeast areas of El Paso were also closed to vehicle traffic.

Based on the city flood plains, observations, and experience from the 2006 flood a model was created to replicate the conditions caused by the rainfall. In order to replicate the transportation infrastructure closure, incidents were coded into the network to reduce the capacity. Figure 14 shows the extreme weather model.

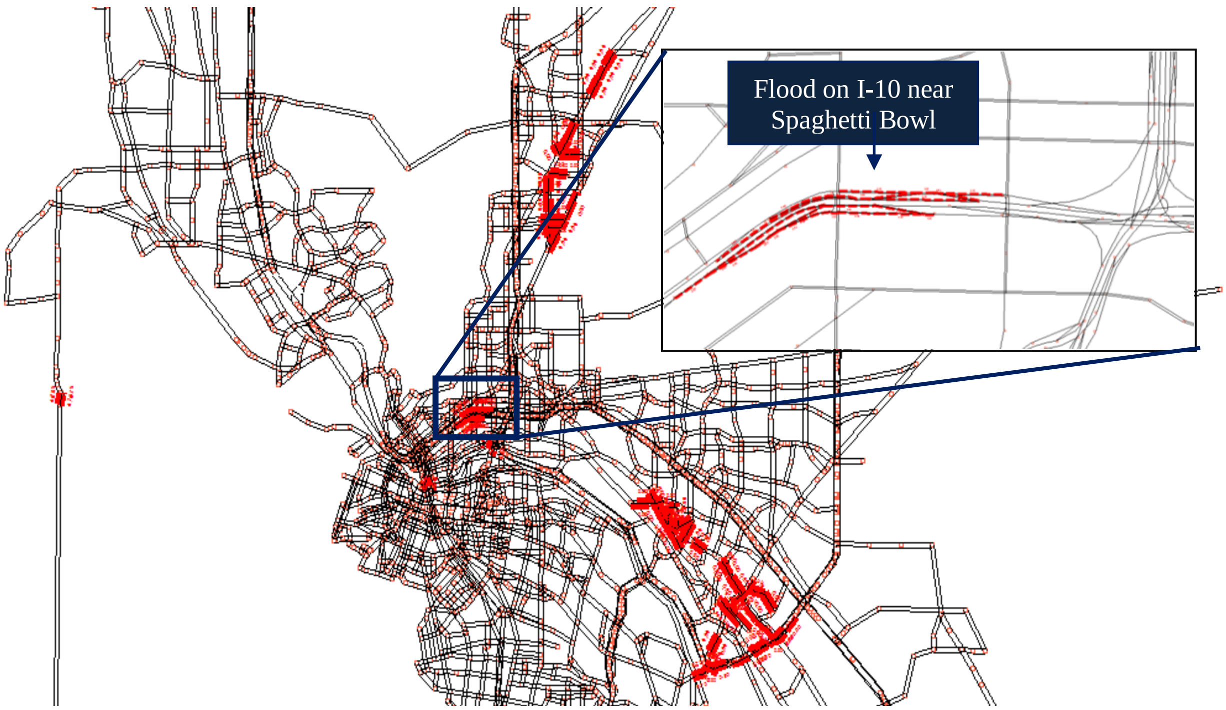

Figure 14: Extreme Weather Event Simulation Model

CHAPTER 4: SIMULATION RESULTS

The simulation measures of effectiveness were obtained for both the long and short term to quantify the impact on the transportation infrastructure caused by the extreme events. The base case was used to compare each scenario and identify the traffic behavior patterns as a result of link closures in the network. In addition, each scenario was simulated for 25 iterations for it to reach user equilibrium defined by the convergence criteria.

4.1 CATASTROPHIC SCENARIO – RESULTS ANALYSIS

4.1.1 Short Term Impact

A short term impact model was simulated to see the effect of the US 54 / I-10 interchange collapse could do to the local traffic. Density levels increased dramatically for both I-10 and US 54 as vehicles could not go through the Spaghetti bowl as pictured in the figure below. Density stayed in the max range of 200 vehicles/mile/lane range for I-10 and US 54 (both directions). Speed upstream of the incident on both I-10 and US 54 remained less than 5 mph (i.e. stop-and-go conditions). On the other hand, downstream of the incident area the freeway remained in free flow conditions as a result of no through traffic.

The BOTA port-of-entry vehicle volume (both SB and NB) decreased because there was no direct connection from/to I-10. Figure 16: BOTA NB Total Vehicle Volume Comparison and Figure 17 represent the volume differences between both scenarios.

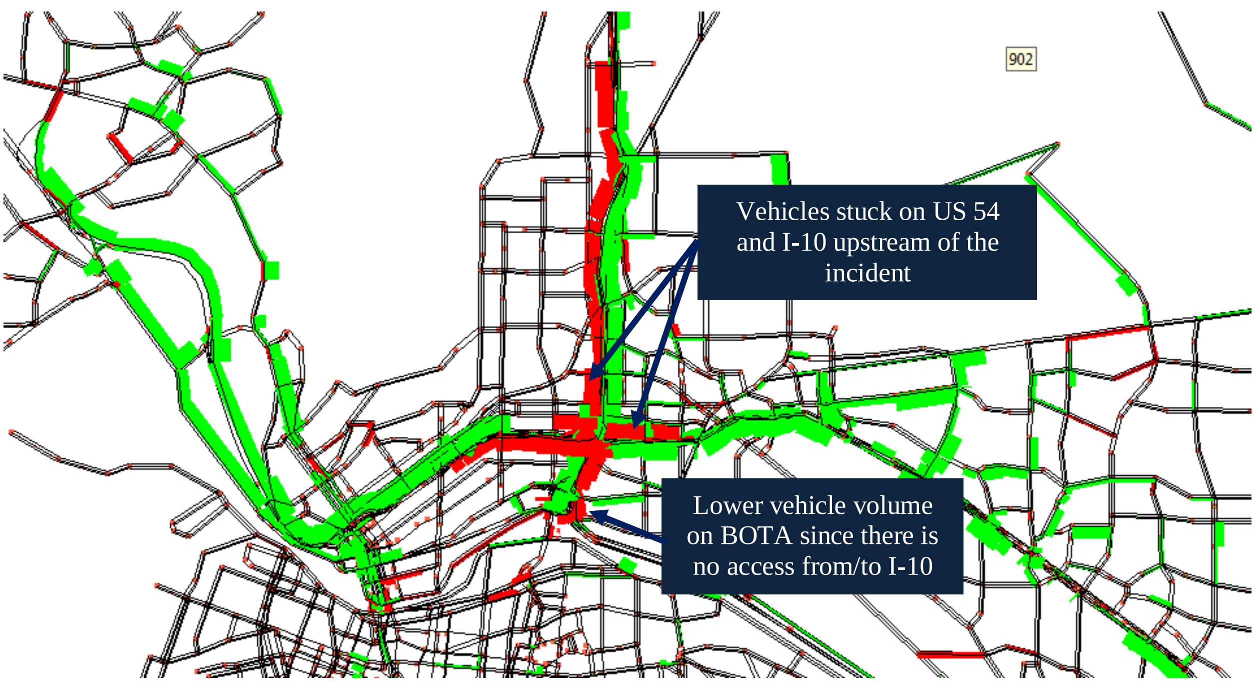

Figure 15: Catastrophic vs. Base Density Comparison

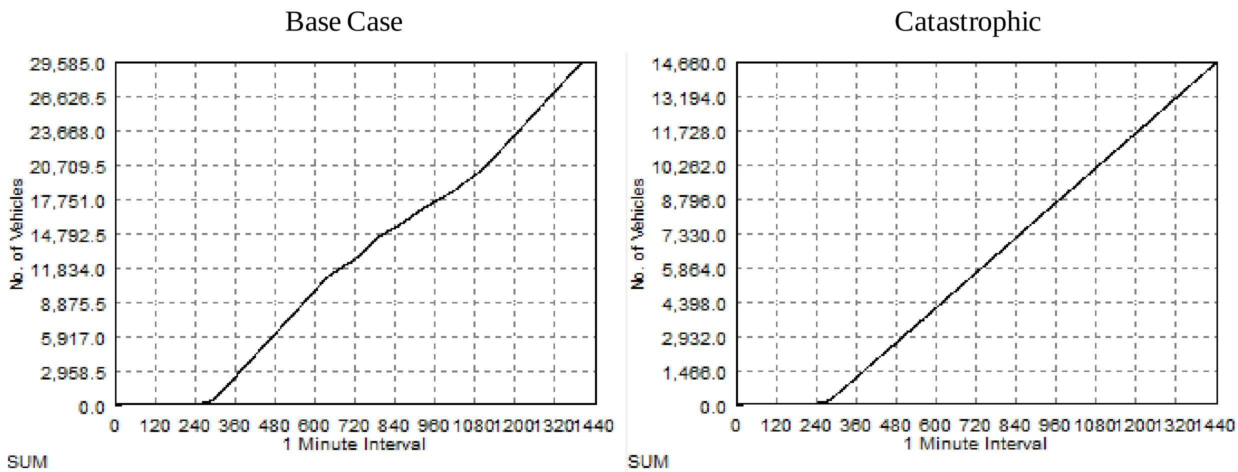

Figure 16: BOTA NB Total Vehicle Volume Comparison

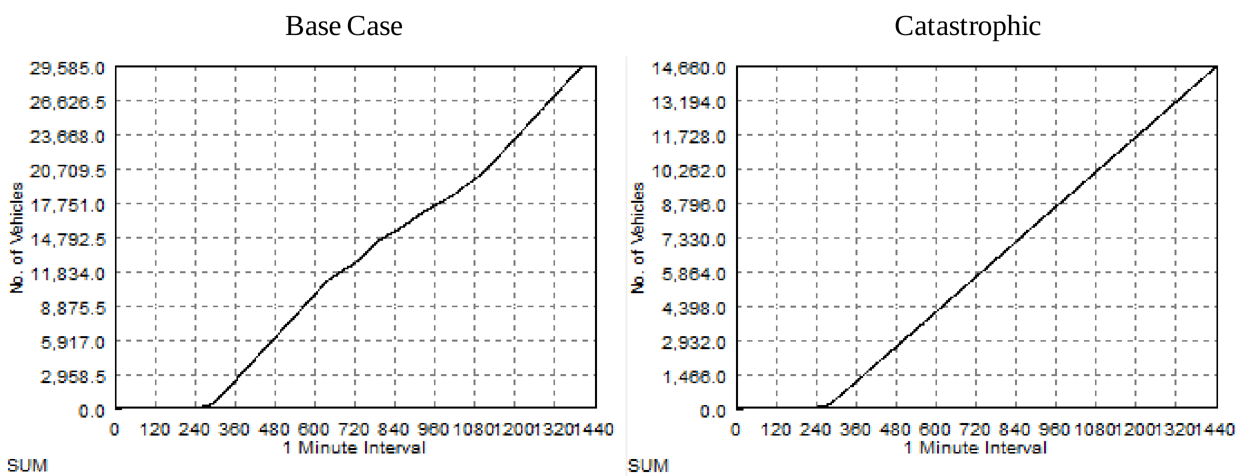

Figure 17: BOTA SB Total Vehicle Volume Comparison

4.1.2 Long Term Impact

The collapse of the I-10 / US 54 interchange had vehicles look for alternative routes through nearby arterials and smaller streets to reach their destination. A comparison between the base case and the catastrophic scenario showed the travel behavior changes as a result of the interchange closure. As seen on Figure 18, vehicles that wanted to take BOTA to cross the border into Juarez diverted to Paisano Dr (red = higher volume, green = less volume). However, due to the congestion experienced at Paisano Dr the total southbound volume at BOTA dropped considerably by about 50%. On the other hand, the northbound traffic at BOTA was 20% lower when compared to the base. Instead, drivers switched to the Zaragoza port-of-entry located on the southeast region on El Paso.

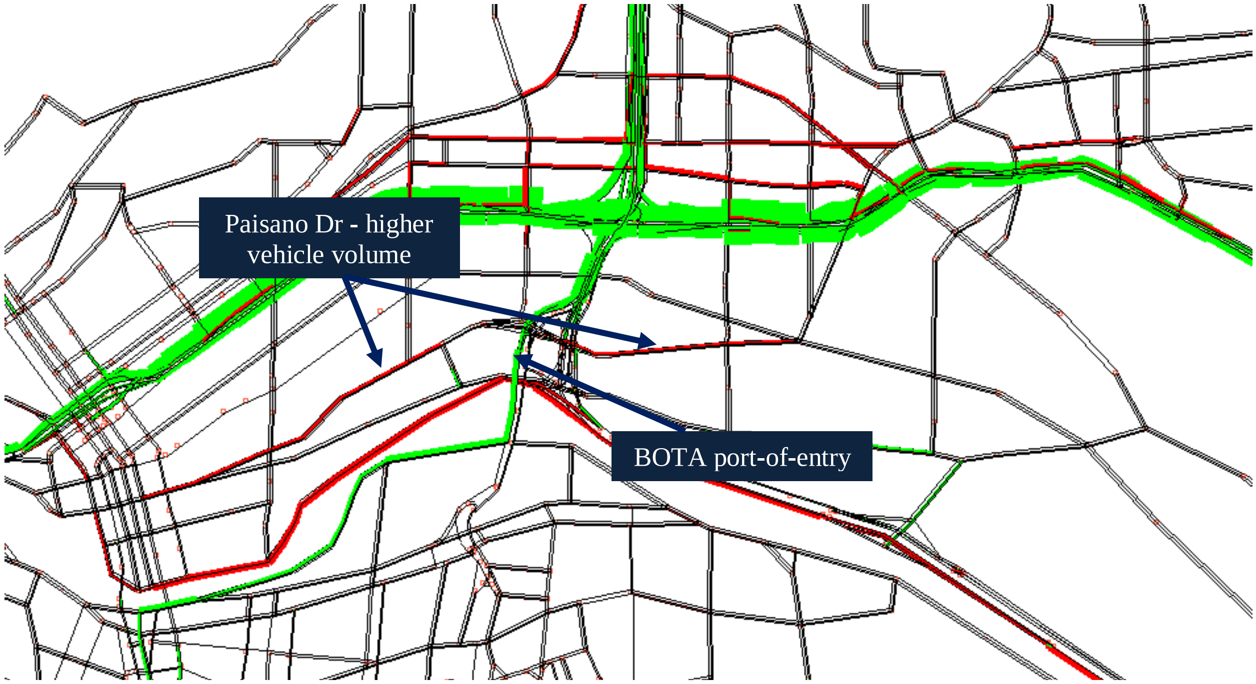

Figure 18: Catastrophic vs. Base Volume Comparison - Paisano Dr as an Alternative Path

Border Highway located south of I-10 was under heavy volume since it connects the west and east portions of El Paso (Figure 19). As a result, intersections on Border Highway had heavy congestion because of people trying to get on and off the highway. Also, vehicles traveling along I-10 WB were exiting the freeway upstream of the Spaghetti bowl to take either Montana Ave, Yandell Dr, or Trowbridge Dr.

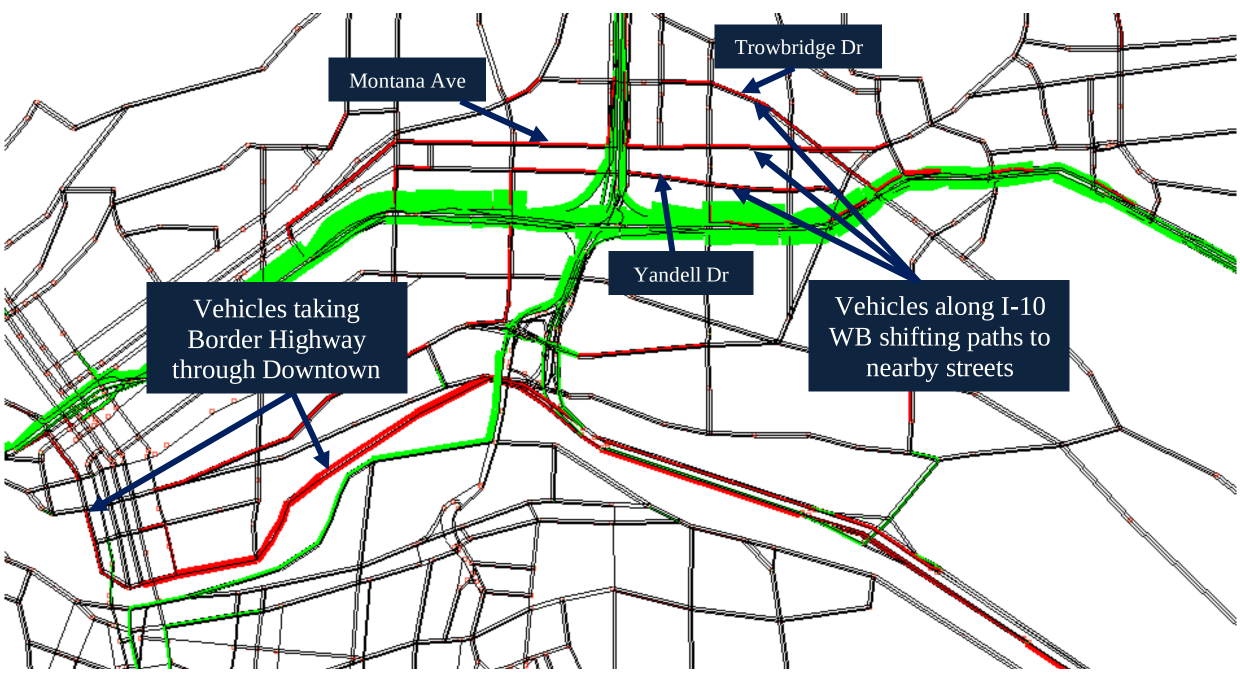

Figure 19: Catastrophic vs. Base Volume Comparison - Border Highway Higher Volume

As shown in Figure 20, during the morning peak hours delay increases significantly on I-10 WB . Also, the high delay at the Paisano Dr / Chelsea St intersection delay is produced due to vehicles exiting I-10 to take Paisano Dr or Alameda Ave.

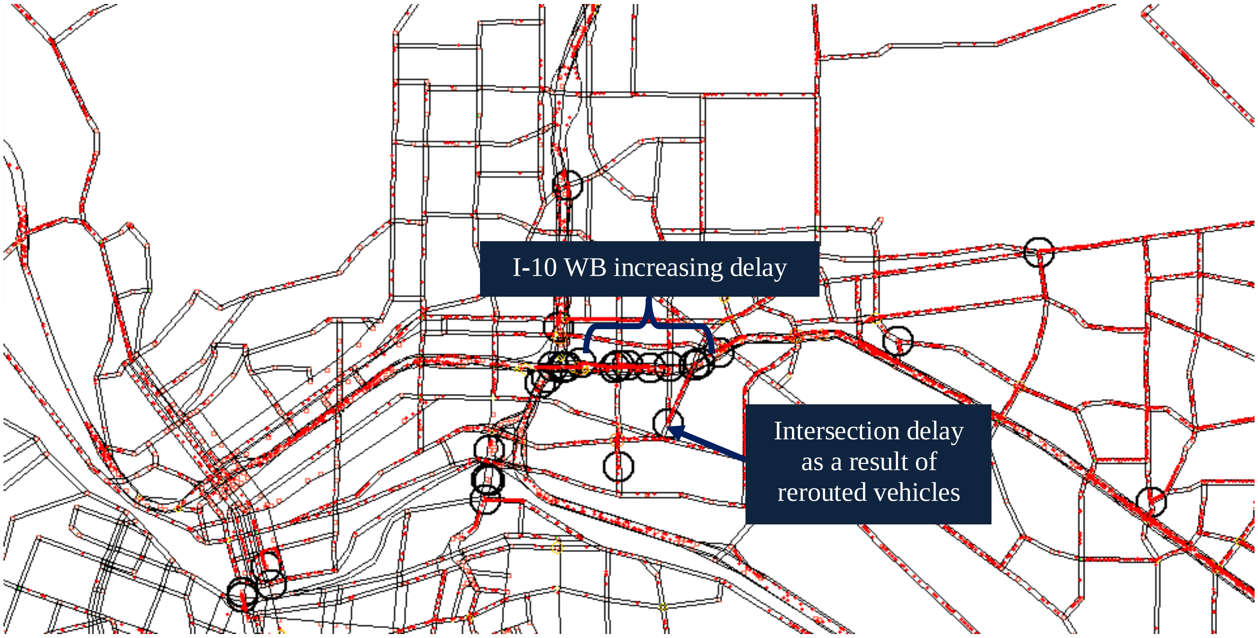

Figure 20: Delay Spots on I-10 and Paisano

Border Highway which is located along the border between El Paso and Juarez maintains with high levels of density (reaching more than 100 vehicles/mile/lane) after 7:00 a.m. The same can be said about the express toll lanes located along the highway. However, Border Highway might be the most viable alternate route when traveling from the west to the east side and vice versa. Other alternative paths drivers utilized such as Paisano Dr, Alameda Ave, and Montana Ave suffered from higher delay times because of the amount of traffic signals. Such signals would need re-configuration to give priority to the heavy through traffic.

4.2 FLOOD SCENARIO – RESULTS ANALYSIS

4.2.1 Short Term Impact

The 2006 flood experienced in El Paso caused high delays on various points of the city including a segment of I-10 near the central business district. The vehicle speed upstream of the freeway segment dropped considerably as capacity kept reducing due to the levels of precipitation. Figure 21 and Figure 22 represent the speed on I-10 WB and I-10 EB respectively when approaching the flood area. Stop-and-go conditions were experienced on both directions of I-10 with speeds of less than 6 mph. Similar speeds were seen on other areas of the city (i.e. southeast and northeast regions) that were also affected by the storm. The areas affected can be seen on Figure 23. The density reached levels of 180 vehicles/mile/lane on flooded streets such as N Loop Dr, Dyer, Railroad Dr, and Dyer St.

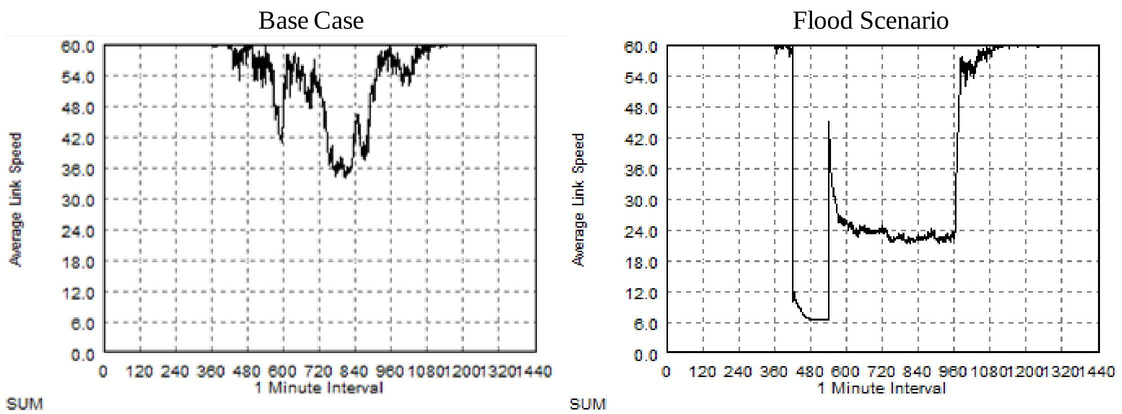

Figure 21: Speed on I-10 Westbound Upstream of Incident Area

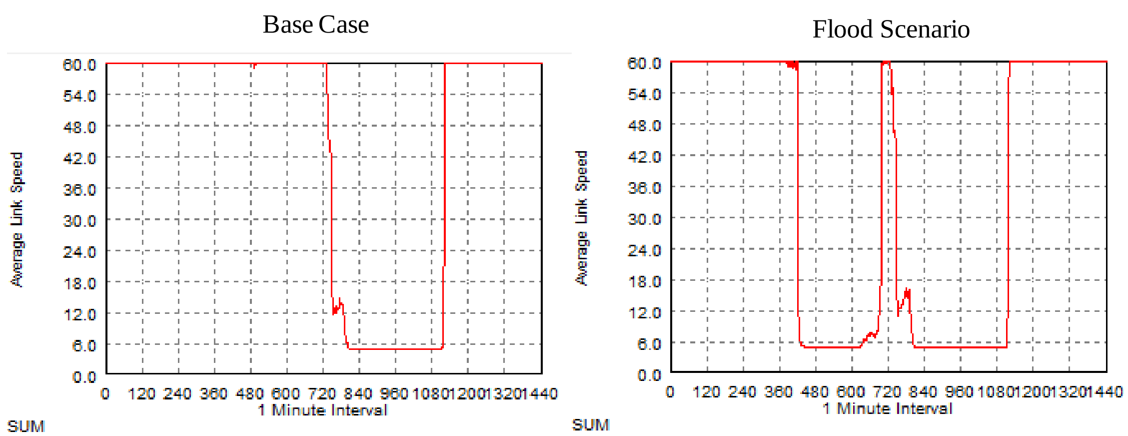

Figure 22: Speed on I-10 Eastbound Upstream of Incident Area

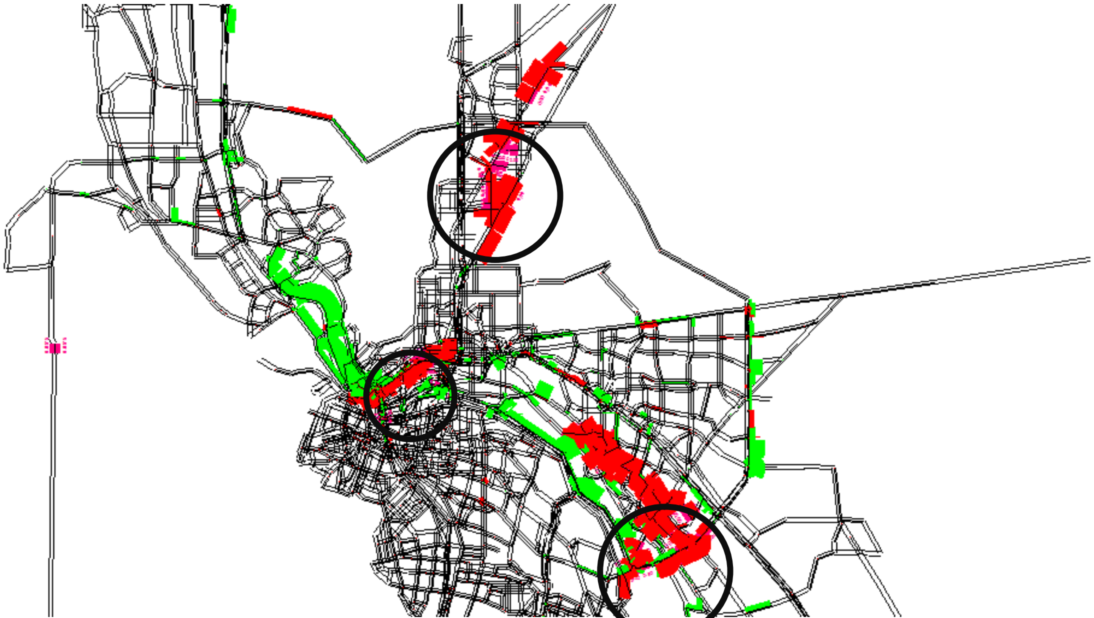

Figure 23: Density Levels on El Paso due to Flooding Incident

4.2.2 Long Term Impact

The flood areas located on the southeast region of El Paso (i.e. lower valley) re-routed vehicles towards Border Highway and Alameda Ave. The majority of the vehicles going into Border Highway from the lower valley utilized the Padres Dr and Yarbrough Dr intersections as shown in Figure 24. Furthermore, Loop 375 SB vehicle traffic decreased due to the flooded area located in the N Zaragoza Rd / Loop 375 intersection.

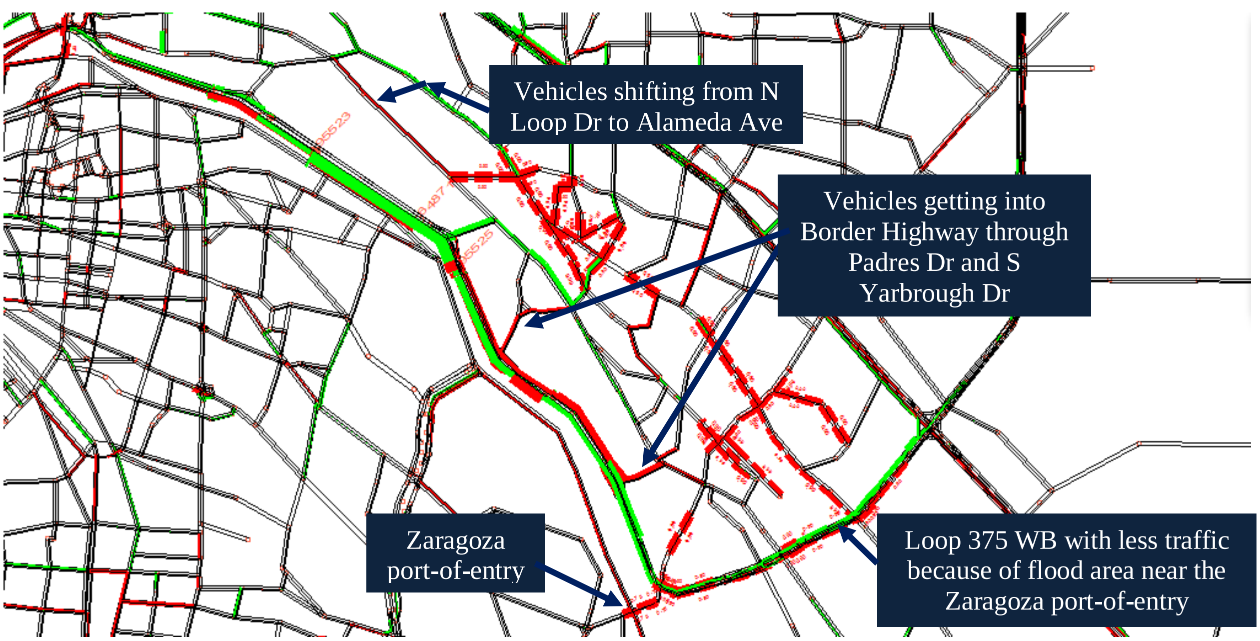

Figure 24: Flood vs. Base Volume Comparison– Southeast Region of El Paso

The northeast region of El Paso affected led to the partial closure of Railroad Dr between Hondo Pass Ave and US 54 (see Figure 25). This caused vehicles to shift routes and take US 54 instead of Railroad as shown in the figure below. As a result, speed dropped significantly (e.g. 5 – 10 mph) during the afternoon peak hours (i.e. 4:00 pm to 7:00 pm) for both NB and SB directions on US 54.

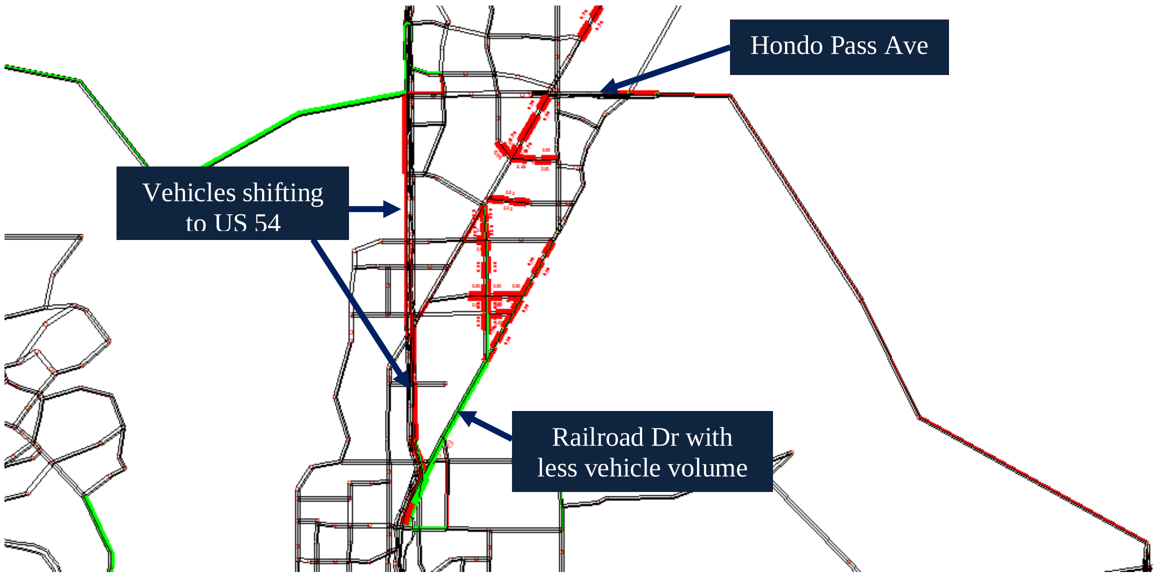

Figure 25: Flood vs. Base Volume Comparison – Northeast Region of El Paso

Similar to the catastrophic scenario, vehicles were shifting towards Border Highway through downtown given that I-10 was shut down completely near Cotton St (see Figure 26). Consequently, density levels throughout the downtown area increased during peak hours. This is also due to the fact that the vehicle capacity on downtown streets is limited by the traffic signals and number of lanes. Vehicles traveling to the west side of the city were utilizing Montana Ave and then taking N Mesa St.

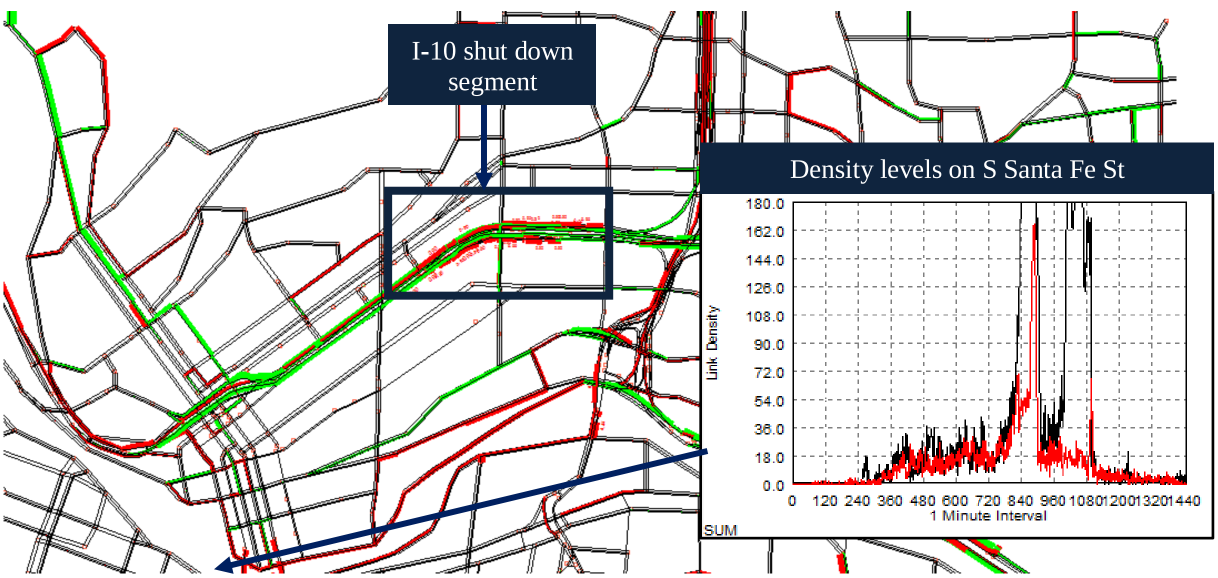

Figure 26: Flood vs. Base Volume Comparison – CBD Area

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The integration of DTA to the El Paso – Juarez bi-national model allowed the researchers to represent successfully a time dependent road network (e.g. vehicle overtaking, spillback) of the border region. However, in order to do so a number of steps were followed to go from an existing bi-national TRANUS land based model to the DynusT software platform (using the newest Dynustudio interface). This ensured that the network would remain without any inconsistencies including: missing attributes, road network errors, and O-D discrepancies. The bi-national TDM was then utilized to model three extreme event scenarios. The scenarios included: simulating the collapse of a major interchange, replicating the 2006 El Paso flood areas, and modeling a hazmat incident on I-10. Traffic pattern changes, hotspots, and general observations were documented after a thorough analysis.

The catastrophic scenario which simulated the collapse of the I-10 / US 54 interchange caused vehicles to look for alternative paths when traveling along I-10, US 54, or nearby arterials. Traffic was utilizing Border Highway to travel between the west and east side of the city. However, given that there is no direct connection from I-10 EB into the highway drivers were re-routing through downtown. As a result, the downtown area experienced congestion on streets like S Santa Fe St and E. Paisano Dr. Vehicles

The 2006 flood replicated in the Dynust model showed similar alternative routes taken when compared to the catastrophic scenario. The flooded south east region of El Paso made vehicles take Border Highway through Padres Dr and S Yarbrough Dr instead of traveling along N Loop Dr. Furthermore, the flood area on the north east region slowed traffic considerably on Railroad Dr (between Hondo Pass and Fred Wilson Ave) and thus vehicles opted to take US 54 to reach their destination. The closure of I-10 near N Cotton St rerouted drivers to nearby streets such as E Paisano Dr, Montana Ave, and Alameda due to the high density levels experienced in the affected infrastructure.

The newly developed DTA based bi-national model was tested with three scenarios effectively. The research team will be able to perform further studies in the border region by taking into account both El Paso and Juarez time dependent traffic behavior patterns.

CHAPTER 6: REFERENCES

1. May, A. *Fundamentals of Traffic Flow.* Englewood Cliff : Prentice-Hall Inc., 1990.

2. Tolle, J. Vehicular Headway Distributions: Testing and Results. *Journal of the Transportation Reserarch Record.* Washington D.C. : Transportation Research Board of the National Academies, 1976. No. 567.

3. J. Darrock, G. Newell, R. Morris. Queues for Vehicle-Actuated Traffic Light. *Operations Research, Vol. 12.* 1964.

4. Center for International Intelligent Transportation Research Texas Transportation Institute**.** *Application of an Integrated Land Use and Transport Model to the El Paso and Ciudad Juarez Bi-national Area.* El Paso, Texas : s.n., 2011.

5. Modelistica. [Online] http://www.modelistica.com/home.

6. El Paso Metropolitan Planning Organization. *Distribution of Vehicle Trips (AUTO driver) by Time of Day Based on a Household Survey.* El Paso, Texas : MPO, 1994.

7. Logistics, PTV Traffic Mobility. *VISUM 11.5 Basics.* Karlsruhe : s.n., 2010.

8. Texas Transportation Institute. *Implementing a Roadway Freight Performance Measure at the Border.* 2008.

9. Rajbhandari, Rajat, Villa, Juan Carlos and Aldrete, Rafael. *Expansion of the Border Crossing Information System.* s.l. : University Transportation Center for Mobility, Texas A&M University, 2009.

10. Texas Transportation Institute. *Measuring Border Delay and Crossing Times at the U.S.-Mexico Border Tasks 1 and 2 Report.* Washington D.C. : Federal Highway Administration, 2007.

11. Federal Highway Administration. *Traffic Analysis Tools.* Washington D.C. : s.n., 2008. http://ops.fhwa.dot.gov/trafficanalysistools/index.htm..