Methods and Assumptions

C-470 Traffic Modeling

draft

report

prepared for

Douglas County

prepared by

Cambridge Systematics, Inc.

June 20, 2013

www.camsys.com

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date

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1.0 Introduction

1.1 Study Purpose

The purpose of this study is to develop a concept plan and toll and revenue estimates for a proposed express lane project on C-470 in Douglas county. The project limits are C-470 at I-25 in the east and to Kipling Road in the west. Figure 1.1 illustrates these project limits.

Figure 1.1 Project Limits

1.2 Background

The Policy Committee (PC) of the C-470 Corridor Coalition (Coalition) has agreed on a technical recommendation for the Segment 1 (I-25 to Kipling), Phase 1 interim solution for the C-470 Corridor, which includes adding one additional lane in each direction along with auxiliary lanes in certain areas from I-25 to Wadsworth Boulevard, as presented by the Technical Working Group (TWG). Although the interim solution for Segment 1 may be adequate for many years to come (possibly even beyond 2035), the ultimate solution (referred to as the 2035 solution) is to provide two additional lanes in each direction along with auxiliary lanes in certain areas from I-25 to Wadsworth and one additional lane between Wadsworth and Kipling.

The Coalition's immediate focus is on Segment 1. However, the Coalition recognizes the need for finding solutions for Segment 2 (Kipling to I-70); and therefore the Coalition intends to perform a Planning and Environmental Linkage (PEL) Study for Segment 2 in the near future. This Methods and Assumptions document describes the modeling process and data to conduct an analysis of managed express toll lanes on C-470 from I-25 to Wadsworth.

1.3 Roles and Responsibilities

The project team includes the TWG, the TWG Traffic Subcommittee, and the consultant team. The Traffic Subcommittee will review all materials and make recommendations that will be passed along to the TWG. The TWG will pass along information to the C-470 Policy Committee. Table 1.1 contains the contact information for key project staff. Figure 1.2 illustrates the organization chart. The individuals in this chart are advisory; all project approvals (NEPA documents, IAR documents, etc.) will occur by other agencies and agency staff. Table 1.2 provides a summary of the work products under this study.

Table 1.1 Contact Database

Name	Agency/Company	Telephone	Email
Art Griffith	Douglas County	(303) 947-8731	agriffit@douglas.co.us
Kevin French	Jefferson County Traffic and Engineering	(303) 271-8495	kfrench@jeffco.us
Steve Hersey	CDOT Region 6	(303) 757-9511	steven.hersey@state.co.us
Erik Sabina	Colorado Department of Transportation	(303) 757-9811	erik.sabina@state.co.us
Scott Ramming	Denver Regional Council of Governments	(303) 480-6711	sramming@drcog.org
Chris Sheffer	City of Centennial	(303) 325-8012	csheffer@centennialcolorado.com
Bob Watts	City of Castle Rock	(303) 814-6415	bwatts@crgov.com
Bryan Weimer	Arapahoe County	(720) 874-6521	bweimer@co.arapahoe.co.us
Chung Tran	FHWA	(720) 963-3201	chung.tran@dot.gov
Eric Pihl	FHWA	(720) 963-3219	eric.pihl@dot.gov
Jim Brady	Wilson & Company	(303) 297-2976	jim.brady@wilsonco.com
Steve Gomez	Wilson & Company	(303) 501-1209	steven.gomez@wilsonco.com
Scott Waterman	Wilson & Company	(303) 501-1227	scott.waterman@wilsonco.com
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Jaimie Sloboden	Cambridge Systematics	(904) 315-7923	jsloboden@camsys.com
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John Lewis	Cambridge Systematics	(617) 234-0519	jlewis@camsys.com

Figure 1.2 Project Organization Chart

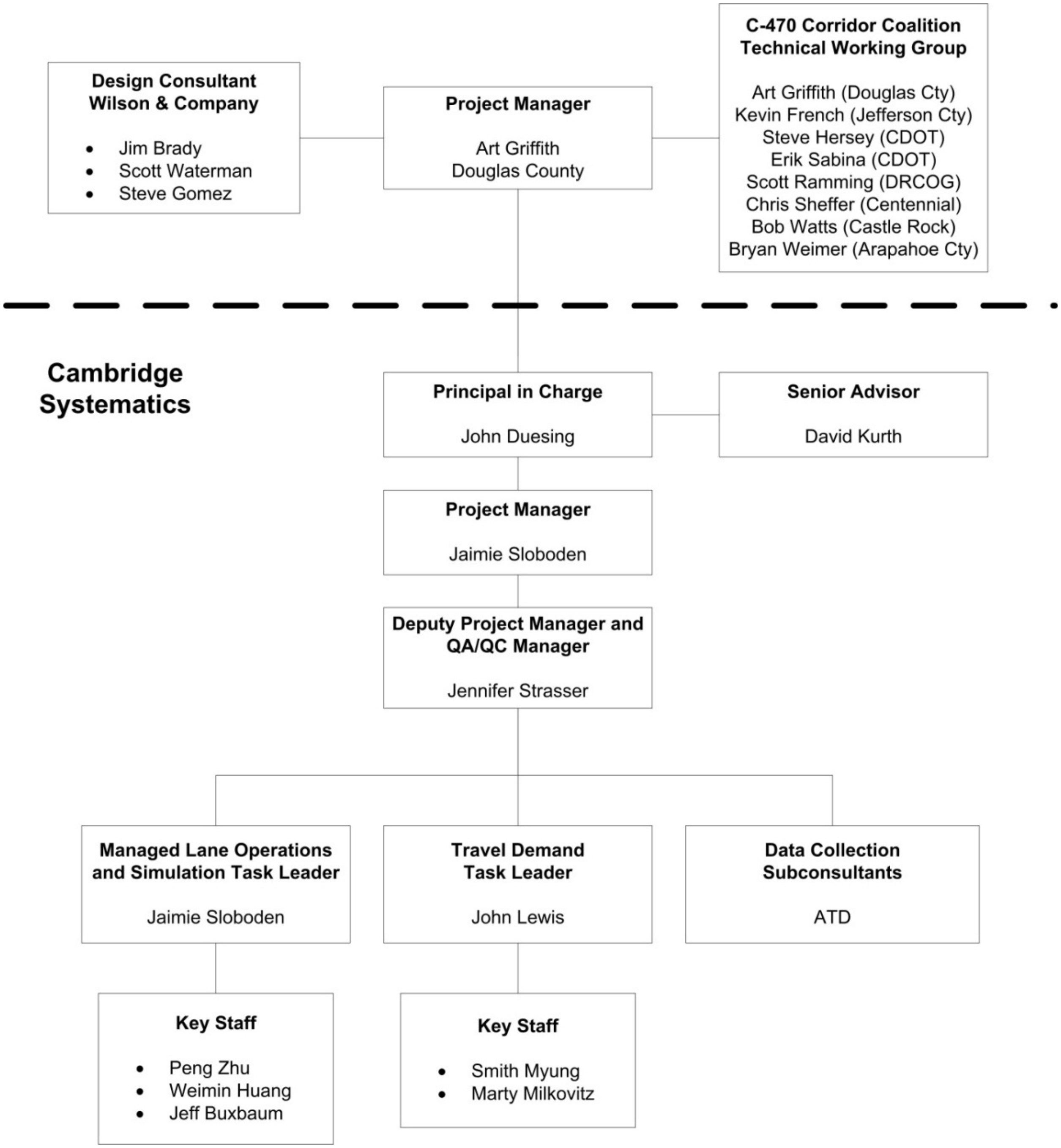


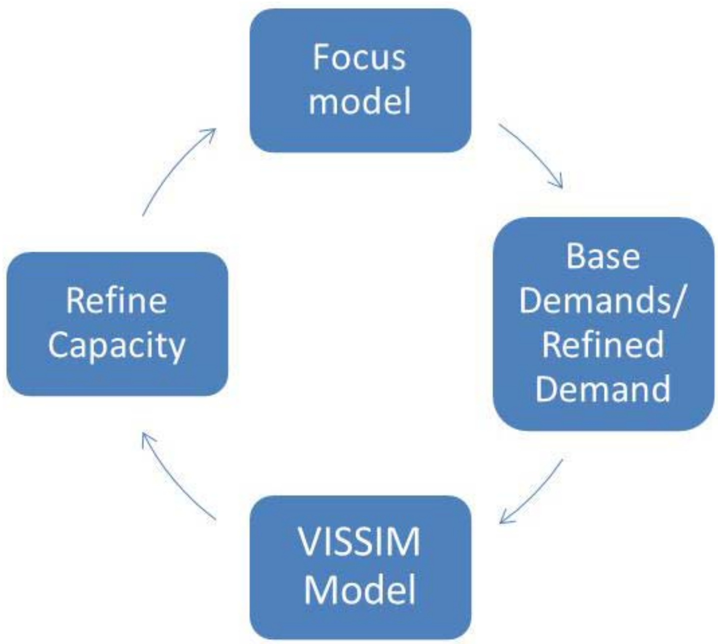
Table 1.2 Summary of Work Products

Task	Deliverables	Submittal Date	Status
1	Kickoff Meeting	12/12/2012	Complete
	Kickoff Meeting Minutes	2/12/2012	Complete
	Project Contact Database		Complete
	Project Schedule		
	List of Action Items	2/12/2012	Complete
2	Project Management Plan		
	QA/QC Procedures and Plan		
	Methods and Assumptions Document		
3	Existing Conditions GIS Database		In progress
	Data Gap Analysis		In progress
	Data Summary Tech Memo		In progress
4	Data Collection Plan	4/ 23/2013	Completed
	Data Collection Activities Tech Memo		In progress
5	Modeling Framework Tech Memo		
	Demand Model Files		
6	VISSIM Base Model Files		
	VISSIM Future Scenario Model Files		
	Operations Analysis/Toll Tech Memo		
7	Draft Final Report		
	Final Report		
	Executive Summary Presentation		
	Monthly Project Meetings/Notes/Action Items		
	Other Meetings and Presentations		

2.0 Modeling Workflow

The modeling workflow for the C-470 managed lane analysis will include two separate traffic models. The first is the DRCOG Regional Demand Model (Focus Model) and the second will be a VISSIM microsimulation model of the Segment 1 corridor. The purpose of the Focus model is to assess regional behavior and to provide travel demand information that will be fed into the VISSIM model. The VISSIM model will be used to model detailed traffic operations and to assign traffic to the Managed Tolled Express Lanes. The two models will be integrated as shown in Figure 2.1.

Figure 2.1 Overall Modeling Workflow



The interaction between the two models will be a manual transfer of information. Origin-Destination (OD) trip tables by vehicle classification will be created from the Focus model in a format that is compatible with the VISSIM model. The VISSIM model will be run using the trip tables generated from DRCOG. As issues such as too much congestion, are observed in the VISSIM model, the issue will be fed back to the DRCOG model for trip table refinement.

2.1 Alternatives

Planning-Level Alternatives

The regional Focus model will be used to develop travel demands for the simulation model and to conduct a range of regional concepts for comparison on Segment 1. Segment 2 will be tested at the regional model scale for three designs: general purpose lanes only, express lanes, and all tolled lanes. Table 2.1 is a summary of the regional model tests.

Table 2.1 Regional Model Scenarios

Regional Model Scenarios	Year	Land Use	Option	Segment 1	Segment 2
Base Year	Base Year	Existing		Existing	Existing
Build	2025	DRCOG E+C	A	2/2 ETL Lanes	No Build
	2025	DRCOG E+C	B	2/2 ETL Lanes	4 GP
	2025	DRCOG E+C		No Build	No Build
	2025	DRCOG E+C	C	2/2 ETL Lanes	4 Fixed Toll
	2025	DRCOG E+C	D	2/2 ETL Lanes	2/2 ETL Lanes
	2025	DRCOG E+C		1/1 ETL Lanes	2/2 ETL Lanes
Build	2035	DRCOG E+C	A	2/2 ETL Lanes	No Build
	2035	DRCOG E+C	B	2/2 ETL Lanes	4 GP
	2035	DRCOG E+C		No Build	No Build
	2035	DRCOG E+C	C	2/2 ETL Lanes	4 Fixed Toll
	2035	DRCOG E+C	D	2/2 ETL Lanes	2/2 ETL Lanes

Simulation Alternatives

The VISSIM simulation alternatives will reflect the Build managed lane condition for Segment 1 and No Build condition for Segment 2. Within the Build condition, the model will be run with a variety of sensitivity tests (pricing, willingness to pay and land use growth levels). The exact sensitivity scenarios are to be determined. The simulation alternatives are outlined in Table 2.2.

Table 2.2 Simulation Alternatives

Regional Model Scenarios	Year	Land Use	Option	Segment 1	Segment 2
Base Year	Base Year	Existing		Existing	Existing
	Base Year	Existing		2/2 ETL Lanes	Existing
Build [a]	2025	DRCOG E+C	A	2/2 ETL Lanes	No Build
Build [a]	2035	DRCOG E+C	A	2/2 ETL Lanes	No Build

[a] A series of sensitivity tests will be conducted on the build alternative for Segment 1.

The analysis years are as follows:

- **Base Year –** An existing Base Year model will be built and calibrated to current conditions.
- **Base Year (Preferred) –** The preferred design alternative will be simulated for the Base Year condition. This analysis will be used in estimating toll and revenue streams. The pricing and willingness to pay will be tested.
- **Interim Year (Preferred) –** The Interim Year (2025) for the preferred design plan will be simulated. The simulations will include sensitivity testing for the development of level II toll and revenue estimates.
- **Design Year (Preferred) –** The Design Year (2035) for the preferred design plan will be simulated. The simulations will include sensitivity testing for the development of level II toll and revenue estimates.

2.2 QA/QC

CS is committed to Quality Control and Assurance. The approach to QA/QC is two-tiered. The first tier includes checks of manual inputs and information that has been entered. This is a "mechanical" check of the model inputs to ensure that there are no mistakes. The second tier of QA/QC is an overall review of the model results and conclusions that are drawn. For example, the reviewer will ask, "does the answer make sense?" This review will be conducted by a team of experts within CS who are not directly associated with the project.

3.0 Data

As described in Section 2.0, the regional demand and traffic simulation models will supply information to make decisions on the design of ingress/egress simulation locations and the revenue potential of tolled lanes. To ensure stakeholders have faith in the models and to confirm the model is functioning properly, it must match field conditions. Accurate and timely traffic data is critical to understanding the field conditions throughout the corridor so that the model development process can be successful. The models will be calibrated to meet a minimum set of calibration and validation criteria, as defined by the Federal Highway Administration. This section of the report outlines the existing sources of data that were made available for this project, the gaps that were identified in that data, and the data collection program that was set in place to fill those gaps. A separate *Data Summary Report* will summarize the data being used for this project in more detail, and will include the final compiled set of data being used for calibration and validation.

3.1 Data Sources

Various types of data are critical to this study, including roadway geometry, speeds, volumes, and signal operations. Table 3.1 summarizes the existing data that was provided for this study along with the year it was collected and the source. The rightmost column labeled "Comment" contains a brief description of the relevancy of the data to this study. Nearly all of these data are valuable, but some data sets are more relevant than others. Even old data (2010 or previous) can be used to compare against new data to identify and examine unusual differences.

Table 3.1 Data Source and Data Applications

Data Items	Source	Year	Comment
Turning Movement Counts	Atkins	2008-2009	Limited locations
	CDOT	2010	Limited locations, AM only
Mainline and Ramp Volumes	CDOT	2012-2013	Current and relevant
Ramp Volumes	DRCOG	2007	AM, MD, PM Peak hours only
Arterial Volumes	Douglas County	2011	Hourly
Arterial Volumes	Jefferson County	2011-2012	Hourly
Signal Timing Plans	CDOT	2010	Limited locations
Signal Timing Plans	Centennial	2011-2013	Outside study area
Signal Timing Plans	Douglas County	2012	Relevant
Ramp Meter Controller Parameters	CDOT	2013	Relevant

Data Items	Source	Year	Comment
Speed Study Review	DRCOG	2009	Information on free-flow speeds
U.S. 36 Stated-Preference Survey	CDOT	2011	Relevant
C-470 Express Lanes Feasibility Study	Wilson & Company	2005	Dated
Aimsun Model Files	Wilson & Company	2012	Relevant
C-470 Plan Drawings	Wilson & Company	2013	Relevant

3.2 Data Gaps

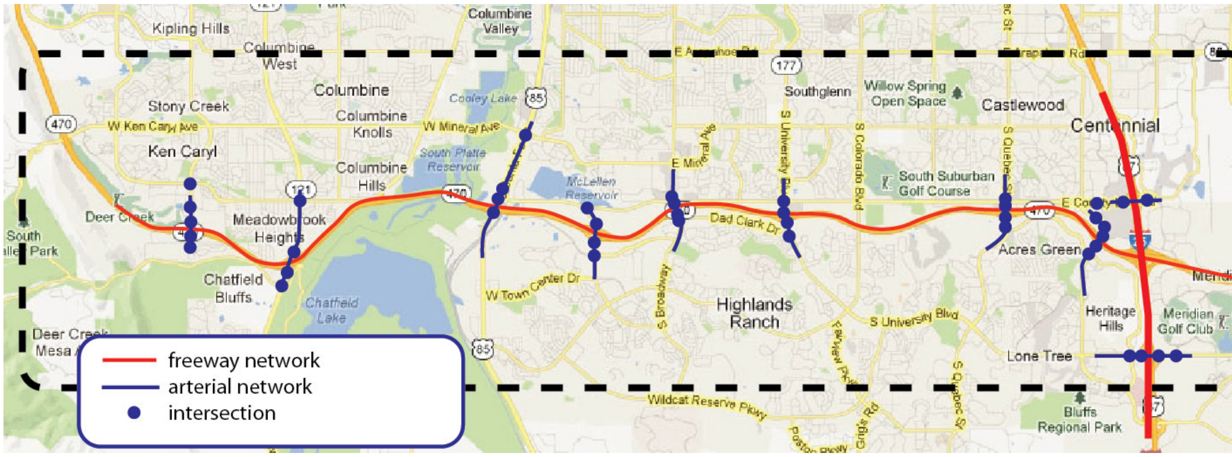
After careful review of all the data listed in the previous section, it was determined that the available data are out of date, not complete enough to conduct a basic traffic study covering the study area, and not robust enough to build a solid 14-hour traffic simulation model. Particularly for a microsimulation model – a critical step in this project – a data set containing speeds and volumes collected simultaneously provides the ideal context to match actual field conditions. Therefore, it was recommended by the Traffic Subcommittee to perform a significant, new data collection effort.

CDOT has current traffic data from Intelligent Transportation Systems (ITS) detectors. That data will be leveraged and supplemented with manual and automated volume counts. In addition, fairly simple speed data will be collected to get an idea of the overall congestion patterns during the time the other data was collected. The data collection program defined in the next section will ensure that all of the calculations in this project are based on the most recent and complete set of data available.

3.3 Data Collection Program

The data collection program will include: automatic traffic collection on freeways, ramps and arterials; turning movement counts at key intersections adjacent to freeway ramps; and speed runs. The sites and locations to be collected will occur within the study area shown in Figure 3.1.

Figure 3.1 Data Collection Study Area



For **mainline freeways**, automatic traffic data collection will be needed to obtain up-to-date traffic volumes, spot speeds, and vehicle classification by direction on I-25 immediately north of the County Line Road interchange and on C-470 immediately west of I-25. These counts will be continuous for a period of three days and will be summarized in 15-minute increments.

For **on-ramps and off-ramps**, the automatic traffic data collection will be needed to obtain up-to-date traffic volumes and vehicle classification for 39 ramp roadway locations along C-470 and I-25. These counts will be continuous for a period of three days and will be summarized in 15-minute increments.

For **arterial roadways**, the automatic traffic data collection will be needed to obtain up-to-date, two-way traffic volumes and vehicle classification for 20 arterial roadway locations for arterials that connect to the freeways in the study area (denoted by the blue lines in Figure 3.1). These counts will be continuous for a period of three days and will be summarized in 15-minute increments.

For **arterial intersections**, turning movement counts will be needed to obtain up-to-date volumes at 26 key intersections on roadways in close proximity to freeway ramps (denoted by the blue dots in Figure 3.1).

Speed data will be needed to obtain up-to-date travel times in both directions of C-470 from east of I-25 and west of Kipling Avenue. These speed runs will occur during the 4-hour morning peak period and the 7-hour evening peak period over two days.

All of the new data will be reviewed along with the existing data that were supplied from other sources such as previous studies, and summarized into a separate *Data Summary Report*.

4.0 Travel Demand Methodology

The objective of this task is to estimate and calibrate base and future year origins and destinations (OD) within the larger regional study area as well as the area representing the C-470 Corridor simulation models. The ODs representing the C-470 Corridor will be used as inputs to the simulation models being developed to analyze the operations and potential revenue of the project.

4.1 Modeling Inputs and Assumptions

Travel Demand Model

The Focus travel model is an activity-based model for the Denver region developed by DRCOG. The model synthesizes individual regional households and persons, and forecasts their travel throughout a typical weekday based on personal and travel-related characteristics. A complete technical description of the model and all of its components can be found on DRCOG's web site at: http://www.drcog.org/index.cfm?page=FocusTechnicalResources.

Inputs and Assumptions

Networks: The 2010 and 2035 TransCAD Focus model datasets were provided to the project team by DRCOG. CS will review the base and future networks to ensure that the networks are acceptable in order to run both travel demand model-related processes, and microsimulation processes, once converted into the respective networks. The checks performed will include, but are not limited to, connectivity, lane configurations, and link capacities.

Land Use: Future Year Land Use from DRCOG will be reviewed and summarized to better understand growth in the region as well as within the study corridor. Particular attention will be given to high-growth areas close to the corridor. Summaries of Base and Future Land Use Assumptions appear in Appendix A.

4.2 BASE YEAR DEMAND CALIBRATION

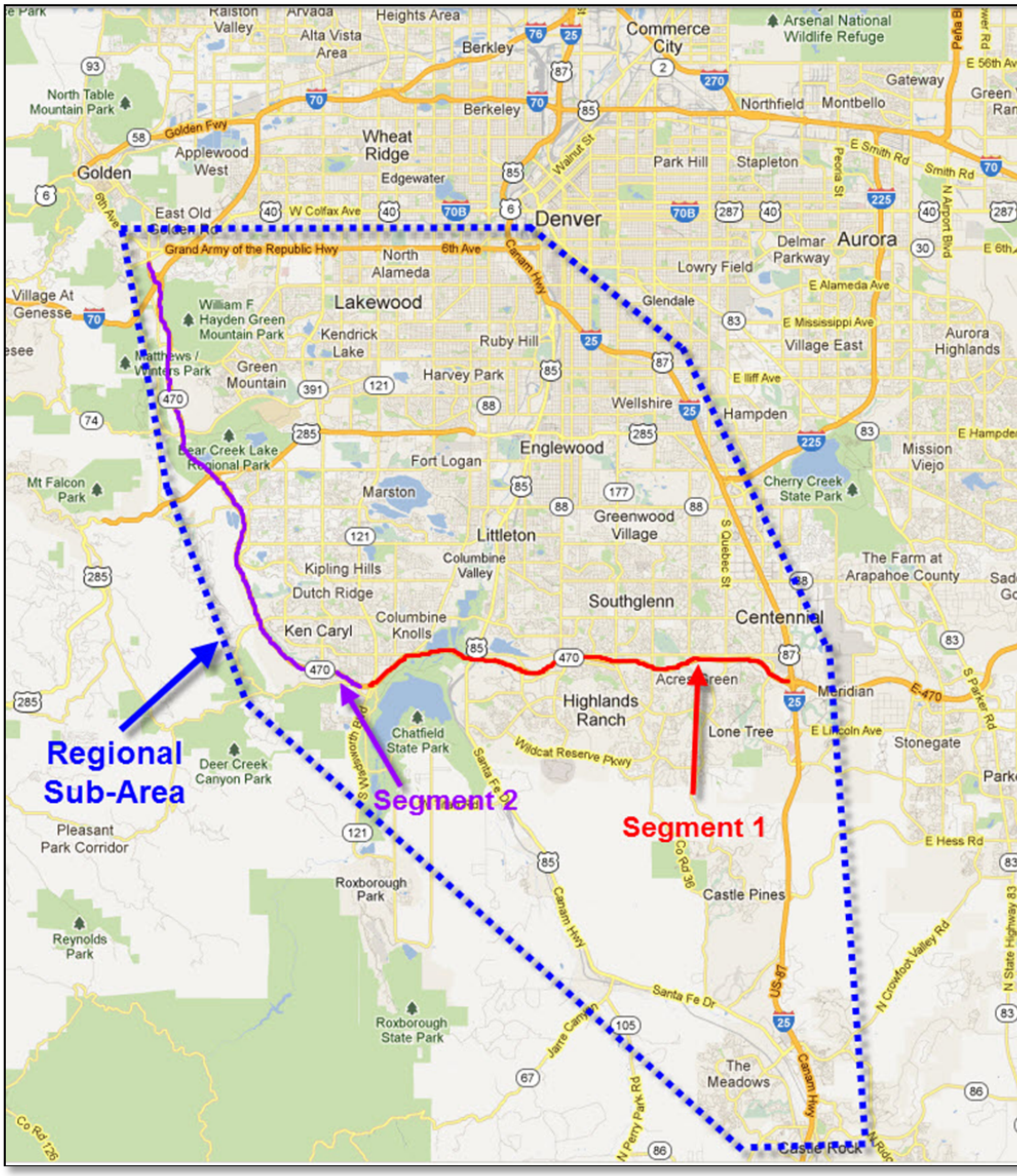
The ODs within the larger regional study area, which includes the smaller portion representing the C-470 Corridor, will be calibrated to better match the observed traffic data. As shown in Figure 4.1, the regional study area includes the area within blue dashed line and the roadways that will be simulated are shown by the solid red line and is referred to as Segment 1.

The decision to calibrate the demands within the larger regional area, although only the trips within the simulated area are utilized for the revenue and operational analysis, was based on the need to be able to capture regional diversion dynamics associated with the proposed project. This is based on the idea that the design and operations of the C-470 facilities will impact regional travelers' decisions with regard to mode and route choice. The inclusion of a regional network affords travelers that option.

In addition, the design of Segment 2, (denoted by the purple line in Figure 4.1), will have a significant influence on the demand for travel in Segment 1, which in turn will impact the revenue estimates. Including all of Segment 2 in the study subarea allows the models to test different design options for Segment 2 to better qualify the estimated design alternatives.

The calibration of demands will be an iterative process that involves refining the demands in the static equilibrium assignment procedure within the Focus model and then testing the operations of these demands within the simulation models. The procedures used to refine the demands is commonly referred to as Origin Destination Matrix Estimation (ODME) and is described in subsequent sections.

Figure 4.1 Study Area



Base Year Trip Table Methodology

Trip matrices will be calibrated for the entire regional subarea using the TransCAD ODME procedures, and traffic counts (both historical and new counts collected in 2013) , for the following periods:

- AM Period (6:00 a.m. to 1:00 p.m.); and
- PM Period (1:00 p.m. to 8:00 p.m.).

The trip table calibration is done with larger time periods because of the use of a static assignment model to perform the ODME. Static assignments assume that all trips within a specific time period trip table make it all the way from their origin zone to their destination zone. Static assignments also allow demand to exceed capacity on roadway links which is unrealistic. For large areas like the C-470 regional study area, these assumptions would be incorrect for trips that depart every 15 minutes or even every hour for some OD pairs. Thus, the trip table calibration is best done at the period level to minimize differences between throughput (counts) and demand (trip tables). The use of dynamic traffic assignment (DTA) ODME techniques would be the preferred approach for this process, however these procedures have not yet proven to be reliable or practical.

The ODME procedure within TransCAD that will be used to calibrate the demands within the regional study area uses a static assignment algorithm. The process is an iterative one that fluctuates between the traffic assignment and matrix estimation stages, and the main objective is to refine the initial OD vehicle matrices from the seed trip tables to better match the observed data. The procedure is based on the Maximum Likelihood technique, which attempts to estimate a trip table that maximizes the probability of all input datasets.

The input datasets include an initial estimate of the OD matrices, (seed matrices from the Focus model) and traffic count data, (link and turning movement counts). OD survey data also is a potential source of observed data that can be used to refine the trip tables, however there was no available surveys and given the schedule will not be collected as part of this task. The procedure is multimodal and multi-Class Assignment (MMA) and the MMA OD Matrix Estimator is based on TransCAD's MMA assignment procedure. The MMA assignment routine is a generalized cost assignment that assigns trips by individual mode or user class to the network simultaneously. Each mode or class can have different congestion impacts, different volume delay function parameters, different values of time, and different sets of excluded facilities and types of tolls. The advantage of using the MMA for ODME is that, rather than producing just one overall trip OD matrix, it can generate estimated trip matrices for each mode or class.

The determination as to what vehicle trip tables to estimate using ODME was based on the study objectives and the availability of the count data. A successful implementation of the multimodal approach requires multimodal count data. A review of the count data revealed that the classification scheme that yielded the most data points was to break the counts into two groups: truck and nontruck or auto. The nontruck group included all vehicle types not classified as a truck in the counts.

Seed Trip Tables

Seed trips will come directly from the Focus model using subarea extraction procedures which are part of the traffic assignment process. The Focus model produces and assigns four vehicle types; DA, SR2, SR3+, and Trucks. These trip tables will be combined to form two tables: truck and nontruck. Vehicle type share information will be retained from the seed trip tables for use after the matrix calibration to allocate the calibrated trips into the four vehicle types.

OD Calibration Criteria

Traffic Count Data Comparison

There currently is no consensus on criteria for determining when an OD table produces traffic flows that are considered validated. For this study, common industry-wide measures of travel demand assignment validation will be used to compare the assigned volumes to observed traffic counts. These include screenline analysis, the percent deviation between the counts and assigned volumes, and the percent Root Mean Square Error (%RMSE) of these deviations. These measures serve as a tool to refine the distribution and magnitude of demands within the study area, however the ODs will be considered validated when they produce traffic conditions within the microsimulation models that closely match the observed conditions. Thus, it will be an iterative process where demands are refined using the regional static assignment ODME and then tested in the dynamic traffic assignment of the microsimulation model.

Trip Length Distribution Comparison

The mechanics of the ODME process may result in the overestimation of the shorter trips compared to the longer trips. Therefore it is critical to monitor the trip length distribution of the ODME trip tables with an objective to keep the resultant average trip length within 15 percent of the original Focus-based seed matrix trip length. The coincidence ratio between the seed trip table and the final adjusted trip table will also be calculated to provide an additional measure of the differences between the Focus-based seed matrix trip length frequency and the ODME matrix trip length frequency. Although, there are no existing standards for the coincidence ratio statistic, a target of 75 percent is seen as a reasonable value for this statistic.

4.3 FUTURE TRAVEL DEMAND

For each of the regional scenarios, the Focus model will be updated to reflect all of the changes associated with the future alternatives and applied utilizing the entire model process. This includes any changes associated with Highway and Transit network projects as well as any changes to the demographic data.

Modeling Express Lanes

The express lanes that will be the focus of this study will have a dynamic pricing component that is based on the levels of congestion experienced within the express lanes at very small time increments. It is expected that the express lanes will have some minimum toll at all times they are in operation. Also, some travelers may be averse to paying a toll regardless of the time savings. Therefore, including express lanes without some consideration of the additional cost might result in an over-prediction of demand.

The behavioral response to the pricing component can be divided into pre-trip decisions and en-route decisions. Pre-trip decisions include the activity location, mode, travel time, and toll receptivity. En-route, the traveler is choosing a path and deciding if the time savings in the express lanes justify the cost. Our approach to capture these sensitivities is described below.

Pre-Trip Decisions

Regional travel demand models assume that decision-makers are aware of the equilibrium level of service and cost for each trip. Models also assume that travelers make pre-trip decisions regarding activity location and mode based on the average price for the time period of travel in addition to transportation network level of service (LOS). Some regional travel models address this issue with the inclusion of toll acceptance models that sort travelers into groups of those that will pay a toll and those that will not. Although there is no explicit toll acceptance choice model within the Focus model system, all of the activity-based model elements are sensitive to roadway pricing and have been calibrated and validated across the region with existing toll facilities. To introduce a new element at this time would be inconsistent and would require the models to be recalibrated. Therefore, we will not modify the current regional model for this study.

In terms of incorporating the cost of the proposed managed lanes, a pricing scheme such as “fixed variable” that matches the assignment time periods would require no changes to the Focus model. To test dynamic pricing, an average price for each time period would have to be estimated. This could be done by applying the microsimulation model with dynamic pricing to determine an “average” price for each time period that matches the Focus model.

En-Route Decisions

Similar to pre-trip decisions, if the pricing scheme for the express lanes is “fixed variable” where the price is constant for a set period of time but changes based on a predetermined schedule, it is possible to incorporate the effects of price on route choice into the existing Focus model assignment procedure. For instance, if the toll for using the express lane is a fixed amount from 7:00 a.m. to 8:00 a.m., the current generalized cost assignment methodology could be used with the corresponding hourly AM trip table by setting a fixed price for the express lane use for that hourly assignment. The price could then be changed for the next time increment as planned, etc. There would be no need to alter the current assignment methodology of the Focus model.

In the case where the pricing level is dynamic at time periods less than the Focus model and is related to congestion levels, the decision to use the express lanes would be made depending on the actual dynamic price level. As mentioned above, the Focus model utilizes a static assignment procedure to assign demands to the highway network. Static assignment cannot represent moment-to-moment fluctuations in volume; instead the average volume over the time period is calculated. Static assignment, however, can be used to find the equilibrium between the delay on the mainline and the toll on the express lanes. The dynamic price is determined by traffic volume so an iterative process is necessary to determine the price demand equilibrium.

We will examine two different potential approaches to estimate the average dynamic price for a time period. The static assignment of volume between the two facilities can be used to estimate the average toll rate for each time segment with some modification to the current Focus model volume delay functions. Alternatively, the average toll rate from the microsimulation model, which does represent the short-term decisions, can be fed back into the Focus model network. The implementation of the two approaches is described below.

1. Develop a Volume Delay Function (VDF) that contains a cost or pricing component that is sensitive to the level of congestion; or
2. Utilize the existing VDF (BPR curve) within the Focus model in a more manual, iterative fashion as follows:
    a. First estimate maximum demand for the express lanes in the static assignment subarea model by allowing all eligible vehicles to use the express lanes at the minimum toll rate;
    b. Run these demands through the microsimulation model that has a variable pricing component to determine an average cost per time slice;
    c. Reestimate the demands with the static assignment subarea model using the average price information from the microsimulation model above; and
    d. Continue this process until equilibrium is reached.

Future Year Growth

After all of the changes to the model inputs associated with the future year scenarios are incorporated into the regional model dataset, the regional model will be used to forecast future year traffic flows in a manner consistent with the base year for each scenario. Incremental growth for every OD pair will be added to the base year calibrated trips. The process is described below:

1. Perform standard Focus model forecast to produce estimates of traffic demands;
2. Extract future year subarea OD demands for the regional study area corridor;
3. Adjust future year demands based on the base year validation. The final scenario-specific future year matrices will be calculated using the following formula for each vehicle type/class:

Adj. Future Year Matrix = (Raw Future Year Matrix – Raw Base Year Matrix) + Calibrated Base Year Matrix

4. Extract C-470 Corridor-level ODs to be used as input into the simulation models. It is possible that multiple iterations of regional travel demand model and simulation model runs may be required to generate reliable future forecasts.

4.4 Time-of-Day Procedures

The main input to simulation models is travel demand in the form of OD tables. Ideally, these OD tables come from regional travel demand models and represent travel demand in small time increments, usually 15-minute slices, to support the dynamic traffic assignment process. Often the data are not available to support OD tables as most regional travel demand models are calibrated and validated to much larger time periods and are estimated by applying factors to every OD pair based on observations from a travel survey. In addition, these same factors are usually applied to future year forecasts and therefore assumes that the temporal distribution of trips is constant by geography, regardless of the location and longevity of congestion. Fortunately, the Focus model's time-of-day procedures are sensitive to congestion levels and allow for different time-of-day distributions in response to congestion levels.

Our approach to split up the trip tables into smaller time slices is to utilize the time-of-day information already estimated within the Focus model. Embedded within the Focus model is a choice model for time of day that estimates each journey by direction with hourly resolution for the entire 24-hour period. This time-of-day information would allow the compilation of hourly trip tables throughout the 6:00 a.m. to 7:00 p.m. study period for the entire study area.

5.0 Microsimulation Modeling

5.1 Simulation Workflow Overview

A microsimulation model using VISSIM 5.4 software of C-470 Segment 1 will be developed to assist in the design and location of managed express toll lane access, evaluate traffic operations, and develop toll and revenue estimates. As discussed in the modeling overview, there will be an iterative process between the DRCOG model to create trip tables that will be fed to VISSIM, and in turn VISSIM results will be fed back to DRCOG as needed to refine the trip tables. The VISSIM model development will have a distinct modeling process, as illustrated in Figure 5.1. This process is in line with the Federal Highway Administration's *Traffic Analysis Tool Box Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*.

Figure 5.1 Simulation Modeling Workflow

VISSIM Model Limits

CS will prepare a traffic microsimulation model in VISSIM software of the C-470 corridor from I-25 to west of Kipling. The VISSIM model will include each interchange within the limits from I-25 and Kipling. Each interchange will include the ramp terminal intersections and at least one signalized intersection on either side of the interchange. Figure 5.2 is an illustration showing the VISSIM model limits. The red line indicates the freeway model limits, the blue lines and blue dots indicate the arterial networks.

Figure 5.2 Simulation Spatial Model Limits

Temporal Limits

The VISSIM models will be built to accommodate two seven-hour model peak periods. The longer periods will allow for more complete toll and revenue information from the simulation, leaving less to estimation. The base year models will only be calibrated to a stringent statistical criteria for the peak three hours within each of the two peak periods. The shoulder hours will be checked for reasonableness but will not receive the same level of scrutiny. The temporal limits are outlined in Table 5.1.

Table 5.1 Temporal Limits of Simulation Models

Time Period	Overall Model Duration	Warm-up Period [a]	Core Peak Period
AM Peak Period	6:00 a.m. to 1:00 p.m.	6:00 a.m. to 6:30 a.m.	To be determined
PM Peak Period	1:00 p.m. to 8:00 p.m.	1:00 p.m. to 1:30 p.m.	To be determined

[a] First half-hour run twice to load network.

5.2 DATA COLLECTION FOR SIMULATION

The data collection that was conducted for this project is discussed in Section 3.0 of this document. In addition, there is a *Data Summary Report*. In brief, the simulation-related data included:

- Multiple days of counts so that statistical T-tests can be conducted for calibration; and
- Limited speed runs to capture the essence of congestion on the corridor.

The simulation model will be calibrated to May 15, 2013 traffic conditions.

5.3 BASE VISSIM MODEL CODING

Coding the VISSIM model will follow the procedures and practices specified by the software vendor and based on CS' professional simulation modeling experience. There are hundreds of settings within all the basic modeling elements. The Base VISSIM model coding will be documented in a report that outlines all the various parameters used in VISSIM, including default values an recommended ranges. The major model elements in VISSIM are summarized in Table 5.2.

Table 5.2 Basic VISSIM Modeling Elements

VISSIM Model Element	Description
Links and Link Connectors	The physical structure of the model is comprised of links and link connectors (where traffic is allowed to pass to another facility). Each type of facility (freeway, arterial, managed lane) will be identified separately with their individual operating characteristics.
Speed control	Desired free-flow speeds, transition speeds are covered in this area. Primarily based on posted speed limits plus other observations. May be modified during calibration.
Nodes and Parking lots	These are locations where traffic is allowed to enter and exit the model.
Traffic Control	Signal operations including intersection signals, ramp metering, yield, and stop signs.
Vehicles	Vehicles are stratified by classifications (heavy truck passenger cars) and by types (single-occupancy user, high-occupancy user, transponder). These are grouped together into vehicle compositions that are applied at nodes and parking lots.
Global Parameters	Car-following parameters that affect spacing and driver aggressiveness

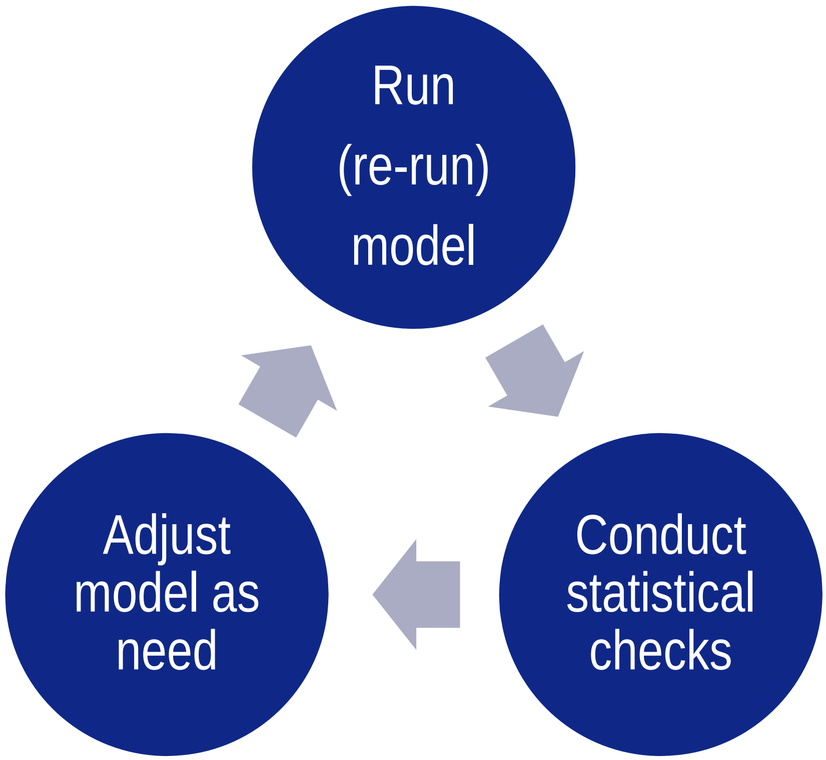
5.4 ERROR CHECKING

The Base VISSIM model inputs will be checked by an individual skilled in VISSIM, but separate from the individual performing the model coding work. This individual will verify that the geometry, signal control and other inputs are correct as compared to field inventories and supporting data. As issues are discovered, the QC person will return the model and comments back to the model preparer to confer on any discrepancies. All changes will be made by the original modeler and reconfirmed by the QC individual.

5.5 VISSIM CALIBRATION

The VISSIM simulation model will be calibrated based on existing conditions, according to the existing traffic demand, current vehicle throughput, and vehicle speeds/travel times that were observed on May 15, 2013 (refer to the *Data Summary Report*). The calibration process is an iterative process in which the model is run and statistical analysis is conducted. If the statistical criteria are not satisfied, the model parameters are adjusted and the run process is repeated. This process is represented in Figure 5.3.

Figure 5.3 Calibration Model Runs

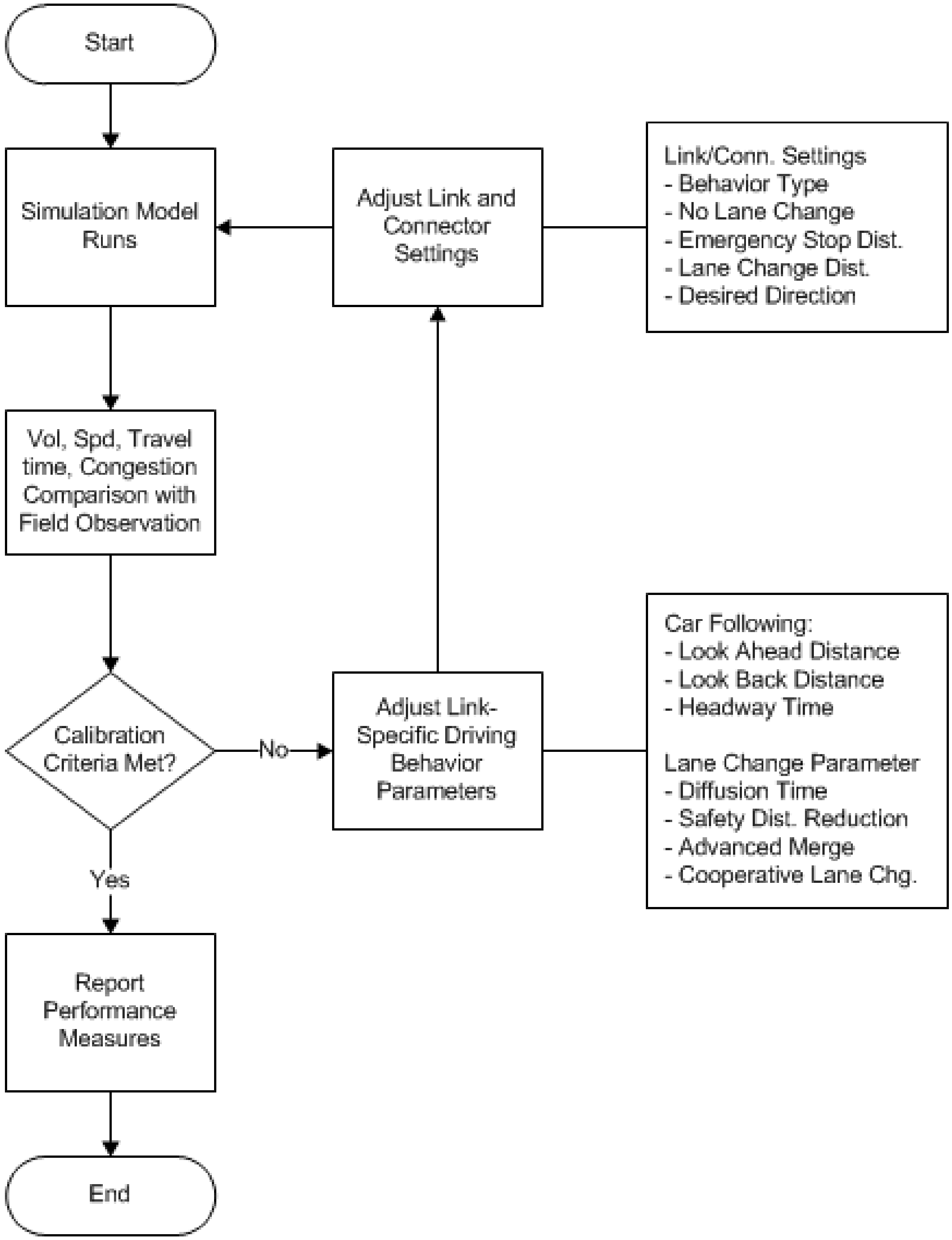


The following subsections describe the calibration adjustment strategy and the statistical methodology that will be used. The final calibration process and results will be documented in a calibration report.

Calibration Parameter Adjustment Strategy

It is anticipated that the VISSIM model will require adjustments to parameters in order to calibrate the model. CS will utilize a hierarchy and strategy for adjusting the model parameters. The process will focus on the more important parameters and will be streamlined so that the process is conducted efficiently. The adjustment strategy is illustrated in Figure 5.4.

Figure 5.4   Calibration Parameter Adjustment Strategy



Statistical Methodology: Primary Time Periods

The statistical methodology for the primary peak hours will follow the methodology published in the Guidance on the Level of Effort Required to Conduct Traffic Analysis. The complete methodology is documented in Appendix B. The process in brief is as follows:

- Select locations for statistical tests.
- Analyze field data to determine variation and error rate.
- Analyze traffic model output to determine adequate number of model runs.
- Compare Field Data to Traffic Model Results:
  - Conduct Statistical Test 2 – Compare field data to traffic model results using a Z-test;
  - If the statistical relationship between modeled output and field data does not indicate a significant difference, then proceed with measure of effectiveness (MOE) comparisons, including volumes, speeds, travel times, and bottlenecks; and
  - If the statistical relationships between field data and modeled output do indicate a significant difference, adjust calibration parameters, rerun models, and repeat Statistical Test 2.

This process will be deployed on the peak three hours within the AM and PM peak period models. The statistical locations will be limited to the locations in the field where sufficient data is collected. This will be documented in the calibration report.

Statistical Methodology Shoulder Hours

The simulation models will be run for extended time periods, (seven hours for each time period). The level of congestion and the required accuracy will be less significant outside the peak hours. For these shoulder hours, we will utilize a less rigorous yet informative statistical test. GEH statistics are shown in Table 5.3.

Table 5.3 Secondary Calibration Criteria and Measures

Criteria and Measures	Calibration Acceptance Targets
Hourly Flows, Model Versus Observed	
Individual Link Flows	
Within 15%, for 700 vph < Flow < 2,700 vph	> 85% of cases
Within 100 vph, for Flow < 700 vph	> 85% of cases
Within 400 vph, for Flow> 2,700 vph	> 85% of cases
Sum of all Link Flows	Within 5% of sum of all link counts
GEH Statistics < 5 for Individual Link Flows	> 85% of cases
GEH Statistics for Sum of all Link Flows	GEH < 4 for sum of all link counts

Criteria and Measures	Calibration Acceptance Targets
Travel Times, Model Versus Observed	
Journey times network	
Within 15% (or 1 minute, if higher)	> 85% of cases
Visual Audits	
Individual link speeds	
Visually acceptable speed-flow relationship	To analyst's satisfaction
Bottlenecks	
Visually acceptable speed-flow relationship	To analyst's satisfaction

5.6 Modeling Alternatives

The future conditions will be analyzed using the VISSIM model. The process will include the coding of the geometry of the managed express toll lane concept, and the proposed the concept of operations. The VISSIM model will be coded to include the Managed Lane Module which incorporates toll price setting and willingness to pay. Within the VISSIM simulations, traffic will be dynamically assigned to the managed express toll lanes. The outcome of the traffic simulation will be traffic operations results in the general purpose lanes and the managed express toll lanes, gross revenue, and the number of toll transactions. The steps for analyzing the express lane alternatives will include the following:

1. Code express lanes and ingress/egress alternatives in the base VISSIM model;
2. Code VISSIM express lane operations including decisions points and tolling zones;
3. Develop and implement willingness to pay logit coefficients;
4. Code and model dynamic pricing to determine fixed variable rates;
5. Model scenarios with willingness to pay, fixed variable rates, and future demands; and
6. Perform sensitivity testing for risk analysis.

Future Demand Trip Tables

The forecasted future travel demand will be obtained from the Focus model and incorporated into the traffic simulation model. As discussed in Section 4.0, the Focus model output will properly transition the trip tables to the VISSIM microsimulation model to ensure that all vehicle paths are captured. The trip tables will be prepared at the 30-minute level and the vehicle classes will be divided into vehicles classes that will help distinguish between transponder vehicles and license plate vehicles.

VISSIM Managed Lane Module

The VISSIM managed lane module will be utilized to assign traffic within the simulation model to the managed express toll lane. The module consists of physical paths in parallel between the general purpose (GP) lanes and the managed express toll lanes, a decision model, and a pricing model. The paths will be coded to reflect the ingress/egress of the design concept and the pricing zone structure. The toll pricing and willingness to pay are discussed in more detail below.

Toll Price Setting

The pricing strategy will need to be determined and deployed in the VISSIM model. The current pricing schemes in the Denver region is time-of-day pricing. In order to develop toll pricing rates for C-470, CS will run VISSIM with dynamic pricing. CS will deploy a dynamic congestion pricing algorithm to help determine the time-of-day pricing rates and schedule. Tolls will be charged by either a transponder or, if there is not a transponder, through license plate recognition. There is a surcharge on the tolls for vehicles using the express lane with only vehicle recognition, and this will need to be reflected in the pricing.

The parameters and objectives of the toll price setting have been established by High-Performance Transportation Enterprise (HPTE) staff and the TWG. The parameters and objectives are as follows:

- Facility Length – ~13 miles;
- Pricing Basis – Per Zone (2);
- Minimum Toll – <u>**$0.50**</u>;
- Maximum Toll – max toll to be determined by CS modeling;
- Toll change time interval – 60 minutes;
- License plate charge – ~25 percent;
- Operational Capacity – <u>1,900 vphpl</u>;
- Performance measure – <u>Travel Speed</u>; and
- Performance target – <u>55 mph</u> exceeded 90 percent of the time (LOS D).

Willingness to Pay

Willingness to pay is represented in the VISSIM model with a logit model. The logit model has coefficients that are developed based on stated-preference surveys. At this stage of the project, there will *not* be a new state preference survey conducted for C-470. CS will utilize the recent U.S. 36 stated-preference survey that was conducted for the proposed managed lanes between Denver and Boulder. The survey will be adjusted according to prevailing socioeconomic differences between the U.S. 36 corridor and the C-470 Corridor.

Sensitivity Testing

Sensitivity testing will be conducted to determine potential ranges in revenue outcomes and to ultimately feed a risk-based assessment of revenue outcomes. The precise number and types of sensitivity tests will be determined as the Toll and revenue risk assessment is prepared. Table 5.4 is a draft table that provides potential risk variables and an estimate of the model run time required.

Table 5.4 Draft Sensitivity Testing Variables and Model Run Estimate

		Potential Risk Variables				Estimated No. of Model Runs		
Test No.	Year	Transponder Ownership Population	Willingness to Pay	Toll Pricing	Land Use	Peak Periods	Estimated No. of Runs per Period	Total No. of Model Runs
1	2025		low	2025 pricing		2	8	16
2	2025		medium	2025 pricing		2	8	16
3	2025		high	2025 pricing		2	8	16
4	2025		low	2025 pricing		2	8	16
5	2025		medium	2025 pricing		2	8	16
6	2025		high	2025 pricing		2	8	16
7	2035		low	2035 pricing		2	8	16
8	2035		medium	2035 pricing		2	8	16
9	2035		high	2035 pricing		2	8	16
10	2035		low	2035 pricing		2	8	16
11	2035		medium	2035 pricing		2	8	16
12	2035		high	2035 pricing		2	8	16
Model runs								192
Estimated hours per run								3
Total hours of computer time								576

6.0 Toll and Revenue Forecasting

Methodology development in progress.

A. Base and Future Land Use Assumptions

Table A.1 2010 SE Data

2010								Density	
County	Area	Population	Households	Employment	Enrollment	HH Size	Population	Employment	Enrollment
Adams	1,183	451,143	164,704	174,179	110,160	2.74	381.2	139.2	147.2
Arapahoe	807	556,375	227,635	287,344	141,355	2.44	689.3	282.0	356.0
Boulder	740	292,014	121,630	161,813	80,984	2.40	394.5	164.3	218.6
Broomfield	33	51,673	19,359	32,599	14,246	2.67	1,559.7	584.3	984.0
Clear Creek	397	10,036	4,456	3,056	1,076	2.25	25.3	11.2	7.7
Denver	155	584,659	265,531	445,062	191,419	2.20	3,770.0	1,712.2	2,869.9
Douglas	843	283,291	101,604	93,042	59,962	2.79	336.2	120.6	110.4
Gilpin	151	5,320	2,368	5,057	362	2.25	35.3	15.7	33.6
Jefferson	773	539,853	222,099	222,381	111,335	2.43	698.8	287.5	287.9
Park	580	56,818	19,170	10,242	10,636	2.96	97.9	33.0	17.6
Weld	589	32,715	11,823	9,040	3,288	2.77	55.5	20.1	15.3
Total	6,251	2,863,897	1,160,379	1,443,815	724,823	2.47	458.1	185.6	231.0

Table A.2 2035 Socio Economic Data

2035							Density		
County	Area	Population	Households	Employment	Enrollment	HH Size	Population	Employment	Enrollment
Adams	1,183	723,290	276,367	281,630	152,509	2.62	611.2	233.5	238.0
Arapahoe	807	778,692	332,203	375,115	181,474	2.34	964.7	411.6	464.7
Boulder	740	361,262	152,827	169,160	102,496	2.36	488.1	206.5	228.5
Broomfield	33	87,665	34,062	67,675	21,000	2.57	2,646.2	1,028.2	2,042.8
Clear Creek	397	12,880	5,838	3,787	2,330	2.21	32.4	14.7	9.5
Denver	155	746,452	353,009	603,018	226,594	2.11	4,813.3	2,276.3	3,888.4
Douglas	843	481,681	178,871	173,940	84,199	2.69	571.6	212.2	206.4
Gilpin	151	7,091	3,223	5,613	829	2.20	47.1	21.4	37.3
Jefferson	773	680,690	290,084	290,590	126,275	2.35	881.1	375.5	376.2
Park	580	118,826	40,644	18,717	2,977	2.92	204.8	70.0	32.3
Weld	589	82,855	30,796	18,737	9,371	2.69	140.6	52.3	31.8
Total	6,251	4,081,384	1,697,924	2,007,982	910,054	2.40	652.9	271.6	321.2

Table A.3 Change in SE Data

Change						Density		
County	Population	Households	Employment	Enrollment	HH Size	Population	Employment	Enrollment
Adams	272,147	111,663	107,451	42,349	(0.12)	230	94	91
Arapahoe	222,317	104,568	87,771	40,119	(0.10)	275	130	109
Boulder	69,248	31,197	7,347	21,512	(0.04)	94	42	10
Broomfield	35,992	14,703	35,076	6,754	(0.10)	1,086	444	1,059
Clear Creek	2,844	1,382	731	1,254	(0.05)	7	3	2
Denver	161,793	87,478	157,956	35,175	(0.09)	1,043	564	1,019
Douglas	198,390	77,267	80,898	24,237	(0.10)	235	92	96
Gilpin	1,771	855	556	467	(0.05)	12	6	4
Jefferson	140,837	67,985	68,209	14,940	(0.08)	182	88	88
Park	62,008	21,474	8,475	(7,659)	(0.04)	107	37	15
Weld	50,140	18,973	9,697	6,083	(0.08)	85	32	16
Total	1,217,487	537,545	564,167	185,231	(0.06)	194.8	86.0	90.2

Table A.4 Percent Changes in SE Data

Change				
County	Population	Households	Employment	Enrollment
Adams	60%	68%	62%	38%
Arapahoe	40%	46%	31%	28%
Boulder	24%	26%	5%	27%
Broomfield	70%	76%	108%	47%
Clear Creek	28%	31%	24%	117%
Denver	28%	33%	35%	18%
Douglas	70%	76%	87%	40%
Gilpin	33%	36%	11%	129%
Jefferson	26%	31%	31%	13%
Park	109%	112%	83%	-72%
Weld	153%	160%	107%	185%
Total	43%	46%	39%	26%

B. Microsimulation Calibration Statistical Methodology

Text From Statistical Section of Level of Effort

The purpose of conducting a statistical test on stochastic traffic simulation models is to ensure that the means of performance measures across different simulation model runs differ significantly from the means of the data in the field. This statistical check requires two primary items. First, there must be a sufficient amount of field data from different days so that an acceptable margin of error in data can be determined. Second, there must be an error-free traffic simulation model that has been built to reflect the conditions in the field (i.e., the model reflects adequate spatial and temporal boundary conditions). With these two pieces in hand, the following general statistical procedure can be conducted.

- Select locations for statistical tests.
- Analyze field data:
  - Calculate Sampling Error (margin of error) of field data from multiple days of data.
  - Calculate Tolerance (margin of error in percent of the mean). This percentage value will be used to determine the minimum number of model runs to perform.
- Analyze traffic model output:
  - Run traffic models 5 to 10 times with different random number seeds and conduct statistical tests on model results; and
  - Conduct Statistical Test 1 – Determine the minimum required number of model runs.
- Compare Field Data to Traffic Model Results:
  - Conduct Statistical Test 2 – Compare field data to traffic model results using a Z-test.
  - If the statistical relationship between modeled output and field data does not indicate a significant difference, then proceed with MOE comparisons, including volumes, speeds, travel times, and bottlenecks.
  - If the statistical relationships between field data and modeled output do indicate a significant difference, adjust calibration parameters, rerun models, and repeat Statistical Test 2.

Analyze Field Data

Field data must be collected for multiple days. These data are initially used to establish model inputs and are then used in statistical tests. The first set of analyses is to understand the variability in the data. The variability is addressed by calculating the Margin of Error '**E**' among different representative days, as follows:

$$\boldsymbol{E = Z\left(\frac{\sigma}{\sqrt{n}}\right)}$$

Where:

Z is the critical Z statistic (for a 95-percent Confidence Interval, Z = 1.96);

σ is the standard deviation; and

n is the sample size (number of observations).

The tolerance percentage is calculated by dividing error 'E' by the mean of the field data.

$$\frac{Error\ 'E'}{Field\ Mean} = Tolerance\ \%\ 'e'$$

Statistical Test 1: Determine the Minimum Required Number of Model Runs

Statistical Test 1 is a determination of the minimum required number of model runs based on an error rate calculated using the procedure described in the previous subsection. For a given target level of **tolerance** (tolerable error determined using variability in field observations), and a given **confidence** level (usually a confidence level of 95 percent is selected), a minimum number of model runs is required using different random number seeds. The minimum required number of model runs is computed using the following formula:

$$\boldsymbol{n = \frac{(S)^2(\sigma)^2}{(e\overline{X})^2}}$$

Where:

n is the minimum number of model runs required;

S is the critical ***Z*** statistic (for a 95-percent Confidence Interval, ***Z*** = 1.96);

σ is the standard deviation calculated on the basis of the conducted model runs for the given performance measure;

e is the Tolerance Error is a calculated value from the field data variability; and

$\overline{\boldsymbol{X}}$ is the Mean calculated on the basis of the performed model runs for the given MOE.

Statistical Test 2: Compare Field Data to Model Output

The next statistical step is to compare the **two populations** (i.e., field data volume mean versus model output volume mean) by testing the following hypothesis:

$$H_0: \bar{x}_{field} = \bar{x}_{model}$$

$$H_1: \bar{x}_{field} \neq \bar{x}_{model}$$

$$Z_{Calculated} = \frac{\bar{x}_{field} - \bar{x}_{model}}{\sqrt{\frac{{s_{field}}^2}{n_{field}} + \frac{{s_{model}}^2}{n_{model}}}}$$

Where:

$\bar{x}_{\boldsymbol{field}}$ is the average (mean) of the field observations;

$\bar{x}_{\boldsymbol{model}}$ is the average (mean) of output from different model runs;

$\mathbf{s}_{\boldsymbol{field}}$ is the standard deviation from field observations;

$\mathbf{s}_{\boldsymbol{model}}$ is the standard deviation from the model runs;

$\boldsymbol{n_{field}}$ is the sample size of the field observations;

$\boldsymbol{n_{model}}$ is the number of model runs with different random number seeds;

$\mathbf{Z}_{\mathbf{calculated}}$ is the Z-test of the field data and modeled data;

$\boldsymbol{Z_{critical}} = 1.96\ for\ a\ 95\%\ Confidence\ Interval$; and

If $\mathbf{Z}_{\mathbf{calculated}} \geq \mathbf{Z}_{\mathbf{critical}}$ **or** $\leq -\mathbf{Z}_{\mathbf{critical}}$, Reject $\mathbf{H_0}$.

The hypothesis test is a two tailed Z-test based on a normal distribution. Figure 6.1 is a graph of the normal distribution. The area between $\boldsymbol{Z_{critical}}$ of ±1.96 is the do-not-reject range.