CAMBRIDGE SYSTEMATICS

Methods and Assumptions

C-470 Traffic Modeling

final

report

prepared for

Douglas County

prepared by

Cambridge Systematics, Inc.

November 10, 2014

www.camsys.com

final report

Methods and Assumptions

C-470 Traffic Modeling

prepared for

Douglas County

prepared by

Cambridge Systematics, Inc.
999 18th Street, Suite 3000
Denver, CO 80202

date

November 10, 2014

Table of Contents

1.0 Introduction 1-1
1.1 Study Purpose 1-1
1.2 Background 1-1
1.3 Roles and Responsibilities 1-2

2.0 Modeling Workflow 2-1
2.1 Alternatives 2-2
2.2 QA/QC 2-3

3.0 Data 3-1
3.1 Data Sources 3-1
3.2 Data Gaps 3-2
3.3 Data Collection Program 3-2

4.0 Travel Demand Methodology 4-1
4.1 Modeling Inputs and Assumptions 4-1
4.2 Base Year Demand Calibration 4-2
4.3 Future Travel Demand 4-11
4.4 Time-of-Day Procedures 4-13

5.0 Microsimulation Modeling 5-1
5.1 Simulation Workflow Overview 5-1
5.2 Data Collection for Simulation 5-2
5.3 Base VISSIM Model Coding 5-2
5.4 Error Checking 5-3
5.5 VISSIM Calibration 5-3
5.6 Modeling Alternatives 5-7

6.0 Traffic and Revenue Forecasting 6-1
6.1 VISSIM Managed-Lane Module 6-1
6.2 Revenue 6-6

A. Base and Future Land Use Assumptions A-1

List of Tables

Table 1.1 Contact Database 1-2
Table 1.2 Summary of Work Products 1-4
Table 2.1 Regional Model Scenarios 2-2
Table 2.2 Simulation Alternatives 2-3
Table 3.1 Data Source and Data Applications 3-1
Table 4.1 Calibration Statistics for Regional Study Area 4-5
Table 4.2 Calibration Statistics for C-470 Corridor 4-5
Table 4.3 Quebec Screenline Results 4-6
Table 4.4 Kipling Screenline Results 4-7
Table 4.5 AM Average Trip Length Comparison 4-8
Table 4.6 PM Average Trip Length Comparison 4-8
Table 5.1 Temporal Limits of Simulation Models 5-2
Table 5.2 Basic VISSIM Modeling Elements 5-3
Table 5.3 Secondary Calibration Criteria and Measures 5-6
Table 5.4 Draft Sensitivity Testing Variables and Model Run Estimate 5-9
Table 6.1 Revenue and Transaction Annualization Assumptions 6-7
Table A.1 2010 Socioeconomic Data A-2
Table A.2 2035 Socioeconomic Data A-3
Table A.3 Change in Socioeconomic Data A-4
Table A.4 Percent Changes in Socioeconomic Data A-5

List of Figures

Figure 1.1 Project Limits 1-1
Figure 1.2 Project Organization Chart 1-3
Figure 2.1 Overall Modeling Workflow 2-1
Figure 3.1 Data Collection Study Area 3-3
Figure 4.1 Study Area 4-3
Figure 4.2 AM Auto Trip Length Distribution 4-9
Figure 4.3 AM Truck Trip Length Distribution 4-9
Figure 4.4 PM Auto Trip Length Distribution 4-10
Figure 4.5 PM Truck Trip Length Distribution 4-10
Figure 5.1 Simulation Modeling Workflow 5-1
Figure 5.2 Simulation Spatial Model Limits 5-1
Figure 5.3 Calibration Model Runs 5-4
Figure 5.4 Calibration Parameter Adjustment Strategy 5-5
Figure 6.1 Express Lane Traffic Assignment Illustration 6-2
Figure 6.2 Dynamic Toll Price Algorithm Illustrations 6-3
Figure 6.3 Fixed Pricing Illustration 6-4
Figure 6.4 Willingness to Pay Probabilities 6-5

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 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 organizational 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
John Duesing	Cambridge Systematics, Inc.	(646) 364-5480	jduesing@camsys.com
David Kurth	Cambridge Systematics, Inc.	(303) 357-4661	dkurth@camsys.com
Jaimie Sloboden	Cambridge Systematics, Inc.	(904) 315-7923	jsloboden@camsys.com
Jennifer Strasser	Cambridge Systematics, Inc.	(646) 364-5475	jstrasser@camsys.com
John Lewis	Cambridge Systematics, Inc.	(617) 234-0519	jlewis@camsys.com

Figure 1.2 Project Organization Chart

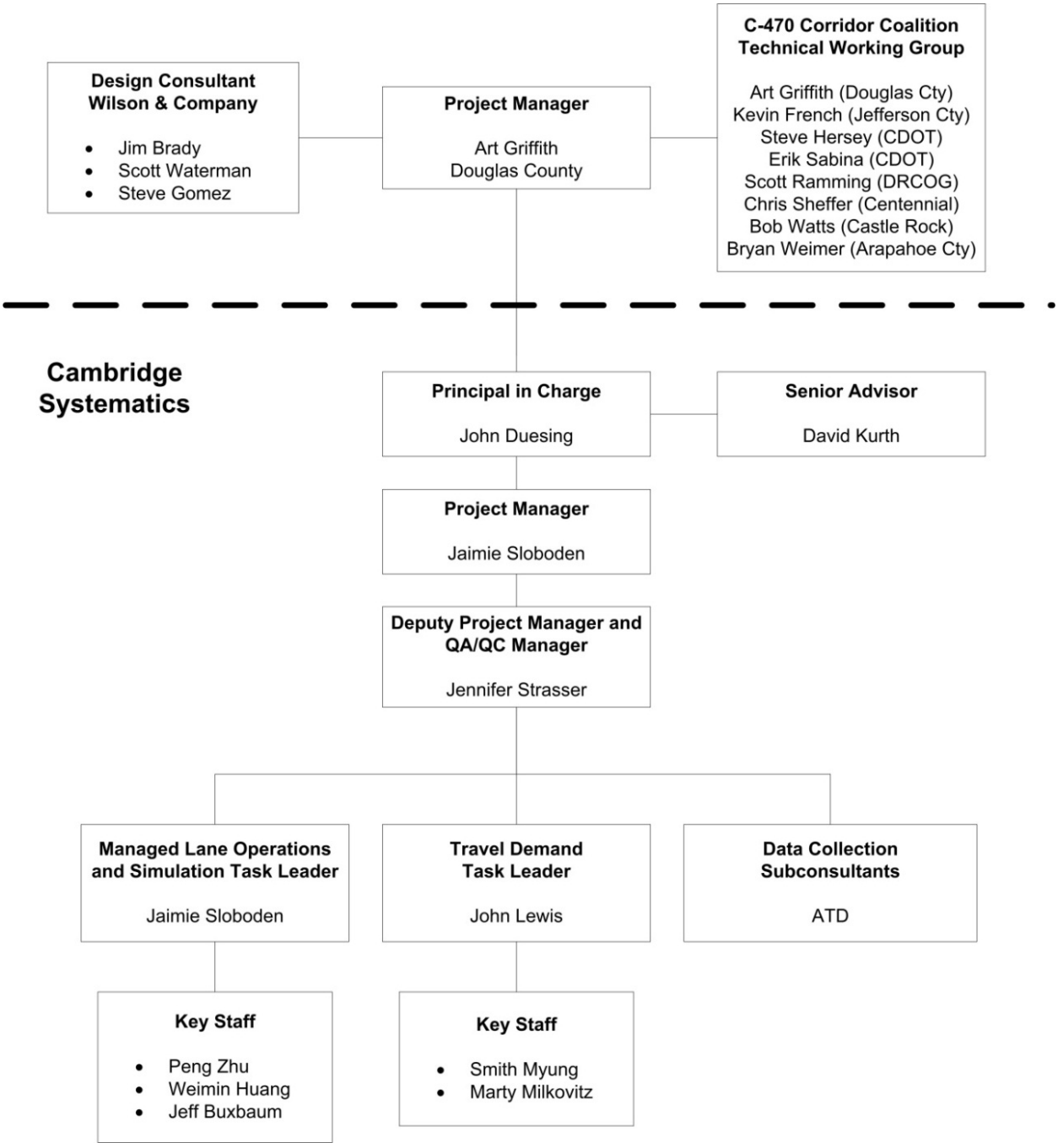


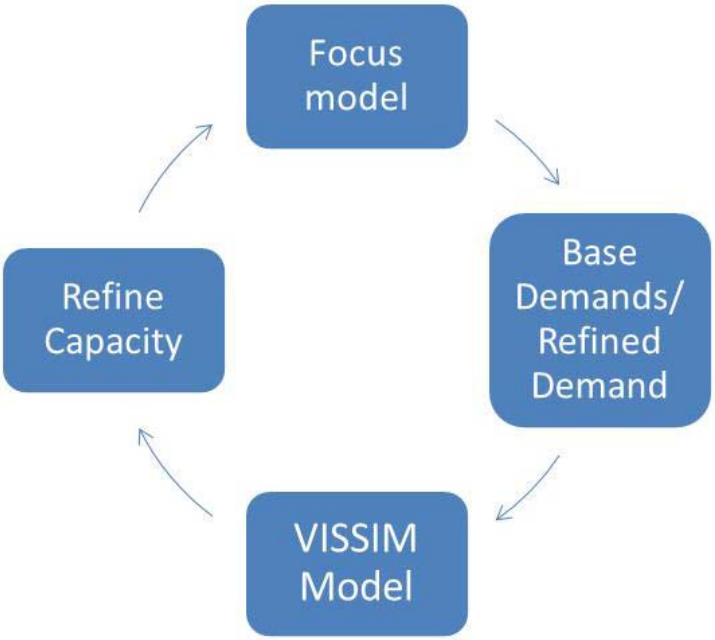
Table 1.2 Summary of Work Products

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 Technical Memo		In progress
4	Data Collection Plan	4/23/2013	Completed
	Data Collection Activities Technical Memo		In progress
5	Modeling Framework Technical Memo		
	Demand Model Files		
6	VISSIM Base Model Files		
	VISSIM Future Scenario Model Files		
	Operations Analysis/Toll Technical 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 Tolls
	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 Tolls
	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
	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 have 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, Midday, 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

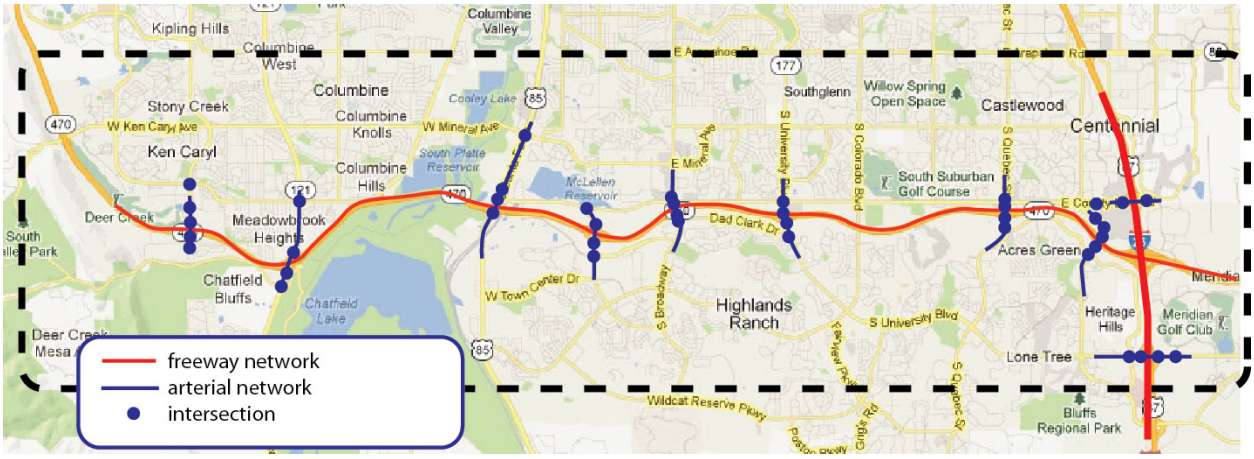
After careful review of all the data listed in the previous section, it was determined that the available data are out of date, not complete enough to conduct a basic traffic study covering the study area, and not robust enough to build a solid 14-hour traffic simulation model. Particularly for a microsimulation 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

Overview

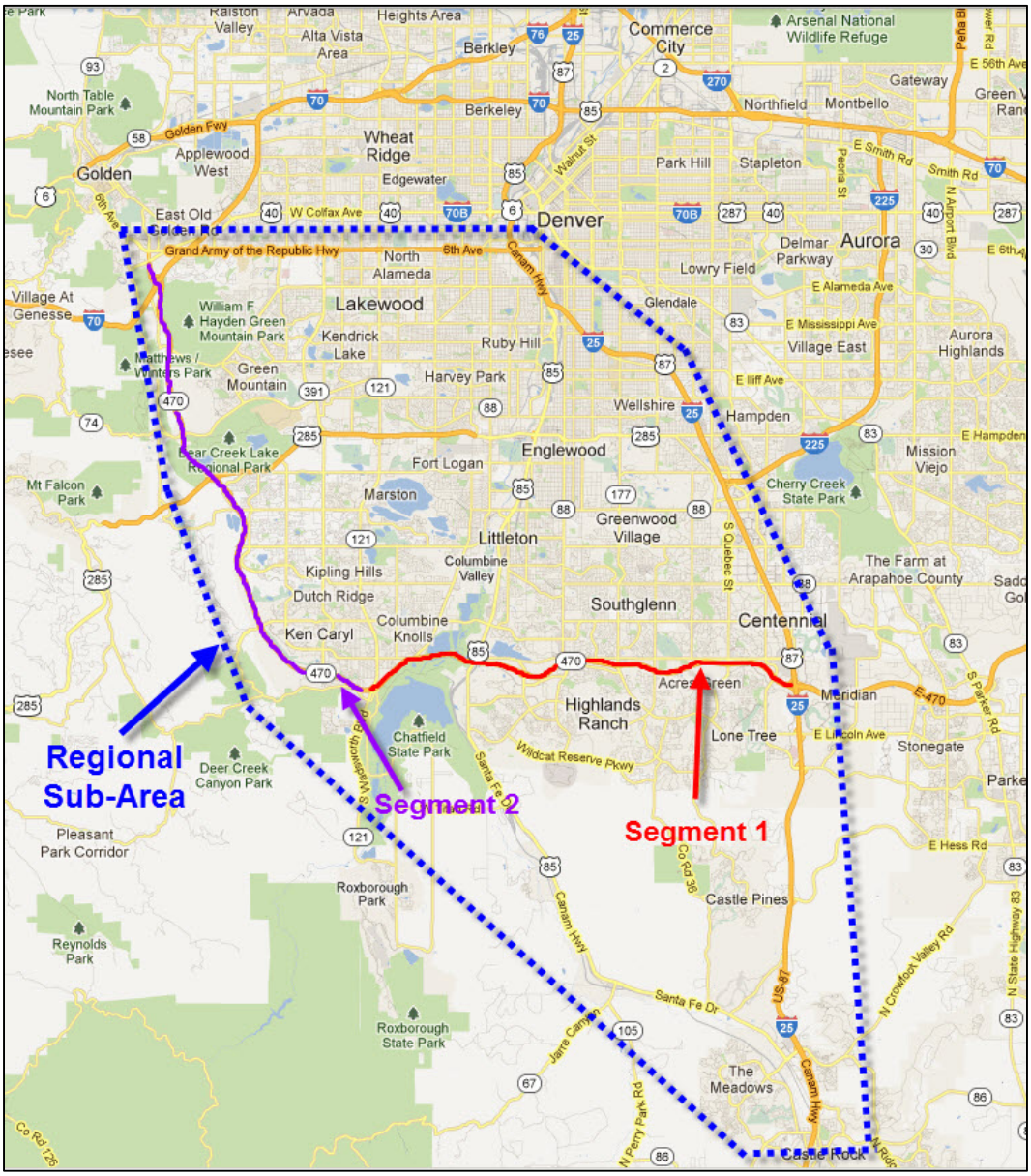
A key input to the microscopic model is a calibrated origin-destination (OD) matrix. A procedure commonly adopted to develop a calibrated OD matrix is Origin Destination Matrix Estimation (ODME). ODME procedures within TransCAD were used in this study. This report describes the methodology utilized to calibrate the OD matrices that will serve as inputs to the microscopic simulation models developed to study alternatives for the C-470 Managed-Lane Project.

The objective of ODME is to provide OD matrices by vehicle type (auto and truck) for each time slice during the AM and PM peak periods, that are consistent with ground counts yet sensitive to future year changes in demand and/or supply. The peak-period matrices are further broken down into smaller time slices to produce traffic demand profiles that are fed as an input into the microscopic simulation model.

A two-tiered approach was utilized:

1. Calibration of the regional subarea (see Figure 4.1) to capture regional diversion dynamics; and
2. Refinement of link-level demands and extraction of the C-470 corridor (Segment 1) trips to be used as input to the microsimulation model.

Figure 4.1 Study Area



Matrix Calibration Inputs

DRCOG's Focus Model served as the basis for the networks and the trip matrices. The Focus travel model is an activity-based model for the Denver region developed by Denver Regional Council of Governments (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; http://www.drcog.org/index.cfm?page=FocusTechnicalResources.

Network Preparation

The study area highway networks were validated against current conditions using field examination and google maps to confirm roadway geometry and alignments. Only minor editing of centroid connector locations was performed.

Zonal System Preparation and Seed Table Development

No zonal changes were necessary to support the analysis.

Seed Tables

The initial seed trip tables for the C-470 corridor were extracted from the Focus model using standard subarea extraction techniques within TransCAD.

Traffic Count Data

The ODME process uses segment traffic counts by mode and/or class (SOV, HOV, and truck), and turning movement counts.

The traffic volume data used was collected in May of 2013. The data that was collected is summarized in a separate *Data Summary Report*.

OD Calibration Procedures (ODME) and Results

Once the auto and truck seed trip tables were developed, an OD trip matrix estimation was performed in TransCAD at the regional level. The ODME procedure entailed:

1. Performing a multimodal ODME process, using auto and truck traffic counts as targets for both links and turning movements.
2. Comparison of estimated flows to observed counts. This whole process was repeated until the estimated ODs produced traffic flows that closely matched the count data. The OD trip matrices were considered calibrated when the calibration criteria (described below) were met.

Calibration Criteria

Consistent with other corridor study projects using microsimulation models, the link flow validation targets presented below are proposed for the base year OD estimation process as well. These standards will be applied to the total link flow for all vehicles. The calibration criteria are listed below:

- GEH ≤5 in C-470 Corridor (Segment 1);
- GEH ≤10 in regional study area; and
- Percentage difference between volume and count across the screenline within 15 percent of observed screenline counts.

Note: The GEH statistic is computed as follows:

$$GEH = \sqrt{\frac{(E-V)^2}{(E+V)/2}}$$

where:

E = model estimated volume; and

V = field count.

Peak Period Results

Regional and Subarea Link Volume Calibration

Statistics consistent with the calibration criteria outlined above also were compiled to check how well the subarea models replicated the observed conditions. The criteria within both the primary and secondary areas for both AM and PM periods were met (see Table 4.1 and Table 4.2).

Table 4.1 Calibration Statistics for Regional Study Area

Area Type	Number of Counts	Average Deviation	Percent RMSE	Percent of Locations Satisfying GEH ≤10
AM Period	514	-1%	4.9%	90%
PM Period	542	-1%	5.7%	87%

Table 4.2 Calibration Statistics for C-470 Corridor
Hourly

Hour	Number of Counts	Average Deviation	Percent of Locations with GEH ≤5
6 a.m. to 7 a.m.	134	-0.09%	94%
7 a.m. to 8 a.m.	134	-1.9%	93%
8 a.m. to 9 a.m.	134	-1.9%	96%
9 a.m. to 10 a.m.	134	-2.3%	92%
10 a.m. to 11 a.m.	134	-1.5%	93%
11 a.m. to 12 p.m.	134	-2.5%	92%
12 p.m. to 1 p.m.	134	-2.6%	91%
1 p.m. to 2 p.m.	134	-1.5%	96%
2 p.m. to 3 p.m.	134	-0.9%	93%
3 p.m. to 4 p.m.	134	-1.5%	94%
4 p.m. to 5 p.m.	134	-1.6%	88%
5 p.m. to 6 p.m.	134	-1.6%	89%
6 p.m. to 7 p.m.	134	-1.4%	93%
7 p.m. to 8 p.m.	134	0.4%	96%

Screenline Comparison

All of the screenline volumes for both AM and PM periods are within 10 percent of the counts, well within the proposed calibration criteria.

Table 4.3 Quebec Screenline Results

Screenline	Count	Volume	Percent Difference
Westbound			
6 a.m. to 7 a.m.	3,264	3,231	-1%
7 a.m. to 8 a.m.	3,946	3,920	-1%
8 a.m. to 9 a.m.	3,403	3,369	-1%
9 a.m. to 10 a.m.	2,699	2,670	-1%
10 a.m. to 11 a.m.	2,869	2,852	-1%
11 a.m. to 12 p.m.	3,031	3,004	-1%
12 p.m. to 1 p.m.	3,192	3,139	-2%
1 p.m. to 2 p.m.	3,279	3,269	0%
2 p.m. to 3 p.m.	4,198	4,179	0%
3 p.m. to 4 p.m.	4,312	4,289	-1%
4 p.m. to 5 p.m.	4,120	4,131	0%
5 p.m. to 6 p.m.	4,137	4,115	-1%
6 p.m. to 7 p.m.	3,236	3,141	-3%
7 p.m. to 8 p.m.	2,469	2,407	-2%
Eastbound			
6 a.m. to 7 a.m.	4,627	4,632	0%
7 a.m. to 8 a.m.	5,141	5,069	-1%
8 a.m. to 9 a.m.	4,834	4,790	-1%
9 a.m. to 10 a.m.	3,749	3,717	-1%
10 a.m. to 11 a.m.	3,004	2,968	-1%
11 a.m. to 12 p.m.	3,160	3,139	-1%
12 p.m. to 1 p.m.	3,373	3,362	0%
1 p.m. to 2 p.m.	3,355	3,339	-1%
2 p.m. to 3 p.m.	3,325	3,339	0%
3 p.m. to 4 p.m.	4,047	4,054	0%
4 p.m. to 5 p.m.	2,769	2,856	3%
5 p.m. to 6 p.m.	2,612	2,672	2%
6 p.m. to 7 p.m.	3,646	3,616	-1%
7 p.m. to 8 p.m.	2,066	2,086	1%

Table 4.4 Kipling Screenline Results

Screenline	Count	Volume	Percent Difference
Westbound			
6 a.m. to 7 a.m.	2,759	2,713	-2%
7 a.m. to 8 a.m.	3,093	3,086	0%
8 a.m. to 9 a.m.	2,299	2,361	3%
9 a.m. to 10 a.m.	1,432	1,469	3%
10 a.m. to 11 a.m.	1,517	1,547	2%
11 a.m. to 12 p.m.	1,552	1,596	3%
12 p.m. to 1 p.m.	1,701	1,742	2%
1 p.m. to 2 p.m.	1,818	1,801	-1%
2 p.m. to 3 p.m.	2,601	2,605	0%
3 p.m. to 4 p.m.	3,294	3,333	1%
4 p.m. to 5 p.m.	3,698	3,697	0%
5 p.m. to 6 p.m.	3,287	3,296	0%
6 p.m. to 7 p.m.	1,334	1,348	1%
7 p.m. to 8 p.m.	1,084	1,039	-4%
Eastbound			
6 a.m. to 7 a.m.	3,094	3,032	-2%
7 a.m. to 8 a.m.	3,548	3,510	-1%
8 a.m. to 9 a.m.	3,246	3,224	-1%
9 a.m. to 10 a.m.	2,344	2,328	-1%
10 a.m. to 11 a.m.	1,835	1,812	-1%
11 a.m. to 12 p.m.	1,855	1,843	-1%
12 p.m. to 1 p.m.	1,901	1,876	-1%
1 p.m. to 2 p.m.	1,901	1,923	1%
2 p.m. to 3 p.m.	2,157	2,151	0%
3 p.m. to 4 p.m.	2,744	2,731	0%
4 p.m. to 5 p.m.	2,075	2,103	1%
5 p.m. to 6 p.m.	2,730	2,719	0%
6 p.m. to 7 p.m.	2,566	2,606	2%
7 p.m. to 8 p.m.	1,370	1,394	2%

Trip Distribution

AVERAGE TRIP LENGTHS

In addition to the calibration criteria outlined above, the average trip lengths of the trips estimated during the ODME were compared against the average trip lengths from the seed trip table, for autos and trucks. As indicated in Table 4.5 and Table 4.6, the average trip lengths remained with 10 percent of the initial seed matrices after the ODME adjustments were made for both AM ands PM periods.

Table 4.5 AM Average Trip Length Comparison

Trip Table	Autos	Trucks
Initial Seed	9.51	9.48
Adjusted	9.14	9.16
Percent Change	-4.1%	-3.5%

Table 4.6 PM Average Trip Length Comparison

Trip Table	Autos	Trucks
Initial Seed	9.58	9.48
Adjusted	9.08	9.00
Percent Change	-5.5%	-5.2%

TRIP LENGTH DISTRIBUTION COINCIDENCE RATIOS

Another way of checking to make sure the ODME process does not significantly change the trip-distribution patterns is to compute trip length frequency coincidence ratios. This measure essentially compares the frequency distributions. This is most easily understood as the area under two curves divided by the area under at least one of the curves. Figure 4.2 through Figure 4.5 illustrate the trip length distributions and show the coincidence ratios for autos and truck trips respectively for the AM and PM Periods between the adjusted (ODME) and seed trip length distributions. Although there are no established standards for this measure, the coincidence ratios in all cases are within 85 percent, indicating a high level of coincidence.

Figure 4.2 AM Auto Trip Length Distribution

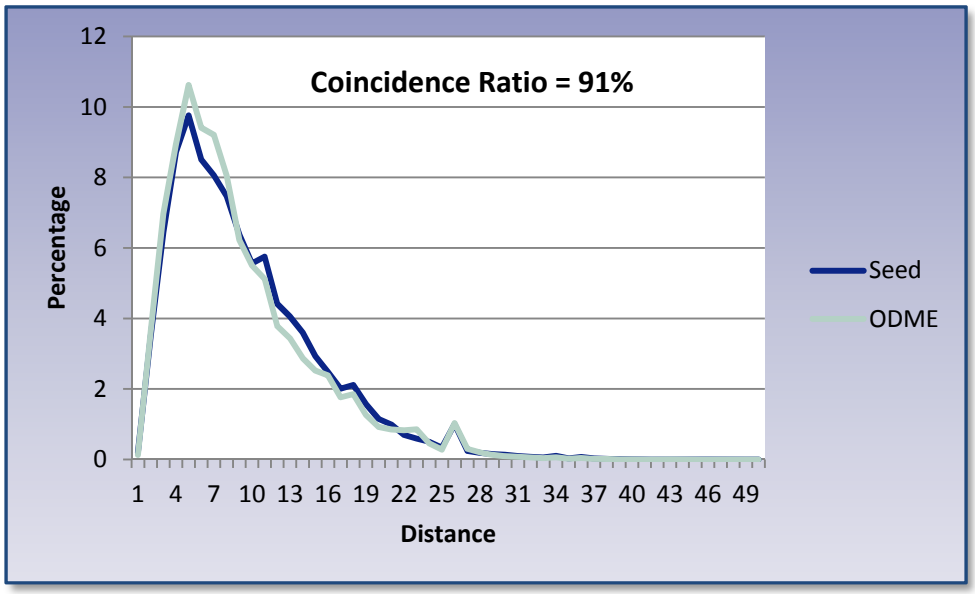


Figure 4.3 AM Truck Trip Length Distribution

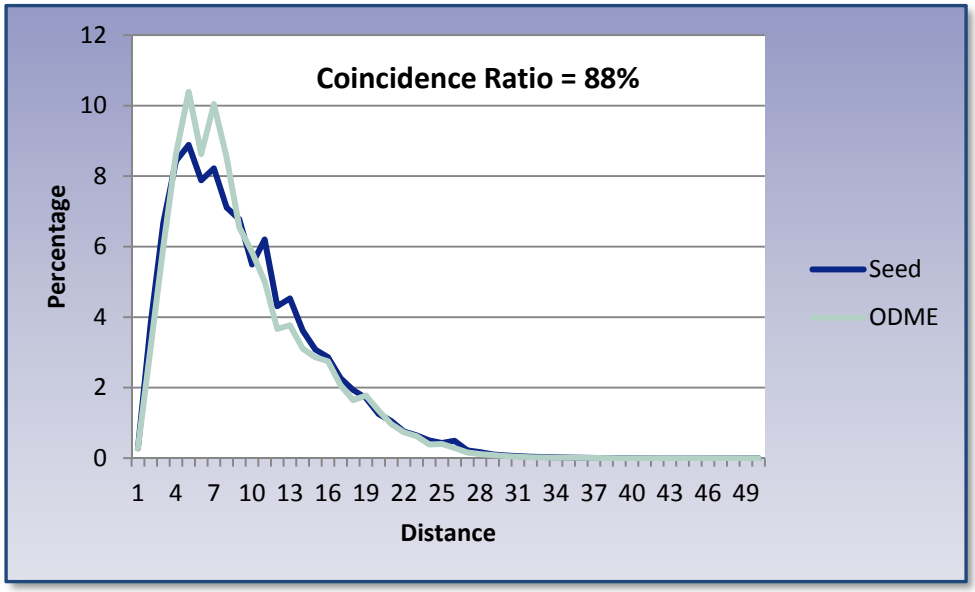


Figure 4.4 PM Auto Trip Length Distribution

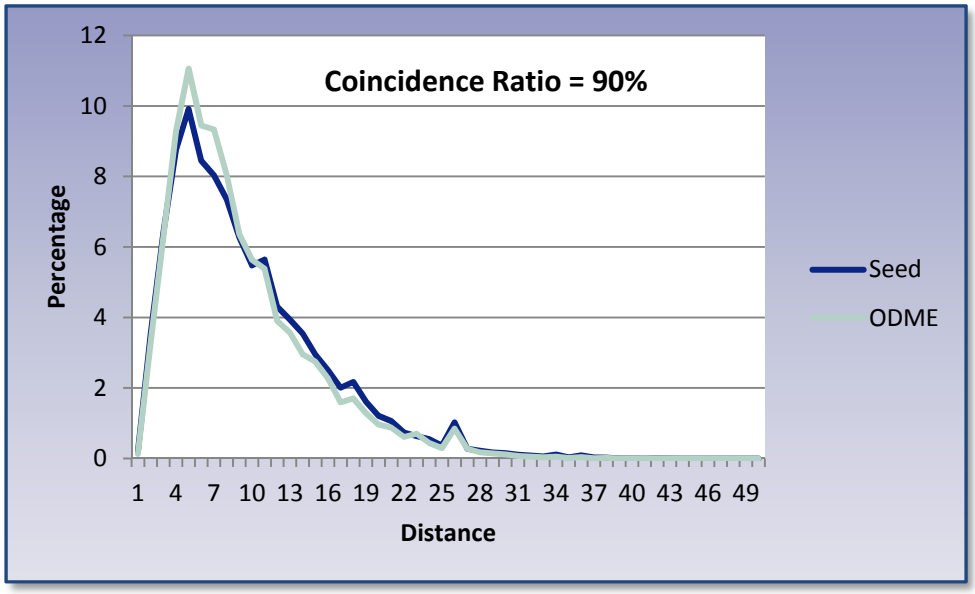
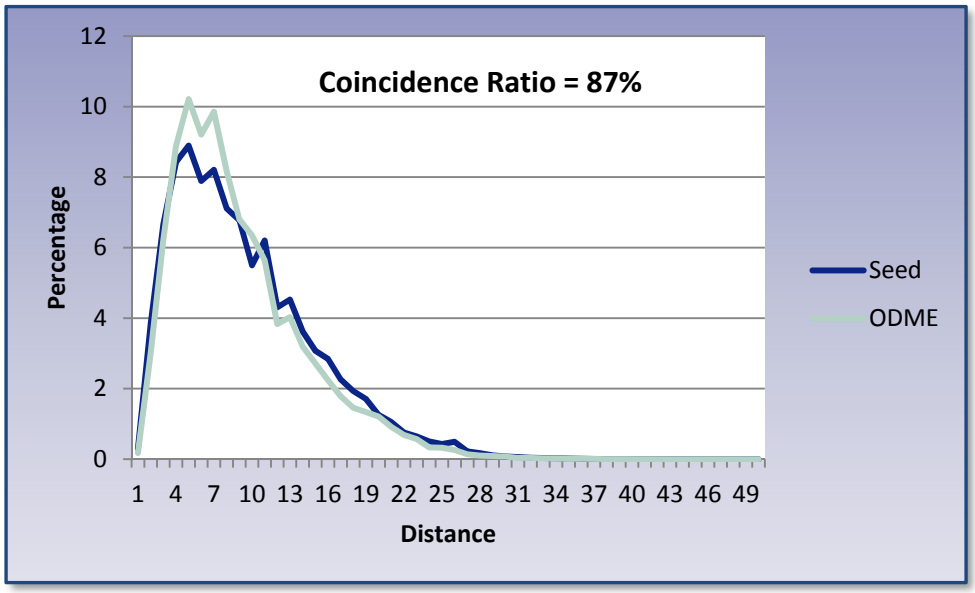


Figure 4.5 PM Truck Trip Length Distribution



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 overprediction of demand.

The behavioral response to the pricing component can be divided into pretrip decisions and en-route decisions. Pretrip 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.

Pretrip 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 pretrip 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 pretrip 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:

- Perform standard Focus model forecast to produce estimates of traffic demands.
- Extract future year subarea OD demands for the regional study area corridor.
- 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:

  Adjust Future Year Matrix = (Raw Future Year Matrix – Raw Base Year Matrix) + Calibrated Base Year Matrix
- 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	Warmup 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 and 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.

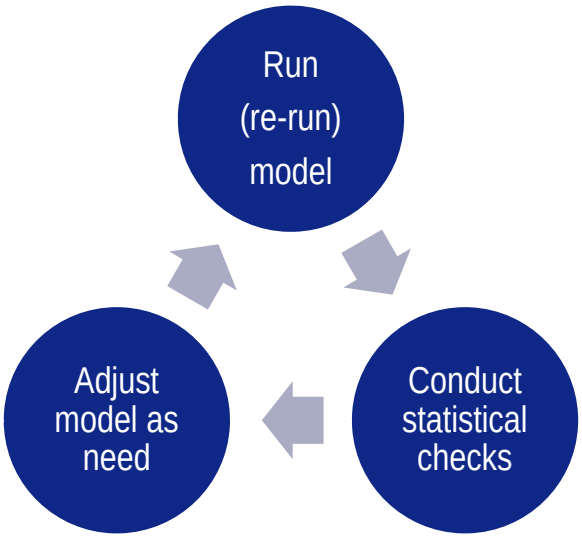
5.4 ERROR CHECKING

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

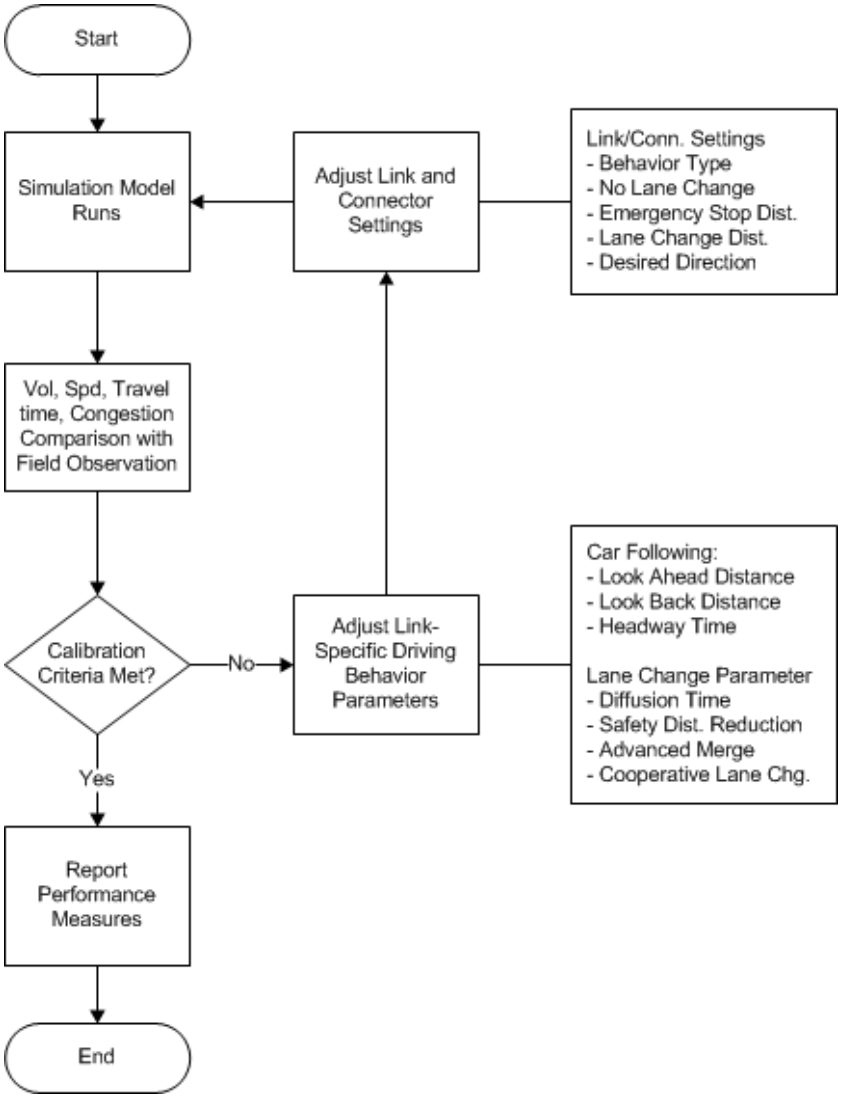


The following subsections describe the calibration adjustment strategy and the statistical methodology that will be used. The final calibration process and results will be documented in a calibration report.

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; and
- 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 percent, for 700 vehicles per hour < Flow < 2,700 vehicles per hour	>85 percent of cases
• Within 100 vehicles per hour, for Flow < 700 vehicles per hour	>85 percent of cases
• Within 400 vehicles per hour, for Flow > 2,700 vehicles per hour	>85 percent of cases

Criteria and Measures	Calibration Acceptance Targets
Sum of All Link Flows	Within 5 percent of sum of all link counts
GEH Statistics < 5 for Individual Link Flows	>85 percent of cases
GEH Statistics for Sum of All Link Flows	GEH <4 for sum of all link counts
Travel Times, Model Versus Observed	
Journey Times Network	
• Within 15 percent (or 1 minute, if higher)	>85 percent 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:

- Code express lanes and ingress/egress alternatives in the base VISSIM model;
- Code VISSIM express lane operations, including decisions points and tolling zones;
- Develop and implement willingness-to-pay logit coefficients;
- Code and model dynamic pricing to determine fixed-variable rates;
- Model scenarios with willingness to pay, fixed-variable rates, and future demands; and
- 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 –** Approximately 13 miles;
- **Pricing Basis –** Per zone (2);
- **Minimum Toll –** $0.50;
- **Maximum Toll –** Max toll to be determined by CS modeling;
- **Toll Change Time Interval –** 60 minutes;
- **License Plate Charge –** Approximately 25 percent;
- **Operational Capacity –** 1,900 vehicles per hour per lane;
- **Performance Measure –** Travel speed; and
- **Performance Target –** 55 miles per hour 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 stated-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 Number of Model Runs		
Test No.	Year	Transponder Ownership Population	Willingness to Pay	Toll Pricing	Land Use	Peak Periods	Estimated Number of Runs per Period	Total Number 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 Traffic and Revenue Forecasting

The future Traffic and Revenue was estimated using the VISSIM model. CS coded the geometry and concept of operations of the express toll lane concept, and used the VISSIM Managed-Lane Module which incorporates toll price setting and willingness to pay. The VISSIM simulations dynamically assign traffic to the express toll lanes and report forecast traffic operations in the general purpose lanes and the express toll lanes, gross revenue, and the number of toll transactions. The steps for analyzing the express lane alternatives included the following:

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

Key elements of this process are described below.

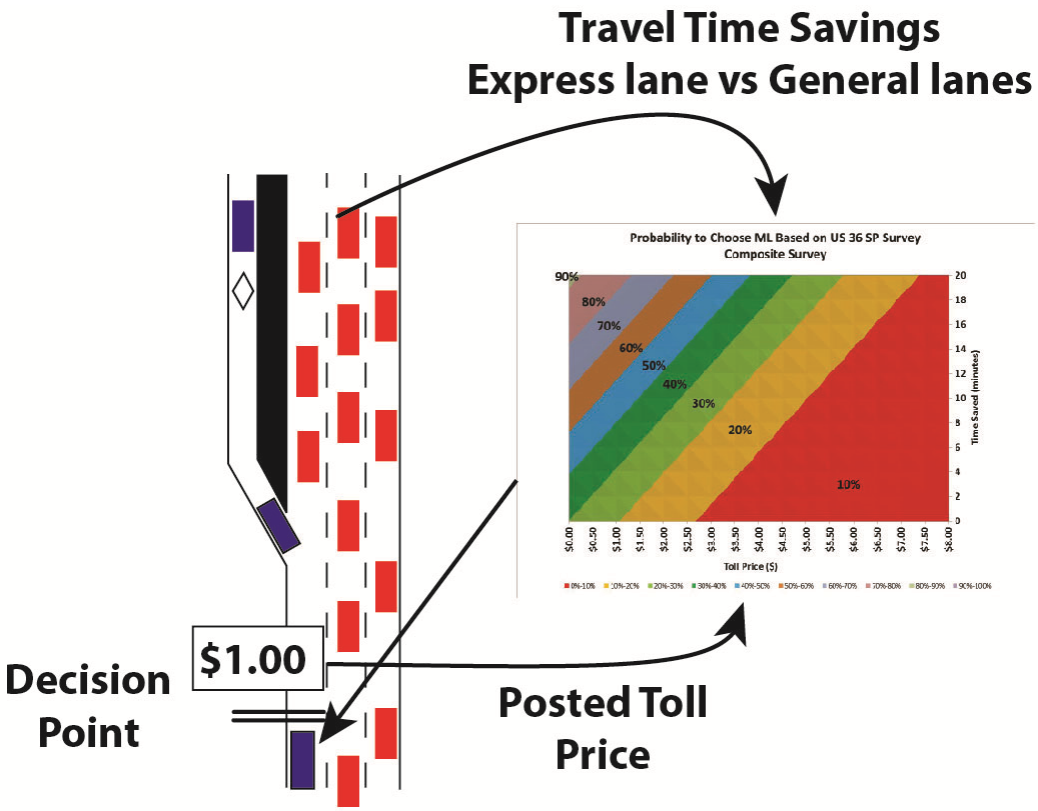
6.1 VISSIM MANAGED-LANE MODULE

We used the VISSIM managed-lane module to assign traffic between the express toll lanes and the general purpose lanes. The module consists of physical paths in parallel between the general-purpose (GP) lanes and the express toll lanes, a decision model, and a pricing model. The paths reflected the ingress/egress of the design concept and the pricing zone structure. Figure 6.1 illustrates how vehicles are assigned within VISSIM. The modeling process follows these steps:

- The toll price is set and in the case of C-470 the toll price will be variable and established and published in advance. The illustration below is a $1.00 toll.
- Travel-time savings between the general purpose lanes and the express toll lanes are calculated in the VISSIM model run.
- Travel-time savings, and toll price are entered into a logit probability model (represented by graph in illustration below and in Figure 6.4).

- Based on logit model express toll lane-eligible vehicle will choose the express lane or not.

Figure 6.1 Express Lane Traffic Assignment Illustration



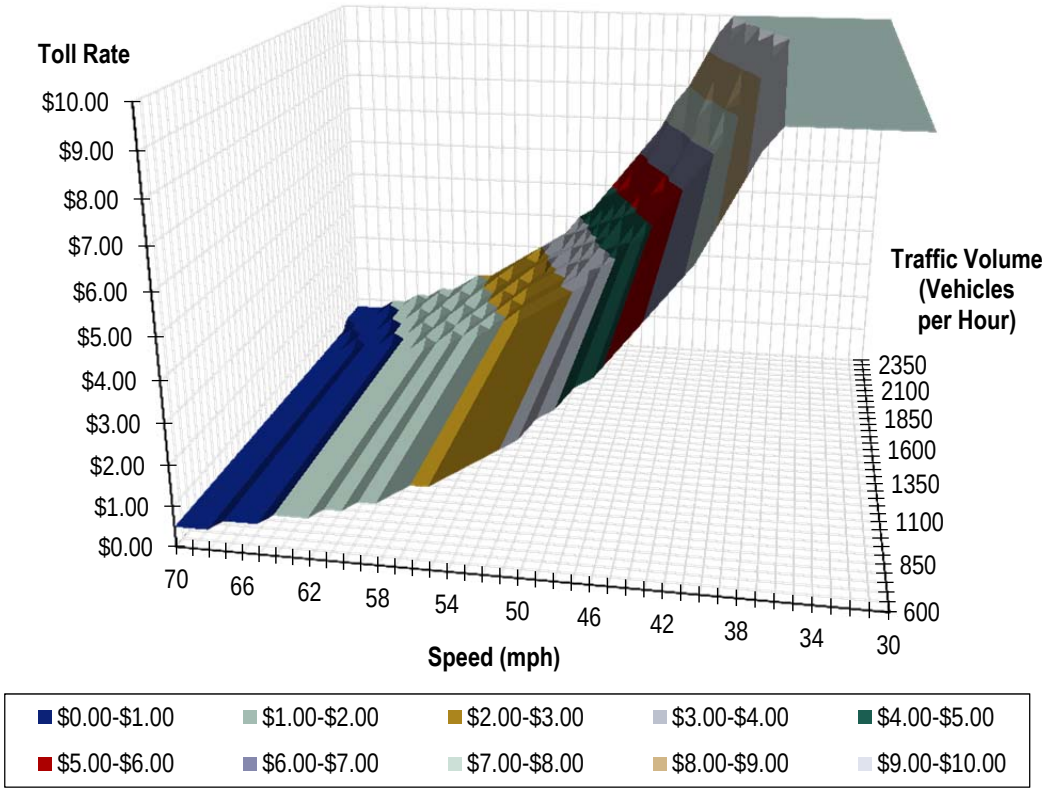
Source: Cambridge Systematics, Inc.

Toll Setting

CDOT established that the toll for the C-470 Express toll lane will vary by time of day on a prearranged schedule rather than dynamically based on real-time traffic conditions. The rationale is that time-of-day pricing is easier to communicate to drivers. Time-of-day pricing also is being used on the I-25 express toll lane project as well as on the U.S. 36 project that is under construction.

CS developed a proposed fixed-price schedule for use in this study by first using the VISSIM model (with managed-lane module) to find the rates that would maintain free-flowing traffic in the express toll lanes using a dynamic pricing system. The pricing formula accounts for both speed and volumes in the express toll lane to come up with a new toll every five minutes. Figure 6.2 is an illustration of the pricing formula used.

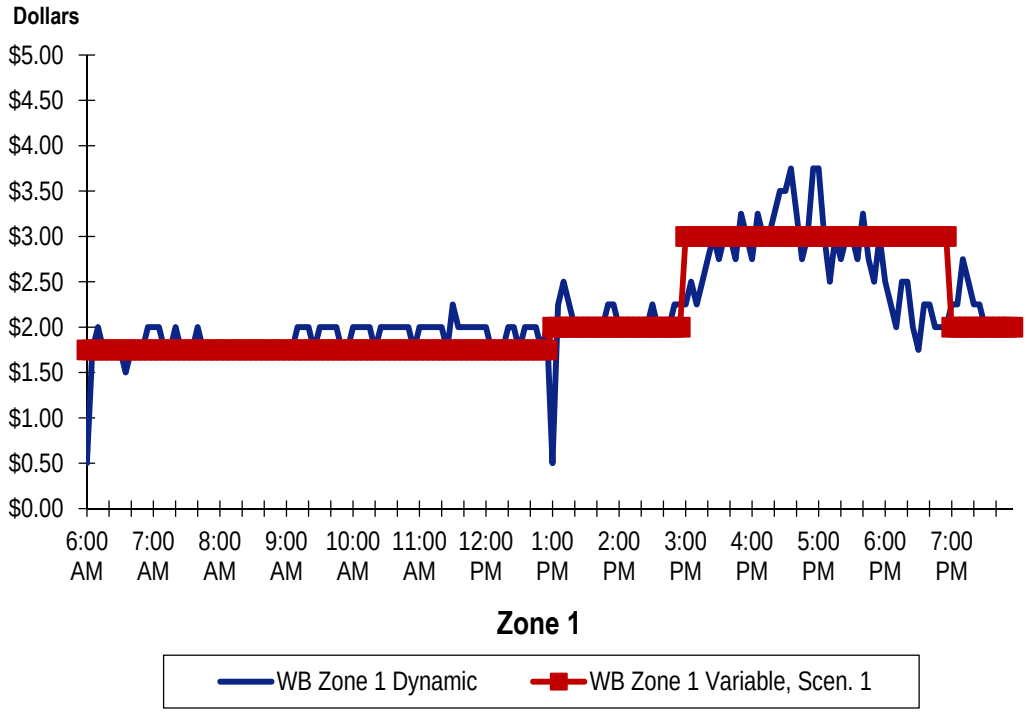
Figure 6.2 Dynamic Toll Price Algorithm Illustrations



Source: Cambridge Systematics, Inc.

We used the outcome of the dynamic pricing evaluation to develop a simpler time-of-day system with only a few toll rates per day, recognizing that too many discrete price changes would be confusing to communicate. Figure 6.3 illustrates conceptually how dynamic pricing results were converted into fixed time-of-day pricing. The dynamic pricing algorithm is designed to maintain reliable operations in the ETL. The first fixed-variable pricing scenario was developed to approximate the dynamic pricing, then the pricing was simplified so a toll schedule could be communicated in schedule. The other fixed pricing scenarios developed were higher and lower than the first scenario.

Figure 6.3 Fixed Pricing Illustration
Westbound C-470 Toll Prices



Source: Cambridge Systematics, Inc.

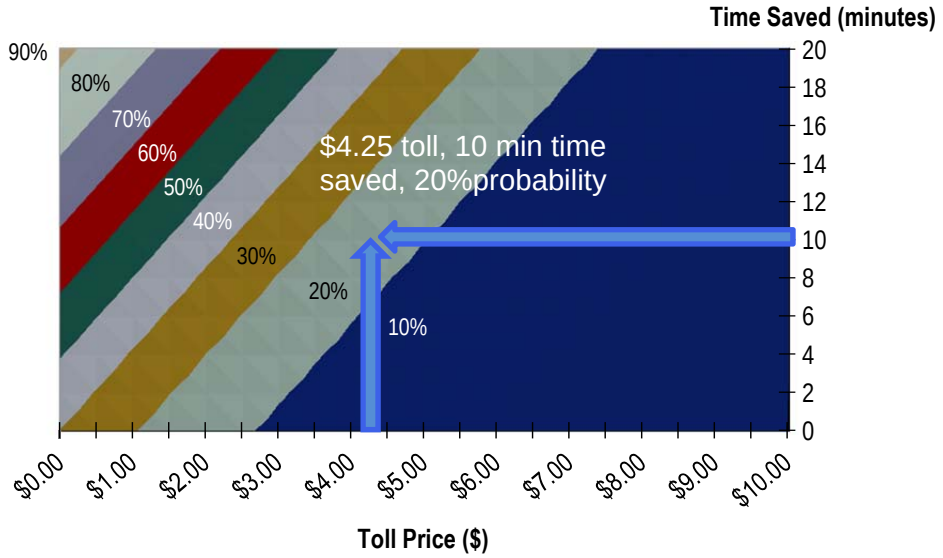
Willingness to Pay

Willingness to pay is represented in the VISSIM model with a logit model that was based on the stated-preference survey conducted for the U.S. 36 Investment-Grade Study.[1] The logit model estimates the probability that drivers will choose the express toll lane or the general-purpose lane given certain travel conditions. The probability model is illustrated in Figure 6.4. In the illustration there are toll prices (*x*-axis), time saved (*y*-axis), and probability color bands. The percentage probability of using the express toll lane may change depending on the combination of toll price and the amount of time saved. For example, in Figure 6.4 a posted toll of $4.25 and time saved of 10 minutes is shown with arrows, these 2 arrows intercept at the 20 percent probability band. This means that there is a 20 percent chance that a toll-eligible vehicle will use the express lane, and or that 20 percent of the express toll lane-eligible population would use the ETL under this condition.

[1] *Denver-Boulder Stated-Preference Survey Report.* Prepared for Wilbur Smith Associates, December 2010 (Appendix 1: Investment Grade Traffic and Revenue Study U.S. 36 Managed-Lanes Study).

It is important to note that willingness to pay varies considerably from person to person, and even from day to day. It is a significant uncertainty in any toll project, and in express toll lane projects in particular. Additional research (by others) regarding the willingness to pay should be conducted for the C-470 corridor as part of an investment-grade study, as should additional sensitivity tests or risk analysis that may vary this value.

Figure 6.4 Willingness to Pay Probabilities



Source: Cambridge Systematics, Inc.

ExpressToll Pass User Percentage Assumptions

Colorado uses ExpressToll passes – a windshield sticker transponder that is connected to customer accounts – for all toll facilities in the State. The C-470 Express toll lane project would use the same system, and also will allow for non-Express pass holders to access the system. Non-ExpressToll users would be billed based on a license plate capture and direct mailing of a bill plus surcharge for processing the bill.

The implications on the percentage of ExpressToll pass users on gross revenue is significant. Generally, the higher the percent of Express Toll Pass users the more likely the Express lane will be used (more vehicles paying a lower toll). The agencies developing the C-470 project have every reason to believe that in this congested, commuter-oriented corridor that many people will have the Express Toll Passes.

We assumed one set of ExpressToll pass percentages that varied by model year. The percentages were based on current ExpressToll pass account information provided by the E-470 Toll Office. The E-470 office provided the total number of ExpressToll accounts by zip code in Arapahoe, Douglass, and Jefferson Counties. CS found that:

- 27 percent of ExpressToll accounts in the three counties had transponders.
- 43 percent of the households that use C-470 have ExpressToll pass accounts.

The following assumptions regarding the percent of ExpressToll accounts, took into consideration information provided by the E-470 office, in projecting the percent of ExpressToll accounts for this project. The following assumptions regarding percent ExpressToll accounts took into consideration information from the E-470 office related to the current number of ExpressToll accounts in the region. A percentages shown below are subjective and based in current account:

- Year Opening 2018 – 45 percent;
- 2025 Interim Year – 60 percent; and
- 2035 Design Year – 70 percent.

It is recommended that additional testing be performed as part of an investment-grade study (completed by others), as the Project Management Team decided not to include those elements in this report. The additional testing should be conducted for the ranges stated above as well as others to better understand the impact of differing ExpressToll account percentages may have on projected revenues.

6.2 REVENUE

Methodology

CS factored the results of the AM and PM peak-period VISSIM models to create annual toll revenue forecasts. The VISSIM models represent 14 hours of a typical weekday (two 7-hour models) which represents the majority of the revenue generated over the course of a year. The overnight revenue will be negligible and for the purposes of this study was not included. The weekend and holiday revenue was estimated by applying a percentage to the typical weekday VISSIM model results. All revenue was estimated in ***2013 dollars***, with any assumed inflation of toll rates applied in the financial model prepared by Parsons Brinckerhoff. The underlying assumption is that toll rates will rise to track inflation, so that the relationship of people's value of time to the toll remains constant over time. This is a reasonable assumption for an express toll lane project where the purpose is to manage traffic flow in the express lane to maintain free-flowing conditions. Table 6.1 is a summary of the assumptions used in annualizing traffic model results.

Table 6.1 Revenue and Transaction Annualization Assumptions

Description	Assumption
Daily Assumptions	
AM Weekday Peak	6 a.m. to 1 p.m.
PM Weekday Peak	1 p.m. to 8 p.m.
Daily Weekday	AM weekday peak plus PM weekday peak
Weekday Off-Peak	8 p.m. to 6 a.m. – negligible revenue not included
Daily Weekend	10 percent of daily weekday
Annual Assumptions	
Annual Weekday	252 times daily weekday
Annual Weekend	113 times daily weekend
Total Annual	Annual weekday plus annual weekend
Ramp-Up	
Year 1	50 percent
Year 2	50 percent
Year 3	75 percent
Year 4	75 percent
Year 5	100 percent (no ramp-up percent applied)
2035 to 2048 Assumptions	
Annual Growth Percentage	1 percent per year

Ramp-Up

The modeled timeframes include 2018 (year opening), 2025 (interim forecast), and 2035 (design year). The revenue estimated by the models assumed perfect knowledge of the system, including pricing, ingress/egress, and general operations. In reality, the public will take time to learn the system, and may not use it in the early months, even though it might be in their best interest to do so. It takes a while for demand to "ramp up" to forecast levels. Ramp-up is difficult to predict, but we have made some reasonable assumptions in this planning study. These assumptions are:

- Year 1: 50 percent;
- Year 2: 50 percent;
- Year 3: 75 percent;
- Year 4: 75 percent; and
- Year 5: 100 percent (no ramp-up assumptions).

30-Year Revenue Streams

We prepared 30-year revenue streams using straight-line interpolation between the modeled years (with ramp-up applied in the early years). The last modeled year is 2035, so there is another 13 years of growth to get to 2048. We applied a nominal percentage growth (approximately one percent) to the 2035 forecasts.

A. Base and Future Land Use Assumptions

Table A.1 2010 Socioeconomic Data

County	Area	Population	Households	Employment	Enrollment	Household Size	Density		
							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 Socioeconomic Data

County	Area	Population	Households	Employment	Enrollment	Household Size	Density		
							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 Socioeconomic Data

						Density		
County	**Population**	**Households**	**Employment**	**Enrollment**	**Household 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 Socioeconomic Data

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%**