APPENDIX E DYNAMIC TRAFFIC ASSIGNMENT METHODS AND ASSUMPTIONS & DYNAMIC TRAFFIC ASSIGNMENT 2010 MODEL CALIBRATION RESULTS

NORTH I-25 PEL
DYNAMIC TRAFFIC ASSIGNMENT (DTA) METHODS AND ASSUMPTIONS

Prepared for:

Colorado Department of Transportation

Prepared by:

Felsburg Holt & Ullevig
6300 South Syracuse Way, Suite 600
Centennial, CO 80111
303/721-1440

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Lyle.DeVries

From: Monica.Pavlik@dot.gov
Sent: Wednesday, August 22, 2012 5:21 PM
To: Andrew.Stratton@dot.state.co.us
Cc: Chung.Tran@dot.gov; Toni.Whitfield@dot.gov; Lyle.DeVries; Shaun.Cutting@dot.gov; Duane.Hendrickson@dot.state.co.us; Leela.Rajasekar@dot.state.co.us; Steven.Hersey@dot.state.co.us; Shaun.Cutting@dot.gov
Subject: RE: Methods and Assumptions Document

Andy,

FHWA concurs in this document for the methods and assumptions for getting to a calibrated sub-model.

Monica Pavlik

FHWA-CO Division
cell - (720)244-6061
office - (720) 963-3012

From: Stratton, Andrew [mailto:Andrew.Stratton@dot.state.co.us]
Sent: Friday, August 10, 2012 11:40 AM
To: Pavlik, Monica (FHWA)
Cc: Tran, Chung (FHWA); Whitfield, Toni (FHWA); Lyle.DeVries@FHUENG.COM; Cutting, Shaun (FHWA); Hendrickson, Duane (Jay); Rajasekar, Leela; Hersey, Steven
Subject: RE: Methods and Assumptions Document

Monica,

Attached is the final methods and assumptions document for the North I-25 PEL produced by FHU that addresses the previous comments. CDOT approves the document and is requesting FHWA provide approval as well. Please respond to this email with concurrence.

Let me know if you have any questions or concerns with the document.

Thanks for the help and input FHWA has provided on this matter.

Andy Stratton, P.E.
Colorado Department of Transportation
Region 6 North Engineering
4670 Holly Street, Unit D
Denver, CO 80216
303-398-6780 (Main)
303-398-6746 (Direct)
303-398-6781 (Fax)

From: Monica.Pavlik@dot.gov [mailto:Monica.Pavlik@dot.gov]
Sent: Thursday, August 09, 2012 11:54 AM
To: Lyle.DeVries@FHUENG.COM; Cutting, Shaun; Stratton, Andrew; Hendrickson, Duane (Jay); Hersey, Steven; Rajasekar, Leela

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1.0 INTRODUCTION

This document describes the methods and assumptions supporting the Dynamic Traffic Assignment (DTA) modeling effort for the North I-25 PEL. The document provides a description of the PEL project, modeling tool(s) to be utilized, analysis time periods, sub-area selection, model calibration, and future-year modeling procedures.

1.1 Overview of PEL

The section of Interstate 25 (I-25) between US Highway 36 (US 36) and State Highway 7 (SH 7) is one of the most congested stretches of interstate in the Denver Metro Area. The average daily traffic along this stretch of I-25 is as high as 174,000 vehicles per day. CDOT is undertaking the North I-25 Planning Environmental Linkage (PEL) Study to look at improving conditions on I-25. The study is evaluating the existing and future operating conditions of the interstate, while considering future development up to Year 2035. The study will identify current trouble spots and a range of improvement alternatives to reduce congestion and improve operations and safety.

The project team has drafted the following purpose statement and supporting problem statements:

PURPOSE: The purpose of the project is to reduce congestion and improve safety on I-25 between US 36 and SH 7 by implementing near-term, multi-modal, and cost-effective transportation improvements that are compatible with long-term options and the recently constructed interchange structures.

PROBLEMS:

- Mobility Problem: Traffic congestion resulting from high traffic volumes and incidents

The corridor regularly experiences extreme and prolonged congestion resulting from high traffic volumes and/or incidents. CDOT speed, volume, and crash data, along with other supplemental data collected, will be used to support this need.

- Safety Problem: Higher than expected crashes due to traffic congestion

Safety performance functions indicate that I-25 between US 36 and 84th Avenue and I-25 at the 120th Avenue interchange experiences higher than expected rear-end and sideswipe crashes when compared to other similar facilities. These types of incidents increase as congestion increases. CDOT volume data and safety performance functions will be used to support this need.

- Multimodal Problem: Over-capacity multimodal facilities

Parking demand exceeds parking supply at the Wagon Road park-n-Ride and the eastern Thornton park-n-Ride. RTD parking data and supplemental data collected will be used to support this need.

GOALS:

The following project goals are based on desires and fiscal realities understood by CDOT and project stakeholders. While the goals are not project needs or the project purpose, they will provide guidance for alternatives development and evaluation throughout the PEL process.

Alternatives should:

1. Expand/enhance transportation options
2. Maximize the use of existing infrastructure
3. Complement and utilize services and goals of the newly formed TMO
4. Avoid and minimize impacts to environmental and cultural resources
5. Identify and prioritize improvements that can proceed independently
6. Coordinate with local plans and projects
7. Maximize sustained benefits
8. Minimize throwaway projects

1.2 Selection of DTA Modeling Tool

The DTA modeling tool DynusT has been identified by the project team as an appropriate traffic modeling tool to utilize on the project for the following reasons:

- Managed lanes are a part of the No Action alternative for the corridor, and DynusT possesses the capability of modeling real-time driver decisions to utilize a managed lane or not.
- A regional DynusT model of Year 2010 conditions is currently being developed by the Denver Regional Council of Governments (DRCOG), so a DynusT model developed for the PEL can be set within the larger context of the region.
- DynusT is capable of modeling the real-time relationship between congestion along I-25 and driver decisions to utilize parallel alternate routes.

2.0 TIME PERIODS

2.1 Time Horizon

As previously mentioned, DRCOG is nearing completion of a regional DynusT model of the full MPO area representing Year 2010 conditions. To stay consistent with the regional efforts, Year 2010 was chosen as the base year for I-25 PEL DynusT modeling. The base year will be used to replicate current conditions and to evaluate the performance of the new managed lane. The Year 2010 model will also be used to evaluate the PEL alternatives for phasing purposes. A future year model will be used to evaluate alternative performance for screening purposes.

The Year 2035 has been selected for modeling of alternatives, for the following reasons:

- A 20-year (or current long-term planning horizon) analysis is required by law for all roadway projects using federal funds.
- Year 2035 analyses would provide more extensive evaluation of the impact of traffic growth on corridor conditions and the longevity of individual improvements.

2.2 Modeling Scenarios

Current Conditions

The Year 2010 model is being developed to replicate Year 2010 conditions, and this model will be calibrated using Year 2010 traffic counts and recorded speeds. The available DRCOG regional model also targets Year 2010 conditions.

No Action

The No Action condition incorporates programmed roadway improvements. Two No Action models will be developed for the PEL: Year 2010 and Year 2035. Importantly, the No Action models will include a managed lane along I-25 between US 36 and 120th.

Components

Components are being identified and screened through the PEL process. Components will be modeled using the Year 2035 condition, and screened based on comparative measures. Some components will also be modeled using the Year 2010 condition to assist with prioritization and phasing.

Of note, calibration adjustments made to the Year 2010 model will be propagated forward into the 2035 modeling process in some form. The exact nature of how the adjustments will be propagated is currently undetermined, but will be coordinated with University of Arizona Staff.

2.3 Analysis Time Periods

The project team has observed that portions of I-25 in the PEL study area are routinely congested during roughly the following time periods:

- 6:00 AM to 9:15 AM
- 3:15 PM to 6:45 PM

To capture these currently congested hours and allow for analysis of potential longer congested periods in the future, the DynusT model will include demand for the following time periods:

- 5:00 AM to 11:00 AM
- 2:00 PM to 9:00 PM

As shown on **Figure 1**, these time periods correspond to the directional peaking characteristics of recorded hourly traffic volumes along I-25 north of US 36, at the south end of the study area.

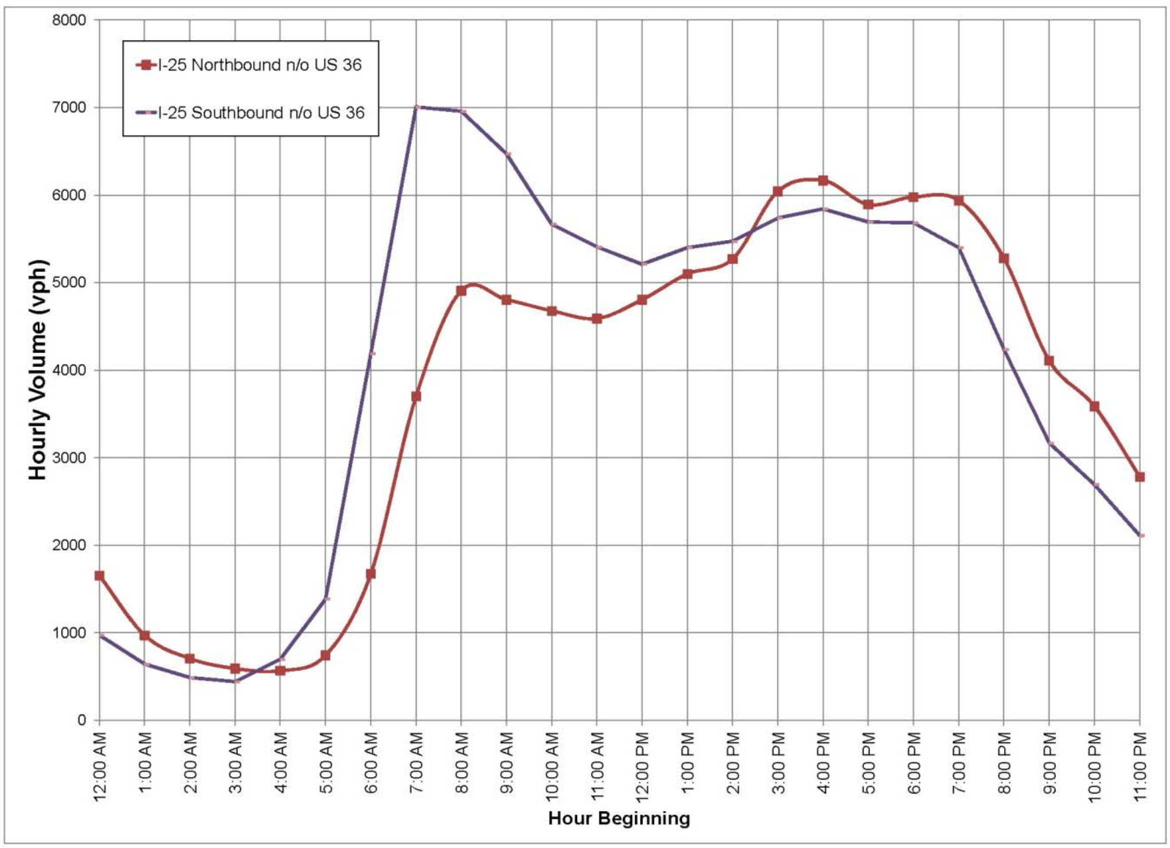


Figure 1. Hourly I-25 Traffic Volume by direction

3.0 SUB-AREA DEVELOPMENT

The objective of the sub-area network is to provide more relevant, detailed information to the specific I-25 PEL project application by analyzing a smaller study area within the regional model. A sub-area model allows input of detail in the project area, such as intersection geometry and traffic signal information. The sub-area network also improves the computational speed of the model run due to limited network and demand size, while retaining origin-destination patterns and vehicle trajectories consistent with the region-wide model.

The following basic steps have been taken to develop the sub-area for the I-25 PEL:

1. Complete dynamic traffic assignment on the regional DynusT model.
2. Define minimum study area
3. Develop sub-area of interest using a multi-link analysis
4. Complete sub-area cut

The resulting sub-area model for the I-25 PEL project is shown on **Figure 2**, with the steps described as follows:

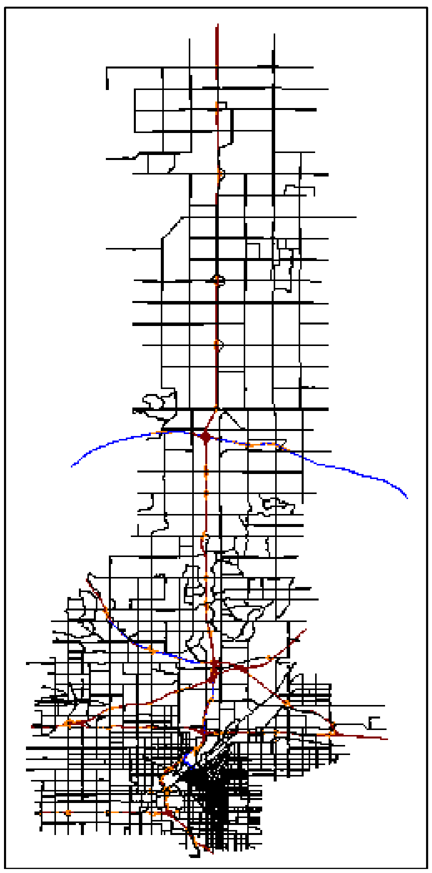


Figure 2. DynuStudio view of I-25 Sub-Area Cut

Step 1: Prepare Regional DynusT Model

The 2010 regional network and trip demand tables have been prepared in DynusT format for the DRCOG model area. The regional network is in good working condition, incorporating any corrections to:

- link connectivity and roadway geometric attributes
- node turn movements
- traffic signal data
- imported vehicle demand information

Calibration of the 2010 regional DynusT model has been performed, ensuring the regional traffic patterns serve as an accurate input into the sub-area demand. The regional network has been run to User Equilibrium (UE) for the analysis period(s) of interest. This means the final path assignment follow UE principles regarding equal and minimum travel time for all used paths from each origin-destination (OD) pair. The sub-area network will undergo further calibration after the sub-area cut is established.

A similar procedure will be utilized to complete the Year 2035 sub-area cut.

Step 2: Identify Minimum Study Area

The minimum study area, the area of interest within which PEL components will be evaluated, includes I-25 from its interchange with US 36 north to the I-25 / County Road 8 interchange (one interchange north of the SH 7 interchange). It also includes Washington, Huron, and Pecos Streets, which parallel I-25 through portions of the study area, and all of the arterials that cross and/or interchange with I-25 between US 36 and SH 7. The area is depicted on **Figure 3**.

Step 3: Perform Multi-Link Analysis

The sub-area is designed to be larger than the minimum study area. The sub-area includes additional network coverage because of the DTA's ability to assess alternative routes near the study area. The design of the sub-area network considers the DTA application at-hand, as different applications require different considerations of the extent of the sub-area boundary. A multi-link analysis is performed using simulation

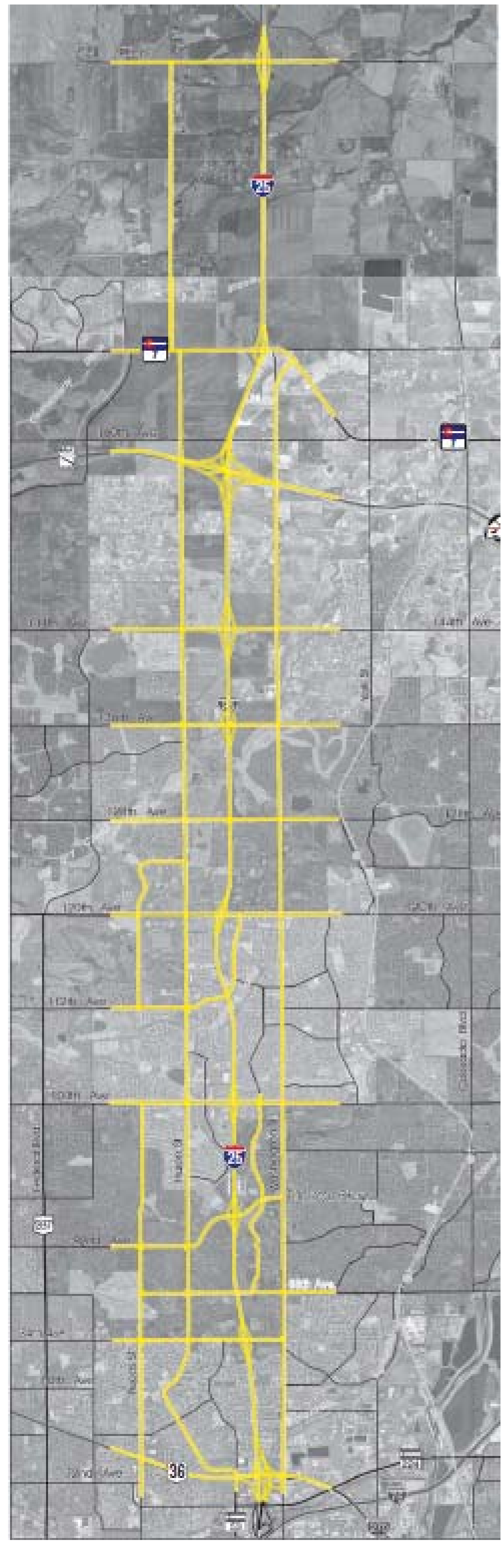


Figure 3. Minimum Study Area

results from the regional network, traffic volumes from links within the study area are used to trace the extent of contributing OD pairs. Vehicle trajectories (simulation data from vehicles based on their assigned routes) are examined based on the selected links within the study area. This examination includes a vehicle's OD pair and time of departure. With this data, the "major" contributing OD pairs whose volumes travel through the study area are determined. This information molds the shape of the sub-area boundary by determining what zones contribute to links within the study area.

The objective of the I-25 application is to examine the north-south I-25 corridor between US 36 and the Northwest Parkway. Therfore, north-south parallel routes need to be considered as part of the sub-area analysis so that potential scenarios being modeled have alternative routes outside the corridor of interest. It was determined that the northern and southern borders of the sub-area would be extended as much as possible to model the characteristics of longer trips on I-25, particularly related to the use of the future managed lane along I-25.

Figure 4 demonstrates the contribution of OD pair volumes based on six links at three selected locations (a pair of links at each location) along the I-25 corridor between US 36 and the Northwest Parkway.

1. I-25 & N/O E 144th Ave
2. I-25 & S/O E 120th Ave
3. I-25 & S/O E 84th Ave

The highlighted zones represent origin or destination zones found to produce at least one vehicle to travel through one of the six links.

Step 4: Complete Sub-area Cut

Figure 4 depicts the analysis performed to approximate the sub-area boundary. The result of the PM peak period (4pm – 6pm) simulation was used in the analysis as it demonstrated a greater zonal coverage of the network for a better understanding of the travel flows throughout the region. The blue color represents a zone of at least one trip that traveled through one of the selected links on I-25. The green color represents a zone of ten or more trips that traveled through one of the selected links on I-25. Finally, the yellow-highlighted zones represent ten or more trips within the sub-area boundary.

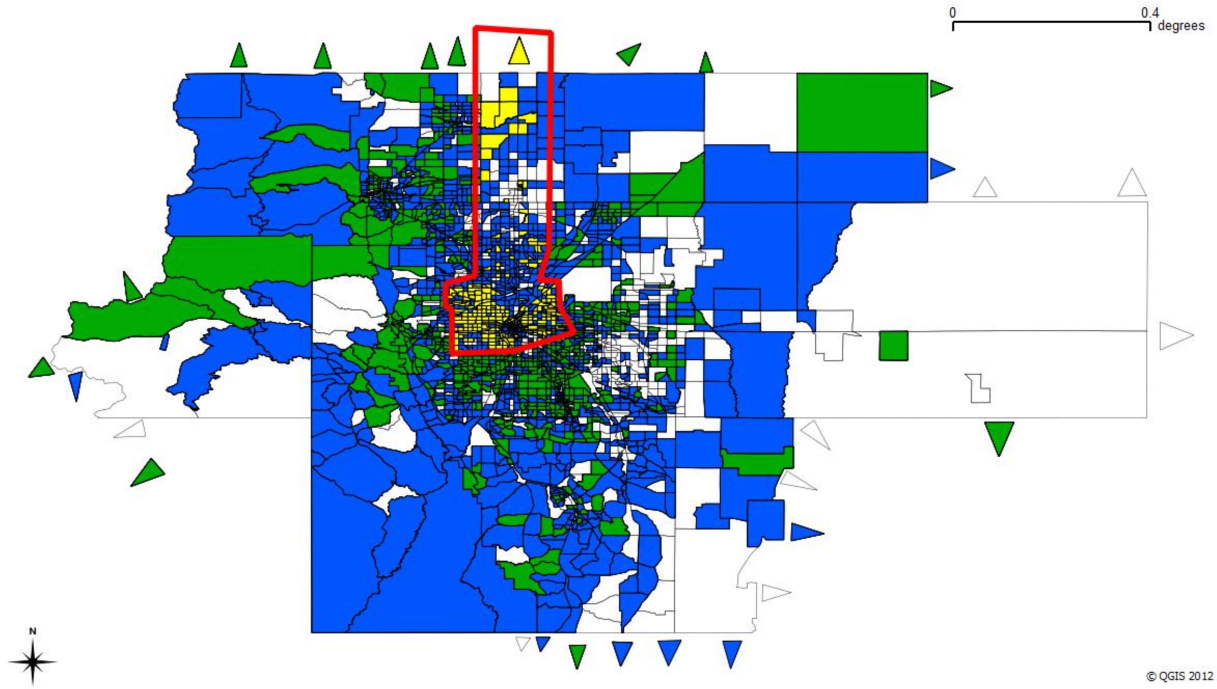


Figure 4. Regional multi-link analysis for the sub-area cut.

In **Figure 4**, yellow highlights the origin and/or destination zones with 10 or more vehicles that traveled through any one of the selected links.The multi-link analysis determined where the majority of traffic is originated or destined. It was found that trips (at least ten or more) from northern external zones traveled through the I-25 study area. A concentration of zones within the central portion of the network (downtown) was largely destination zones. This information helped determine that the downtown area and south of the downtown area should be included in the network. It was found that trip origins (at least ten or more) were largely concentrated near the central portion of the network, as well as the northern portion of the network.

The result of the process is depicted on **Figure 5**. As shown on the figure, the sub-area extends beyond the minimum study network to include portions of several major freeways and tollways, as well as additional parallel arterial links such as Colorado Boulevard and Federal Boulevard.

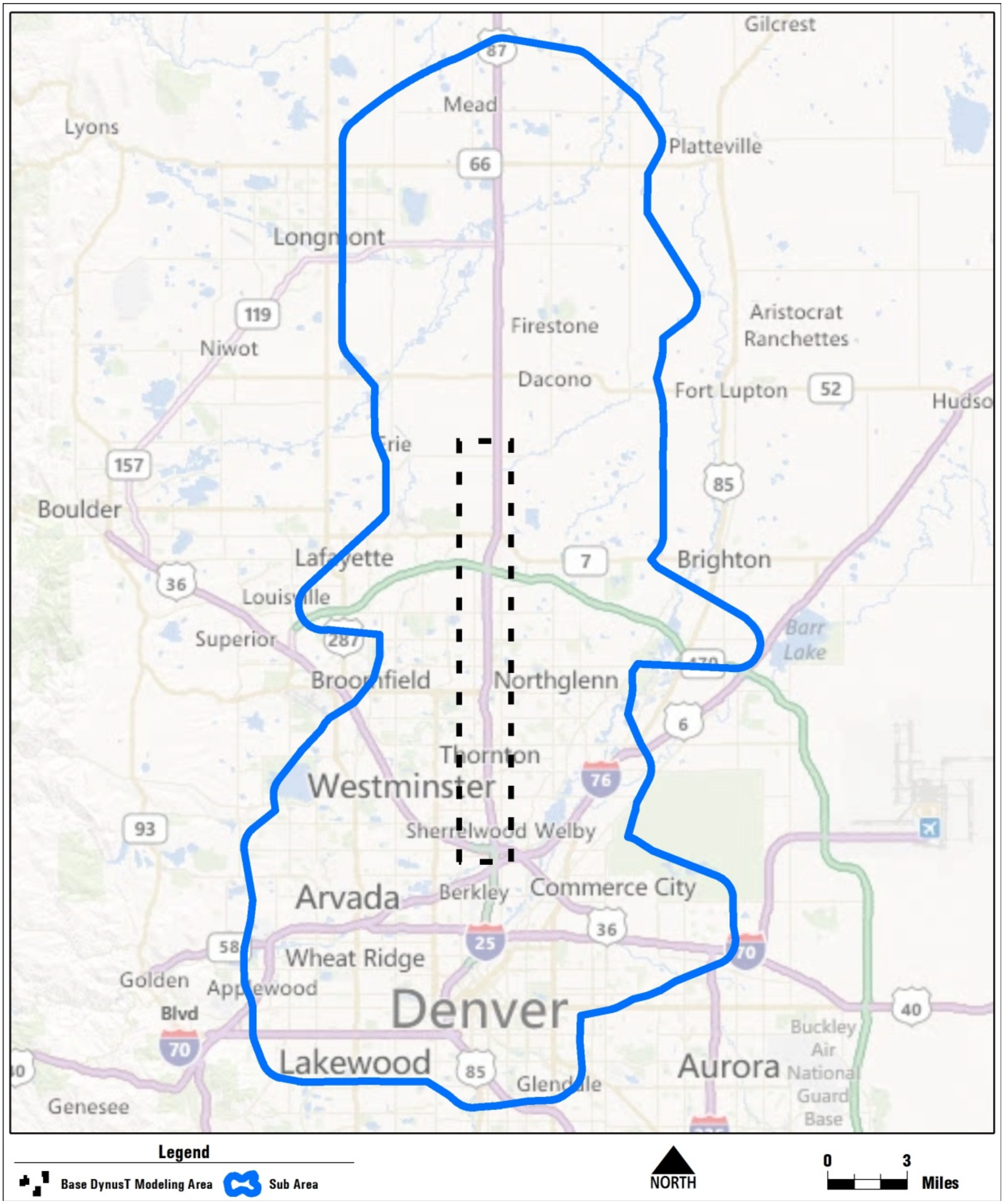


Figure 5. Sub-Area and Minimum Study Area

4.0 MODEL ADJUSTMENTS AND CALIBRATION

The process to prepare and calibrate the sub-area model is depicted on **Figure 5.**

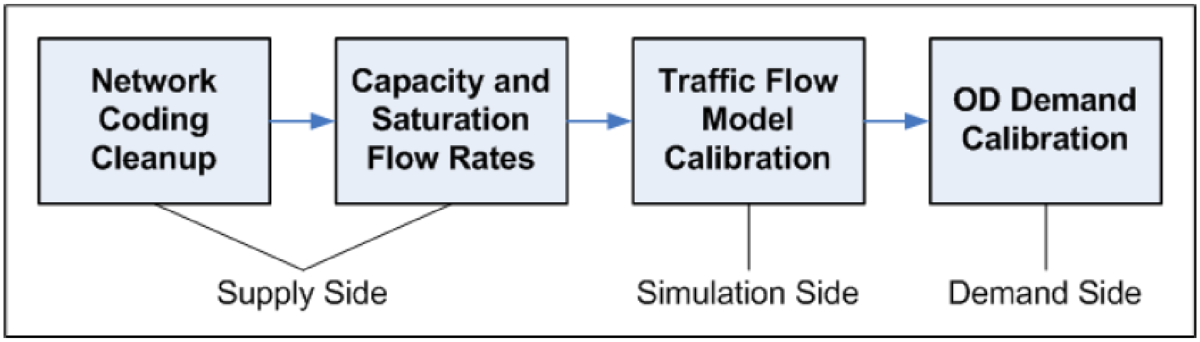


Figure 6. Model Adjustments and Calibration Steps

As shown, the process of creating a viable, representative sub-area model begins with adjustments to the characteristics of the physical transportation network and finishes with calibration of the traffic flow model and Origin-Destination tables.

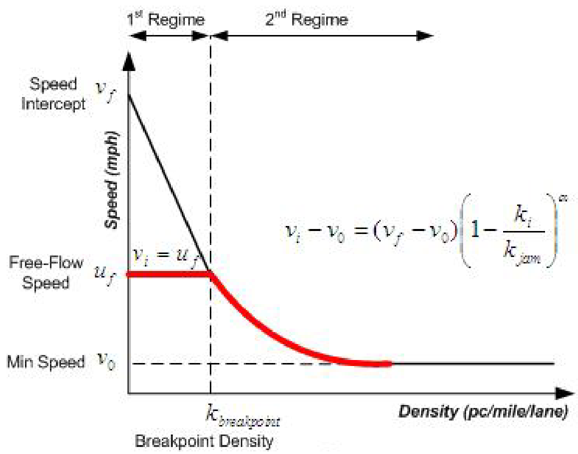
4.1 Supply Side

Network coding cleanup has been performed to correct any network link continuity problems or intersection misrepresentations. Capacity and saturation are specified for the network based on typical observed conditions. A saturation flow rate of 1,800 vehicles per hour per lane will be utilized for the I-25 PEL sub-area.

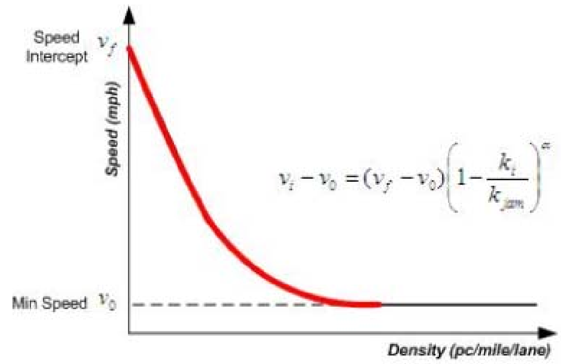
4.2 Simulation Side

Any necessary changes will be made to the simulation component of the DynusT sub-area to calibrate the freeway traffic flow model (TFM) used in the network. The TFM is the simulation mechanism that updates the state of a vehicle based on density and speed. The flow model utilized in DynusT is called the Modified Greenshield's Model, which follows the basic traffic engineering principles and relationships of speed, density, and flow.

There are two types of TFMs identified in DynusT. *Type 1* dictates the freeway's traffic flow behavior because freeway-type facilities represent uninterrupted flow and can withstand higher density at nearly free-flow conditions. *Type 2* is arterial facility traffic flow behavior, which is more sensitive to density changes due to interrupted flows (traffic control devices and cross-street traffic). The flow models are demonstrated in **Figure 7**.



(a) Type 1 Traffic Flow Model



(b) Type 2 Traffic Flow Model

Figure 7: Examples of Type 1 (a) and Type 2 (b) traffic flow models used in DynusT

Five-minute interval speed, flow and occupancy data collected during September of 2011 are available for mainline I-25 in the study area, and will be used to develop a custom Type 1 TFM. The standard Type 2 TFM shown on **Figure 7** will be used for arterial facilities, based on default models used from previous DynusT networks of similar size. The parameters of the TFMs are given in **Table 1**.

Table 1: Traffic flow models used in the DynusT Network

Type 1 (Freeway)		Type 2 (Arterial)	
Density Breakpoint	To be determined	Density Breakpoint	N/A
Minimum Speed	5	Minimum Speed	7
Jam Density	180	Jam Density	165
Shape Term	To be determined	Shape Term	2.4

4.3 Origin-Destination Calibration

4.3.1 Traffic Data Periods

The traffic data that is used to calibrate the model will cover the time period of interest for the I-25 PEL. Typically, the calibration period extends beyond the typical peak period to model the ramp up to and recovery from traffic congestion. In the case of the I-25 PEL, it is proposed that the calibration period extend for 4 hours during and beyond the morning peak period (6-10 AM) and 4 hours during and beyond the afternoon peak period (3-7 PM). Extending the calibration period is helps to capture the shoulders of the peak period and the duration of congestion. As previously described, the modeled demand period is going to start earlier than the calibration period to capture the time offset between the arrival time of traffic data and the departure time of vehicles as **Figure 8** depicts.

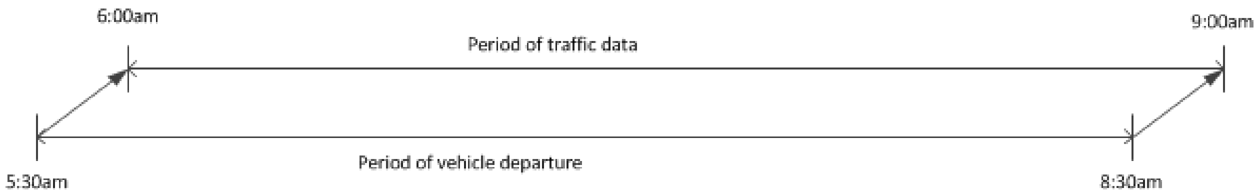


Figure 8. Example of data collection versus vehicle departure

4.3.2 Traffic Data Collection

Traffic data was collected to represent a typical travel weekday in the network. Where available, traffic counts have been compiled from historical data in order to determine not only the average traffic count, but also the range and variance of daily traffic. The calibration should be reflective of this range with an understanding that traffic does naturally vary from day to day.

Traffic volumes were recorded continuously throughout the Year 2010 at the Automatic Traffic Recording (ATR) location along I-25 north of State Highway 7. Using guidance provided in the Traffic Monitoring Guidebook published by FHWA in 2001, the data from this ATR location were used to evaluate the day-to-day variation in traffic levels and select an average month for calibration. **Figure 9** depicts the recorded traffic throughout the year.

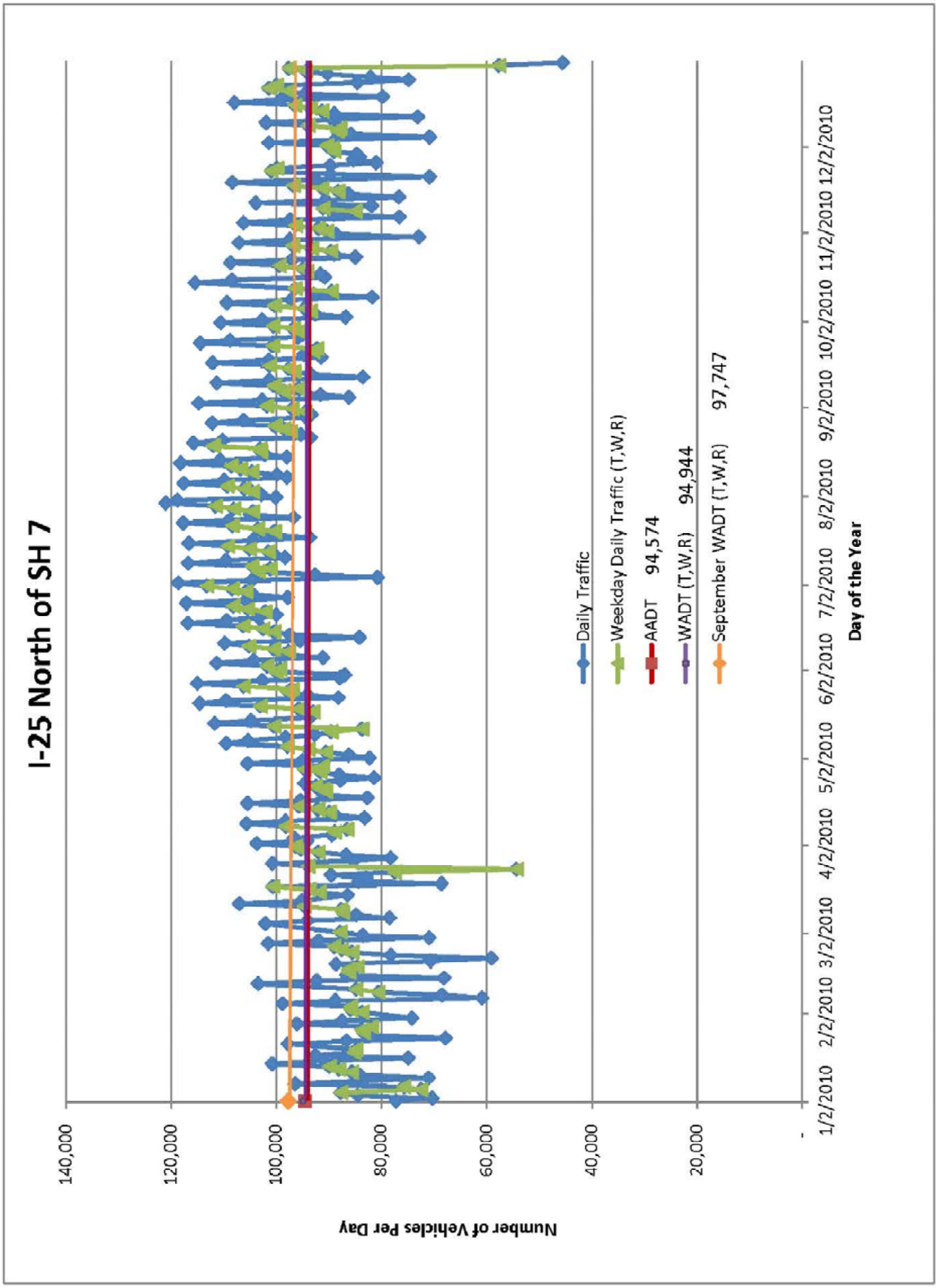
Based on the variation in traffic throughout the year, the month of September was selected as an appropriate representation of the average condition. Traffic counts gathered in other months of the year will be adjusted to reflect September conditions using daily traffic factors for each individual month. The calibration process will focus on Single-Occupant Vehicles (SOV). To estimate the number of SOVs at each count location for comparison with model output, the total counted traffic volume will be reduced by the percentage of overall traffic volumes composed of non-SOVs. Vehicle class percentages from the DRCOG regional travel demand model will be used to calculate the estimated amount of SOV traffic at each count location.

2010 data have been acquired from the following sources:

CDOT Highway Performance Monitoring System (HPMS) – HPMS counts are conducted on arterial facilities at 6-year intervals. All available HPMS counts taken in Year 2010 within the sub-area were provided to the project team by CDOT Staff. **Figure 10** depicts these count locations. The counts capture a 24-hour weekday time period on an hourly basis. As shown, HPMS counts are scattered throughout the sub-area, with the majority located outside of the study area. The HPMS counts available within the study area will be used for calibration, while the HPMS count locations outside of the study area will not be utilized for the following reasons:

- These count locations are not of primary importance to the study area, so calibration of these volumes is not necessary to enhance the quality of PEL outcomes
- These counts represent only a single day, and using more of them could introduce more error into the modeling process

Figure 9. Year 2010 recorded daily I-25 traffic levels



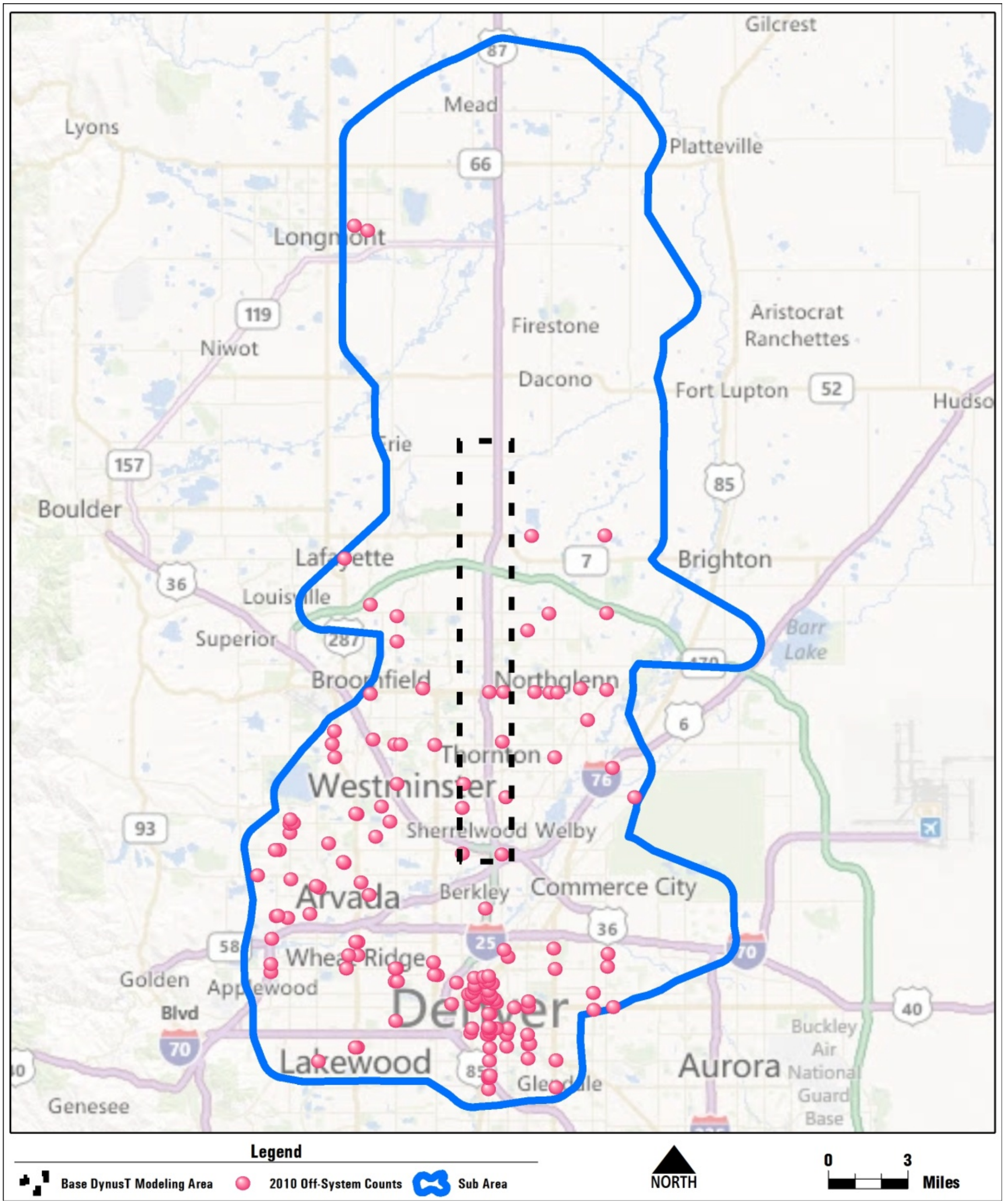


Figure 10. CDOT HPMS count locations 2010

- The sub-area does not necessarily include O-D pairs contributing to these links, meaning that O-D calibration adjustments made on the basis of these counts would be less accurate than counts within the study area

CDOT Short Duration State Highway Counts – CDOT conducts short duration counts along every state highway segment every 3 years. The counts capture a single 24-hour weekday time period on an hourly basis. There are a number of short duration counts along I-25, 120th Avenue, and State Highway 7 available for the Year 2010 in the study area. For the reasons described above for the HPMS counts, the short duration counts outside of the study area will not be utilized for calibration.

CDOT Automatic Traffic Recorder (ATR) Locations – There are five ATR locations within the sub-area:

- I-25, North of SH 7
- I-25, South of SH 6
- I-76, Northeast of 88th
- I-270, Southeast of York Street
- SH 44 (104th Avenue), West of Brighton Rd

Of these locations, four are located along interstate freeway facilities in the sub-area. The counts from these four locations will be used for calibration.

Figure 11 depicts the set of traffic counts to be utilized in the calibration process. A total of 22 hourly counts will be utilized within the study area from HPMS, CDOT short duration and CDOT ATR sources. The three additional ATR's located within the sub-area but outside of the study area will be used as 'anchor points' for calibration.

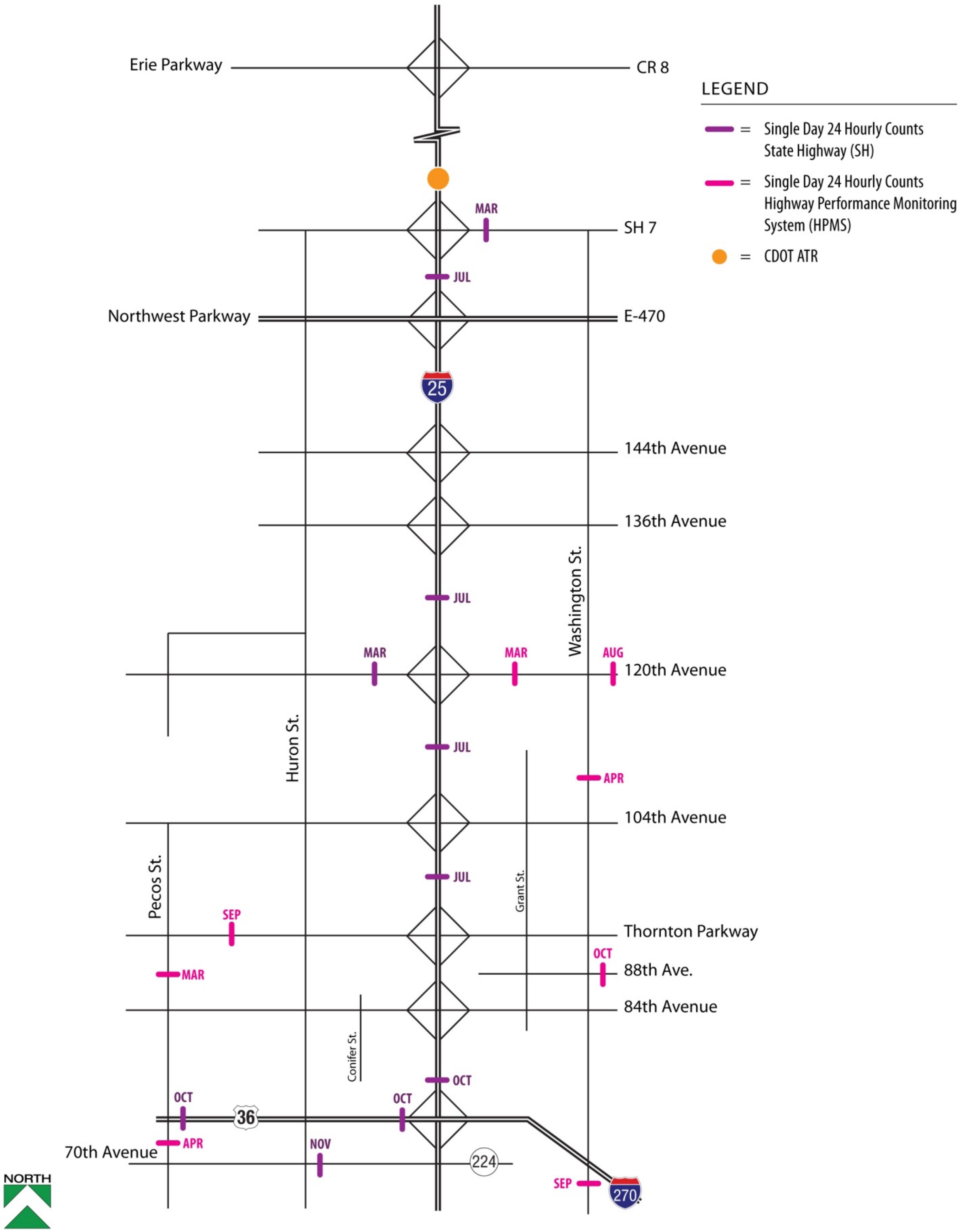


Figure 11. 2010 Count Locations to be Utilized for Calibration Effort

In addition to using the counts, the project team will utilize September 2010 speed data available from the CDOT Intelligent Transportation System (ITS) database for calibration. The speed information will serve as a secondary calibration measure.

4.3.3 Calibration Methodology

The University of Arizona DynusT team has developed a time-dependent Origin/Destination (OD) demand calibration methodology. It is an iterative approach, shown on **Figure 12**, which systematically matches the total link volumes/counts over the entire analysis period (extended peak hours) by adjusting the OD entries through the optimization model. The optimization model adjusts the demand so that the difference between simulated link volumes and observed link volumes is minimal. This minimization is accomplished by a one-norm Linear Programming (LP) formulation, allowing the model to be easily solved by any standard LP solver; MATLAB is used for the proposed methodology.

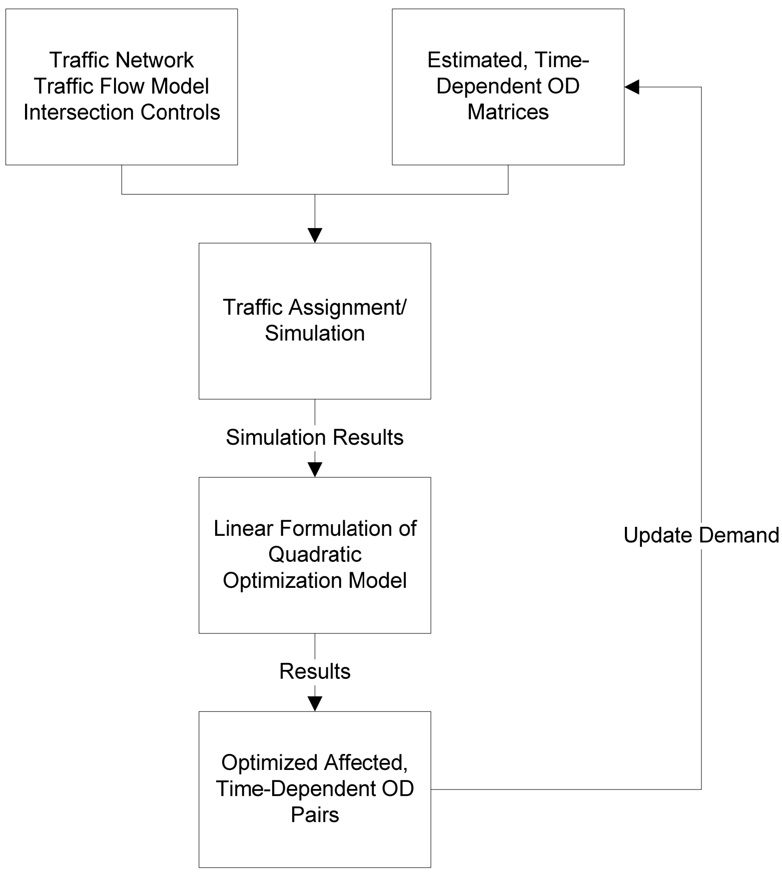


Figure 12: The DynusT OD demand calibration framework

The calibration procedure is formulated as a bi-level optimization problem. The first level is a least-square optimization problem minimizing total link count deviation, and the second level is a time-dependent user equilibrium (TDUE) problem solved by DynusT. The initial OD demand, based on DRCOG's regional model, will be run to user equilibrium to start the process. A post-processing program written in Python will be called to evaluate vehicle-based output data and accumulate information of vehicles (and their associated OD pair), whose paths traverse through any link being evaluated. OD pairs found to have vehicles traveling through evaluated links will be considered affected OD pairs. The ratio of vehicles from an OD pair that travel an evaluated link and the total number of vehicles from that same OD pair will be calculated. The linear optimization solver will then be called to determine the optimal number of vehicles to adjust for each affected OD pair according to the weighted ratios of each affected OD pair. The time-dependent OD demand tables will be rebuilt to reflect the changes, and the demand will be fed into DynusT, which will then be re-run to evaluate the new demand. This will be done in multiple iterations until the convergence criteria is met at each count location.

The convergence criteria have been identified based on statistical analyses and collaboration with FHWA and CDOT Staff. As previously discussed, traffic flow data from the full calendar year 2010 was available from the ATR location along I-25 north of SH 7. The project team computed an average and standard deviation value for weekday daily traffic volumes to assess the amount of variability present in current I-25 mainline traffic levels. It is reasonable to assume that this variability would also apply to each of the 12 traffic count locations along mainline I-25 shown in **Figure 11**. The data possess a Coefficient of Variation (COV) of 11.3 percent, calculated as the standard deviation divided by the average. The error tolerance was calculated using the following equation:

$$e = \frac{COV * Z}{\sqrt{n}}$$

where:
e = Error Tolerance
COV = Coefficient of Variation of ATR data
Z = Z-value for standard normal distribution for selected Confidence Interval
n = Number of count locations along I-25 being calibrated, 12

A confidence interval of 95 percent was selected based on input from CDOT Staff, translating to a Z-value of 1.96. The resulting error tolerance was calculated at 6.5 percent. The 2010 model will be calibrated with the goal of achieving a 6.5 percent maximum difference between the model result and actual count at each of the 12 I-25 count locations.

The above calculation applies to the I-25 count locations. The calibration process for the remaining 32 traffic count locations located on other facilities in the sub-area will also seek to achieve a maximum error of 6.5 percent. It is important to note that this error tolerance will serve as a goal, and may not be achievable at all count locations. One reason for this is that many of the calibration traffic counts were conducted on only a single day in 2010 and may not represent a consistent condition. The consultant will work with CDOT during the convergence process to determine acceptable deviations in error tolerances based on volumes, facility types, etc.

In addition to the primary traffic-volume based origin-destination calibration, the DynusT simulation effort will include a verification of travel speeds in the model against recorded travel speeds along mainline I-25. Manual adjustments to model parameters will occur if inconsistencies are evident.

5.0 SUMMARY AND NEXT STEPS

This document outlines the Dynamic Traffic Assignment (DTA) methods and assumptions to be utilized for the North I-25 PEL project. The information contained herein includes analysis time periods, the sub-area being addressed by the modeling effort, and the adjustments and calibration efforts entailed in producing an accurate model.

Upon approval of these methods and assumptions, the project team will proceed with modeling efforts and will continue to coordinate with CDOT and FHWA Staff as needed to address questions or provide information from the modeling effort.

NORTH I-25 PEL
DYNAMIC TRAFFIC ASSIGNMENT
2010 MODEL CALIBRATION RESULTS

Prepared for:

Colorado Department of Transportation

Prepared by:

Felsburg Holt & Ullevig
6300 South Syracuse Way, Suite 600
Centennial, CO 80111
303/721-1440

FHU Reference No. 11-166-01
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LIST OF FIGURES

1.0 INTRODUCTION

The purpose of the PEL is to reduce congestion and improve safety on I-25 between US 36 and SH 7 by implementing near-term, multi-modal, and cost-effective transportation improvements that are compatible with long-term options and the recently constructed interchange structures. Implicit with this stated goal is the desire to reduce congestion along the I-25 corridor while minimizing impacts to adjacent parallel north-south facilities.

DynusT has been selected as the principal modeling tool for evaluating alternatives for the North I-25 PEL. This software tool utilizes Dynamic Traffic Assignment (DTA) modeling techniques to evaluate the real-time relationship between congestion along I-25 and driver decisions to utilize parallel alternative routes. DynusT is able to provide insight about the location, duration, and intensity of congestion of the transportation system as vehicle demand on the facility changes over time.

This report describes the calibration results for the Year 2010 I-25 PEL subarea model. The 2010 model was developed to accurately replicate current travel behavior along the corridor, setting the stage for a Year 2035 model to be developed and used to test the effectiveness of various road network alternatives along the corridor as future growth occurs.

2.0 CALIBRATION PRIORITIES

The goal of model calibration is to make adjustments to network and modeling parameters to reach a DTA model that reasonably replicates field traffic conditions, and provides a useful tool for comparative evaluation of components being considered in the PEL. In view of the PEL's focus on I-25, the DynusT calibration effort has been structured to meet the following two priorities, in order of importance:

Priority #1: The calibration outcome needs to ensure that the DynusT model replicates traffic flows at locations along I-25 between US 36 and SH 7 within a tolerance of 6.5 percent or less. Travel speeds are also checked at key I-25 locations to confirm that the model depicts current I-25 congestion.

Priority #2: The secondary calibration priority for the study is to reasonably match traffic flows along other regional freeways in the model subarea; parallel north-south facilities adjacent to the I-25 study corridor; including Pecos, Huron, and Washington, as well as collector and arterial roadways within the minimum study area. Many of the collector and arterial roadways are low-volume, east-west roadways whose role is to properly supply the principal regional roadway system with traffic from adjacent land uses. PEL components applied to I-25 could affect traffic levels along some Priority #2 roadways parallel to I-25, and the DTA model may be used to evaluate the extent of traffic shifts along these roadways resulting from PEL components.

The focus of the PEL components and traffic operations modeling is the I-25 study corridor (Priority #1). Because the Priority #2 locations are not along the I-25 study corridor, the project team determined that as long as Priority #1 locations are matched within 6.5 percent, a less rigorous tolerance would be acceptable for the Priority #2 locations. Therefore, the calibration effort sought to achieve 6.5 percent at a majority of Priority #2 locations.

3.0 CALIBRATION STEPS

The DynusT calibration process involved the following steps, as outlined in the *North I-25 PEL Dynamic Traffic Assignment Methods and Assumptions*, dated August 2012:

1. Pre-calibration Network Adjustments
2. Traffic Flow Model Calibration
3. Origin-Destination (OD) Calibration
4. Speed Verification

The execution and results of these steps are described in the following subsections.

3.1 Pre-Calibration Network Adjustments

In support of the calibration process, the project team conducted a thorough review and made necessary adjustments to the transportation network to ensure consistency with field conditions. Adjustments were made to address general roadway characteristics including travel speed, laneage, intersection movements, and current toll rates on applicable roadways. Ramp metering locations on I-25 within the study area were incorporated into the model to provide realistic vehicular access to the corridor.

3.2 Traffic Flow Model Calibration

The Traffic Flow Model (TFM) included in DynusT governs the speed-flow-density relationship for individual vehicles in the model. A default TFM included in the software provided a starting point for the calibration effort, but this model required further adjustment to ensure proper representation of I-25 traffic characteristics. As described in the *Methods and Assumptions*, a TFM specific to I-25 was developed using existing I-25 speed and density information available from CDOT data sources, and specific changes were made to the default TFM to better reflect observed I-25 traffic flow conditions.

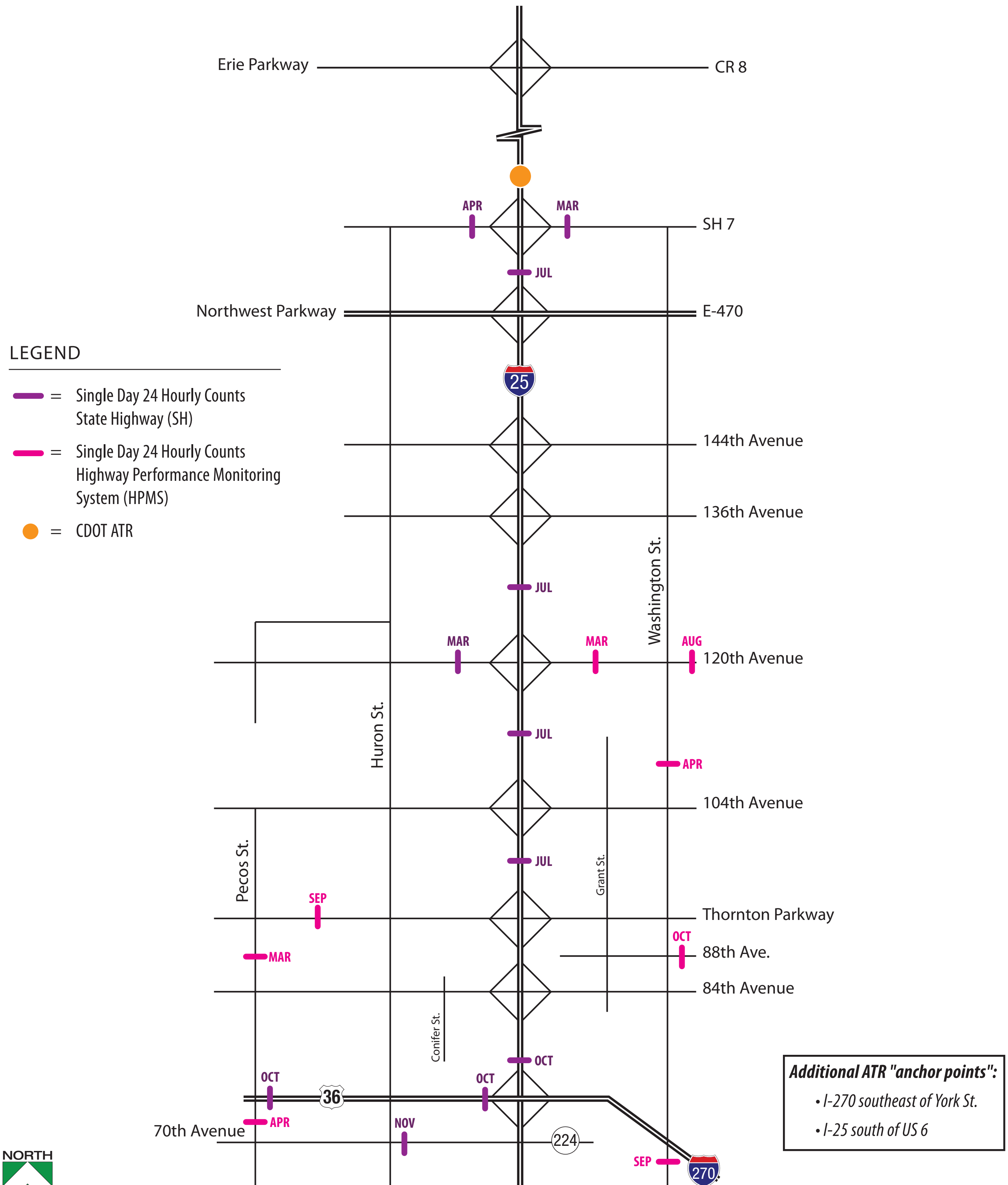
3.3 Origin-Destination (OD) Calibration

3.3.1 Process

The OD calibration methodology evaluates the difference between the total counted traffic volume and the current iteration results at each calibration link, making an attempt to alter the origin-destination pairs passing through the subject link to more closely match the model to count data. A map of count locations used for the OD calibration effort is provided on **Figure 1**.

The OD calibration process required separate calibration of the morning and afternoon time periods. The morning period was calibrated to a four hour period (6:00am-10:00am) and the afternoon period was calibrated to a six hour period (3:00pm-9:00pm). The original procedure outlined in the *North I-25 PEL Dynamic Traffic Assignment Methods and Assumptions*, dated August 2012, anticipated using a four hour period in the afternoon, but during the OD calibration

Figure 1 . 2010 Count Locations to be Utilized for Calibration Effort



process it became clear that in order to accurately replicate operations on the transportation system, two additional hours needed to be added to the calibration process.

As outlined in the *Methods and Assumptions*, forty-two[1] Year 2010 directional daily traffic volumes within the study area have been collected from various sources. Due the natural variation in traffic count data as well as the variation in the count data resulting from the standardization process, a goal for meeting the I-25 traffic volumes in the study area with the model by a 6.5% calibration target has been identified. Other count locations also aimed to reach a 6.5 percent error at the majority of locations, but a less rigorous error tolerance is more acceptable for locations away from I-25 through the PEL study area because the PEL effort is directed toward I-25 improvements.

The OD calibration was an iterative process whereby constant review of interim iteration steps was necessary to ensure the validity of the final model. During this process, the results of interim model runs were reviewed to ensure the calibration process was providing improvements and to identify any subsequent road network or traffic flow model issues identified throughout by the calibration.

Prior to calibration, the DynusT model was generally overestimating AM peak period traffic flows and underestimating PM peak period flows, likely a result of extracting atypical demand intervals from the 24-hour DRCOG Regional model. The OD calibration process addressed these variations by incrementally adjusting demand to more closely match traffic flows.

3.3.2 Results

Priority #1 Results: The OD calibration effort resulted in excellent convergence for the top priority locations along I-25. Considering the AM and PM periods together, 95 percent of the I-25 locations achieved the 6.5 percent target. Full convergence fell short only by 1½ percentage points at a single count location, northbound I-25 north of E-470.

Priority #2 Results: 55 percent of locations away from I-25 reached the 6.5 percent level, including a key count location along the adjacent parallel arterial Washington Street. This percentage is considered a good result that will satisfy PEL modeling objectives. Several factors make full convergence difficult to reach, if not impossible. These include:

1. The error between the model and counted volumes is recalculated after each iteration to determine how the OD tables should be adjusted for the next iteration. During this process, adjustments made to some locations are in direct opposition to needed adjustments at other locations, hindering the model's ability to make decisive steps towards equilibrium.

2. The structure of the overall model network has been imported from the DRCOG regional travel demand model. This network focuses on collectors, arterials, and highways within the network, and does not incorporate local roads and the way access onto the network actually occurs, instead simplifying the local network to enable DRCOG to be able to

[1] The *Methods and* Assumptions listed forty-four locations, two locations along US 36 have been dropped due to duplicate data immediately adjacent on US 36.

provide travel demand for the entire DRCOG study area within computation limits of existing modeling tools. Because of its basis in the DRCOG model, The I-25 PEL DynusT model is similarly subject to misrepresenting local access and failing to adequately capture vehicle-trips along the lesser Priority #2 roadways.

3. Calibration is difficult on the secondary roads due to the magnitude of the vehicle counts being matched. Low volume roadways requiring a match of 6.5% are extremely limited in the number of vehicles and associated OD pairs contributing volume. The following comparison is helpful in understanding the difficulty in matching low-volume roads within such a tight error allowance. Southbound I-25 north of US 36 in the AM period has a counted volume of 21,150 vehicles which allows for a variation up to 1,375 vehicles while southbound Pecos Street north of 84th Avenue has a counted volume of 3,065 vehicles which only allows a variation up to 200 vehicles. This example highlights the difficulty in calibrating low volume roadways within the small 6.5% error tolerance because while the final variation on I-25 is well within the error tolerance by percent, such a strict requirement on low volume contributor roadways makes for a very narrow acceptable range, which is ultimately very difficult for regional models to match.

For those Priority #2 locations not meeting the more rigorous threshold, but the modeling effort would still provide sufficient information about relative traffic shifts.

Overall, the OD calibration results have been determined to be within an acceptable range based on the goals for this study. Tabulated calibration results for all of the count locations are provided in the **Appendix**.

3.4 *Speed Verification*

In addition to calibrating I-25 to counted volumes, speed verification was performed to confirm that the model is accurately replicating conditions under which those traffic flows are occurring along I-25. It should be noted that while speed is the measure under consideration, this is a proxy performance measure to quantify the model's ability to replicate congestion along the corridor. In order to declare that the DynusT model accurately reflects travel conditions along the I-25 corridor, the model must be able to demonstrate reasonable correlation to measured speeds.

The speed verification process was generally successful at replicating speed in terms of location, duration, and magnitude for the morning and afternoon simulation periods. Importantly, speed verification focused on the peak direction, inbound to downtown in the morning and outbound from downtown in the afternoon.[2] The results of the verification effort have been produced for this report by comparing speed over time for three locations along the I-25 corridor: US 36 to 88th Avenue, Thornton Parkway to 104th Avenue, and 120th Avenue to 136th Avenue.

Figure 2 provides the southbound morning peak period speed verification results. As shown, the model speeds track closely with actual data depicting traffic congestion south of 88th Avenue

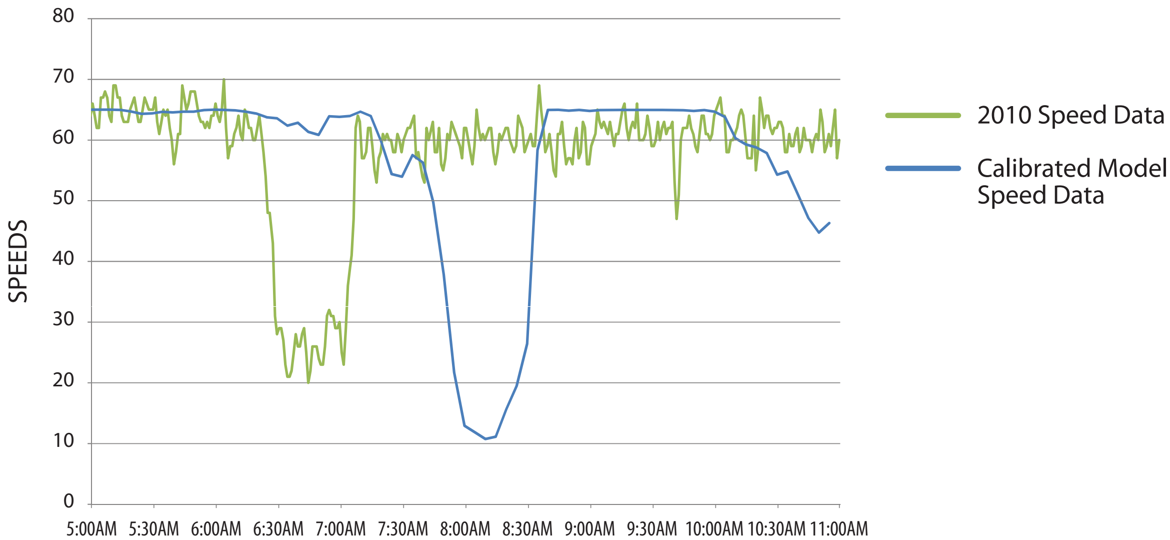
[2] Results from the off peak direction were also reviewed and were found to acceptably replicate 2010 speed conditions along the corridor.

and north of Thornton Parkway. North of 120th Avenue, the model sufficiently predicts the duration and magnitude of a speed decrease but inaccurately places the congestion approximately one-hour after the congestion actually occurs. Calibration adjustments were not pursued for this location due to the inherent changes that would occur downstream from changes in the upstream segment, which represents a more critical section of the corridor and which currently approximates speed decreases appropriately.

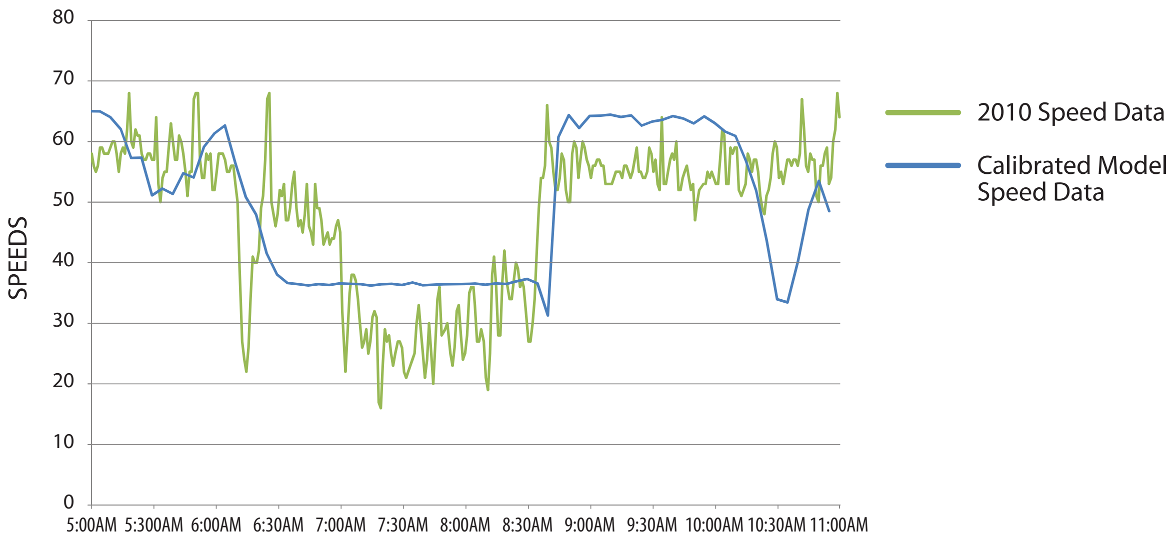
Figure 3 provides the northbound afternoon peak period speed verification compared against 2010 speed data collected during the same periods. The results of the northbound afternoon peak period demonstrate that the DynusT model appropriately captures the well-documented bottleneck condition north of US 36 and the sporadic speeds experienced farther north along I-25.

Figure 2. **Southbound I-25 Speed Verification (AM Peak Period)**

120th Avenue to 136th Avenue



Thornton Parkway to 104th Avenue



US 36 to 84th Avenue

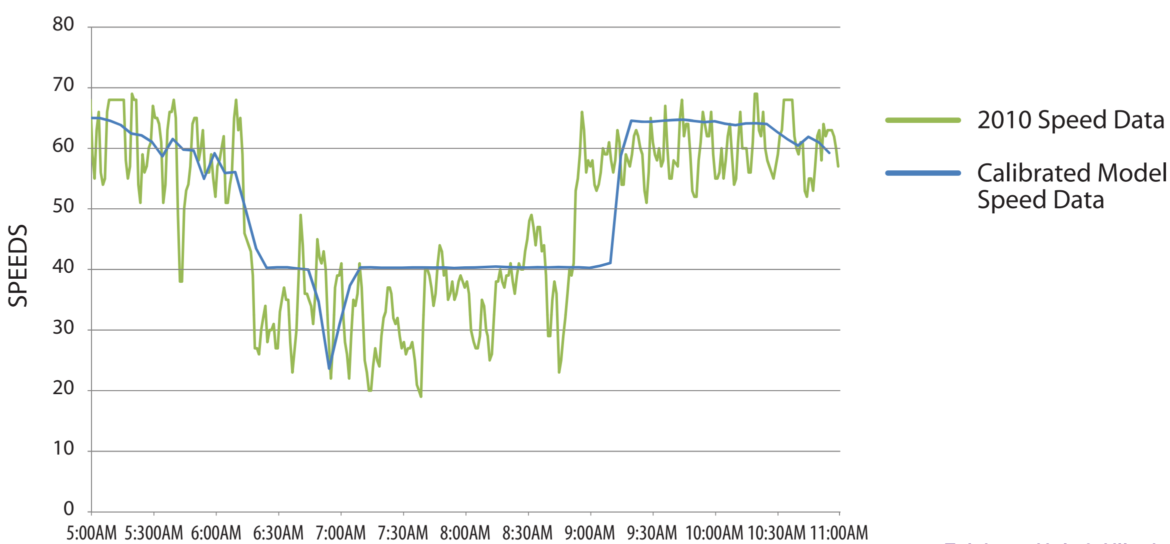
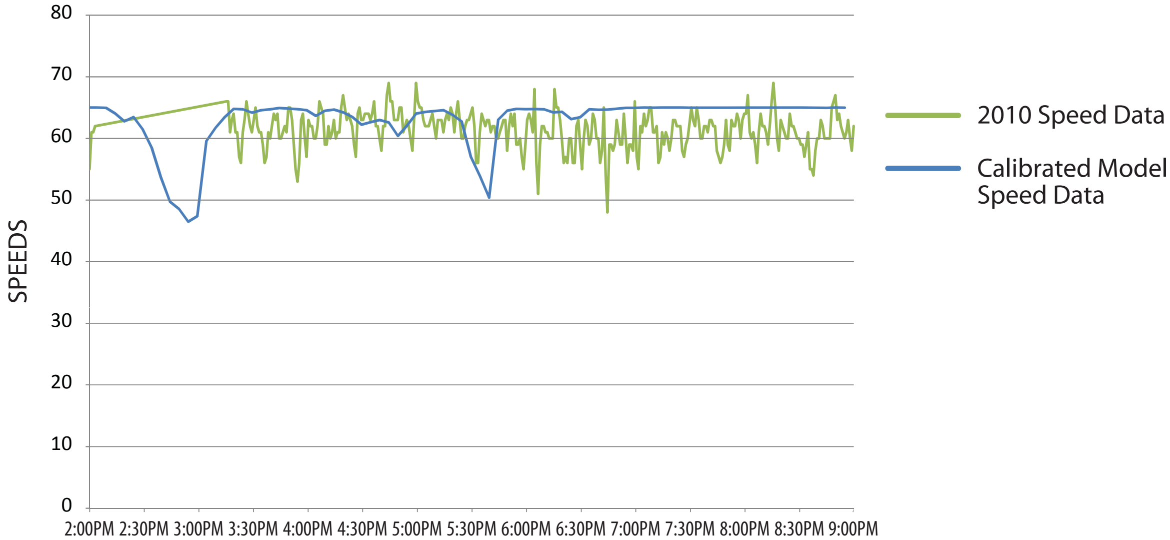
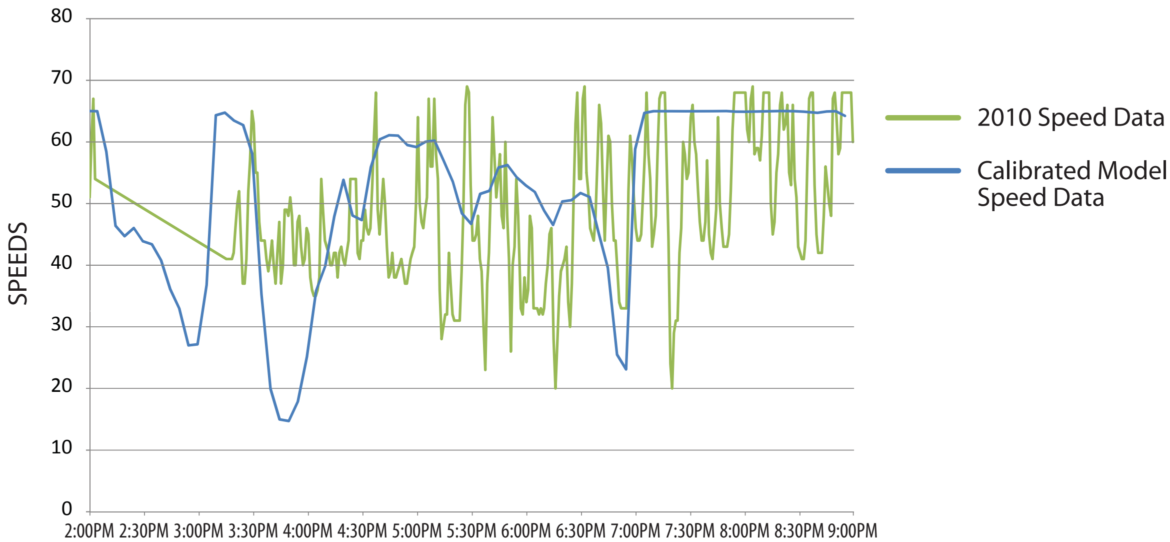


Figure 3. Northbound I-25 Speed Verification (PM Peak Period)

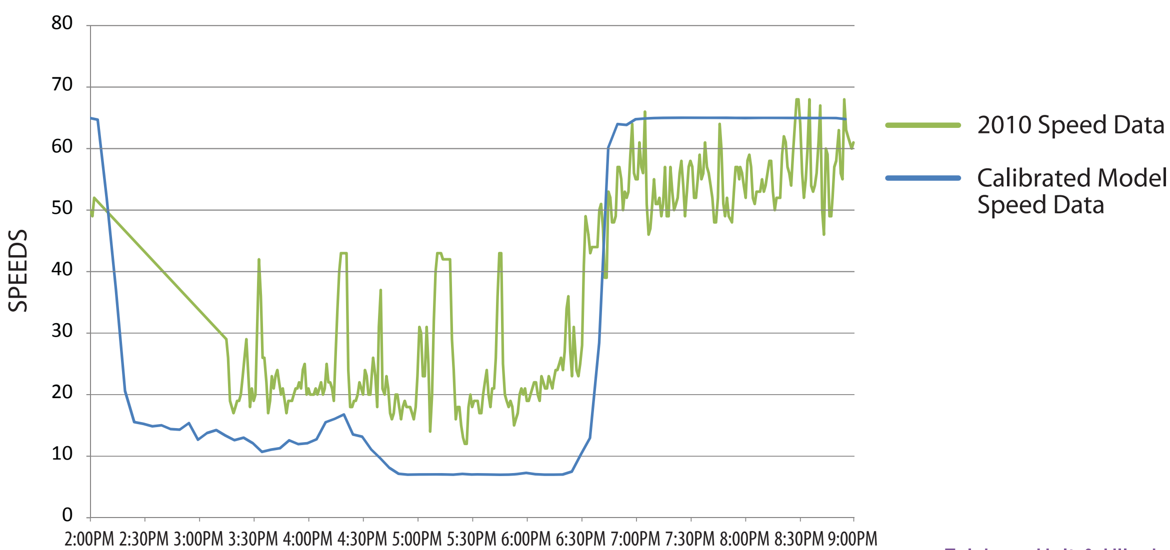
120th Avenue to 136th Avenue



Thornton Parkway to 104th Avenue



US 36 to 84th Avenue



4.0 CONCLUSION

Based on the OD calibration and speed verification, it is the North I-25 PEL team's assessment that the AM and PM models have been adequately calibrated to existing conditions. The calibration procedures followed are consistent with the procedures outlined in the *Methods and Assumptions*. Having achieved these results, the next step is to proceed with the Year 2035 adjustments and model setup integrating findings from the 2010 model calibration process. The adjustments made to the network and traffic flow model will be directly represented in the 2035 model.

In addition, the 2010 Origin-Destination adjustments will be directly translated into the 2035 modeling effort. The project team proposes adjusting the 2035 model OD pairs by the exact numerical calibration adjustments made to the OD pairs included in the Year 2010 model.

APPENDIX - FULL OD CALIBRATION RESULTS

AM Calibration Results, 6 AM to 10 AM Total Flow

Location ID	Counted Flow	Modeled Flow	% Error	Count Location
1	14767	14197	-3.9%	On SH 36 se/o Pecos Street, Denver (EB)
2	1174	1369	16.6%	ON PECOS ST N/O 70TH AVE (NB)
3	13094	13706	4.7%	On SH 36 se/o Pecos Street, Denver (WB)
4	1203	6171	413.0%	On SH 224, Broadway s/o SH 36 (EB)
5	3277	3047	-7.0%	On SH 224, Broadway s/o SH 36 (WB)
6	3058	6992	128.6%	ON WASHINGTON ST S/O SH 224 (SB)
7	10438	10515	0.7%	ON I-270, Southeast of York Street (WB)
8	11218	11741	4.7%	ON I-270, Southeast of York Street (EB)
9	2182	4422	102.7%	ON THORNTON PKWY E/O PECOS ST, THORNTON (EB)
10	1334	1572	17.8%	ON PECOS ST N/O 84TH AVE, FEDERAL HEIGHTS (NB)
11	21151	20264	-4.2%	On I-25 n/o SH 36, Denver (SB)
12	10521	10484	-0.4%	On I-25 n/o Thornton, Thornton (NB)
13	1617	1628	0.7%	ON 88TH AVE E/O WASHINGTON ST, THORNTON (EB)
14	2569	2687	4.6%	ON 88TH AVE E/O WASHINGTON ST, THORNTON (WB)
15	14441	14626	1.3%	On I-25 n/o Thornton, Thornton (SB)
16	12929	12259	-5.2%	On I-25 n/o 104th Avenue, Thornton (SB)
17	7406	7674	3.6%	On I-25 n/o SH 128, 120th Avenue, Thorton (NB)
18	10466	10470	0.0%	On I-25 n/o 104th Avenue, Thornton (NB)
19	5109	5946	16.4%	On SH 128, 120th Ave, w/0 I-25, Westminster (WB)
20	4590	4525	-1.4%	ON 120TH AVE E/O I-25, NORTHGLENN (EB)
21	6846	6558	-4.2%	ON 120TH AVE E/O I-25, NORTHGLENN (WB)
22	1657	1731	4.5%	ON WASHINGTON ST N/O 104TH AVE, NORTHGLENN (NB)
23	3559	3546	-0.4%	ON WASHINGTON ST N/O 104TH AVE, NORTHGLENN (SB)
24	2306	2367	2.6%	ON 120TH AVE E/O WASHINGTON ST, NORTHGLENN (EB)
25	9398	9112	-3.0%	On I-25 n/o SH 470, Broomfield (SB)
26	9357	9484	1.4%	On I-25 n/o SH 7 (ATR) (NB)
27	2622	2646	0.9%	On SH 7 168th w/o I-25, Broomfield (WB)
28	2046	2207	7.9%	On SH 7 168th e/o I-25, Broomfield (EB)
29	11157	11059	-0.9%	On I-25 n/o SH 7 (ATR) (SB)
30	2082	2068	-0.7%	ON THORNTON PKWY E/O PECOS ST, THORNTON (WB)
31	3491	4882	39.8%	On SH 128, 120th Ave, w/0 I-25, Westminster (EB)
32	25308	25433	0.5%	ON I-25, South of SH 6 (SB)
33	27237	26972	-1.0%	ON I-25, South of SH 6 (NB)
34	4257	4618	8.5%	ON 120TH AVE E/O WASHINGTON ST, NORTHGLENN (WB)
35	2240	3064	36.8%	ON PECOS ST N/O 84TH AVE, FEDERAL HEIGHTS (SB)
36	1278	1403	9.8%	ON WASHINGTON ST S/O SH 224 (NB)
37	2011	2018	0.3%	On SH 7 168th w/o I-25, Broomfield (EB)
38	12445	12467	0.2%	On I-25 n/o SH 36, Denver (NB)
39	8172	8407	2.9%	On I-25 n/o SH 128, 120th Avenue, Thorton (SB)
40	7342	7939	8.1%	On I-25 n/o SH 470, Broomfield (NB)
41	2366	2440	3.1%	On SH 7 168th e/o I-25, Broomfield (WB)
42	2209	4948	124.0%	ON PECOS ST N/O 70TH AVE (SB)

OVERALL PERCENT ERROR: 8.1%

(shaded) **=I-25 Locations in PEL Study Area (Priority #1)**

PM Calibration Results, 3 PM to 9 PM Total Flow

Location ID	Counted Flow	Modeled Flow	% Error	Count Location
1	22494	24538	9.1%	On SH 36 se/o Pecos Street, Denver (EB)
2	3763	2541	-32.5%	ON PECOS ST N/O 70TH AVE (NB)
3	26323	28711	9.1%	On SH 36 se/o Pecos Street, Denver (WB)
4	3559	1186	-66.7%	On SH 224, Broadway s/o SH 36 (EB)
5	2614	1553	-40.6%	On SH 224, Broadway s/o SH 36 (WB)
6	2030	479	-76.4%	ON WASHINGTON ST S/O SH 224 (SB)
7	14591	14902	2.1%	ON I-270, Southeast of York Street (WB)
8	13663	13069	-4.3%	ON I-270, Southeast of York Street (EB)
9	4745	4261	-10.2%	ON THORNTON PKWY E/O PECOS ST, THORNTON (EB)
10	3894	4146	6.5%	ON PECOS ST N/O 84TH AVE, FEDERAL HEIGHTS (NB)
11	26661	27277	2.3%	On I-25 n/o SH 36, Denver (SB)
12	21662	22229	2.6%	On I-25 n/o Thornton, Thornton (NB)
13	3755	3792	1.0%	ON 88TH AVE E/O WASHINGTON ST, THORNTON (EB)
14	3441	3586	4.2%	ON 88TH AVE E/O WASHINGTON ST, THORNTON (WB)
15	21750	22344	2.7%	On I-25 n/o Thornton, Thornton (SB)
16	20923	21489	2.7%	On I-25 n/o 104th Avenue, Thornton (SB)
17	14791	15393	4.1%	On I-25 n/o SH 128, 120th Avenue, Thorton (NB)
18	21627	22190	2.6%	On I-25 n/o 104th Avenue, Thornton (NB)
19	6864	6490	-5.4%	On SH 128, 120th Ave, w/0 I-25, Westminster (WB)
20	9805	9893	0.9%	ON 120TH AVE E/O I-25, NORTHGLENN (EB)
21	7849	7786	-0.8%	ON 120TH AVE E/O I-25, NORTHGLENN (WB)
22	5362	5344	-0.3%	ON WASHINGTON ST N/O 104TH AVE, NORTHGLENN (NB)
23	4214	4388	4.1%	ON WASHINGTON ST N/O 104TH AVE, NORTHGLENN (SB)
24	7574	7891	4.2%	ON 120TH AVE E/O WASHINGTON ST, NORTHGLENN (EB)
25	16260	16069	-1.2%	On I-25 n/o SH 470, Broomfield (SB)
26	14589	14734	1.0%	On I-25 n/o SH 7 (ATR) (NB)
27	2793	1993	-28.6%	On SH 7 168th w/o I-25, Broomfield (WB)
28	4496	3007	-33.1%	On SH 7 168th e/o I-25, Broomfield (EB)
29	13645	13785	1.0%	On I-25 n/o SH 7 (ATR) (SB)
30	4317	3655	-15.3%	ON THORNTON PKWY E/O PECOS ST, THORNTON (WB)
31	7363	7567	2.8%	On SH 128, 120th Ave, w/0 I-25, Westminster (EB)
32	32465	32473	0.0%	ON I-25, South of SH 6 (SB)
33	28497	27700	-2.8%	ON I-25, South of SH 6 (NB)
34	5310	5363	1.0%	ON 120TH AVE E/O WASHINGTON ST, NORTHGLENN (WB)
35	2600	2614	0.5%	ON PECOS ST N/O 84TH AVE, FEDERAL HEIGHTS (SB)
36	4179	2671	-36.1%	ON WASHINGTON ST S/O SH 224 (NB)
37	3715	4124	11.0%	On SH 7 168th w/o I-25, Broomfield (EB)
38	28877	29616	2.6%	On I-25 n/o SH 36, Denver (NB)
39	14524	14699	1.2%	On I-25 n/o SH 128, 120th Avenue, Thorton (SB)
40	13656	14072	3.0%	On I-25 n/o SH 470, Broomfield (NB)
41	2114	2835	34.1%	On SH 7 168th e/o I-25, Broomfield (WB)
42	2532	956	-62.2%	ON PECOS ST N/O 70TH AVE (SB)

OVERALL PERCENT ERROR: 5.7%

=I-25 Locations in PEL Study Area (Priority #1)