

North Front Range Regional Travel Demand Model

2015 Base Year

technical report

prepared for

North Front Range MPO

prepared by

Cambridge Systematics, Inc.

with

Felsburg Holt & Ullevig, Inc.

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date

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1.0 Introduction

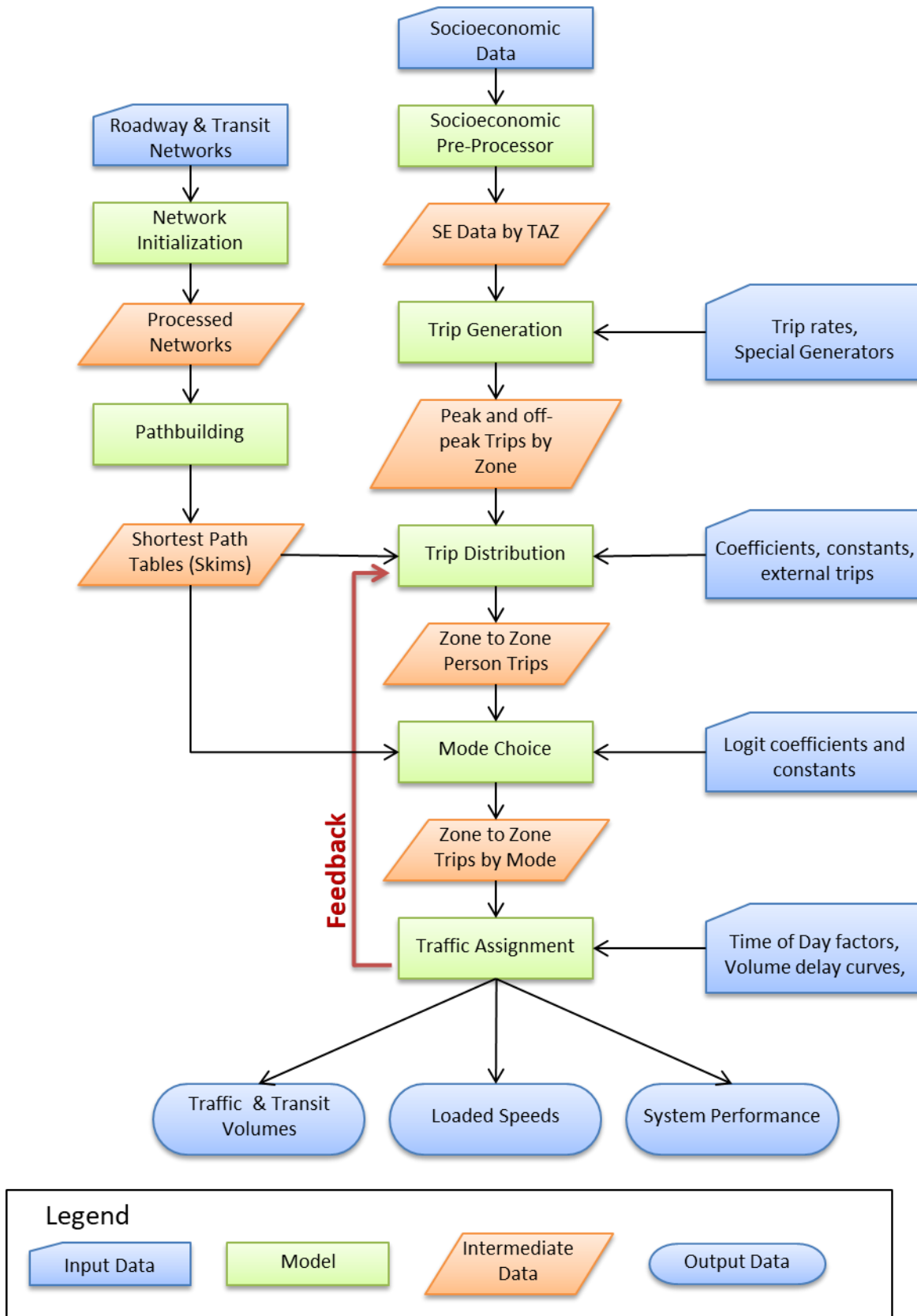
The North Front Range Metropolitan Planning Organization (NFRMPO) and member jurisdictions use the NFR Regional Travel Demand Model (NFR Model) as a tool to forecast traffic and travel in communities throughout the region. The primary purposes of the travel model are to support the Regional Transportation Plan (RTP) and air quality conformity analysis. Additionally, the model can support evaluation of proposed roadway and transit projects, help evaluate potential impacts of proposed development projects, and support various other studies of the region, subareas, corridors, and other planning activities. The model has been calibrated to reflect a base year of 2015 and contains future year data reflecting forecast 2045 conditions. Interim year data representing several intermediate timeframes is also maintained in the travel model dataset.

The previous version of the model featured a 2012 base year and 2040 forecast year. The model is regularly updated by the NFRMPO to reflect current conditions and the most recent available data. This version of the model includes moderate changes to the previous version of the model. Changes include bringing model data up to date, incorporation of new disaggregate socioeconomic data from the 2010 Land Use Allocation Model (LUAM), improved modeling of commercial vehicles, addition of a school trip purpose, replacement of the trip distribution model with a destination choice model, and addition of bicycle facilities to the transportation network. Data sources include a household travel survey, an external station survey, a commercial vehicle survey, a travel time survey, and a transit on-board survey. All of these data sources were accounted for in the 2012 base year version of the travel model with the exception of the commercial vehicle survey and the Transit on-board survey data which was conducted in 2017 and replaces older transit on-board survey data from previous model updates.

Throughout the course of model development, the NFRMPO enlisted a Model Steering Team to review land use and travel model inputs, procedures, and results. This group included representatives from jurisdictions within the NFRMPO modeling area and NFRMPO staff. The group held several meetings over the course of the model development process.

The NFR Model's process and functions are shown in the model flow diagram in **Figure 1.1**. It is an adaptation of the standard 4-step modeling process that has dominated travel models in small and medium-sized regions throughout the U.S. for several decades.

Figure 1.1 NFR Model Structure



2.0 Roadway Network

The roadway network contains basic input information for use in the travel demand model and represents real-world conditions for the 2015 base year and expected conditions for future years or tested alternatives. The roadway networks are used in the model to distribute trips and route vehicle trips. The networks in the GIS environment used by the model are databases in which all kinds of information can be stored and managed. In addition, the networks provide a foundation for system performance analysis including vehicle miles of travel, congestion delay, level of service, and other performance measures. This section provides a description of the network attributes and lookup tables for the roadway networks. The assumptions and parameters identified herein were identified during the development of the model's 2015 base year network, but they generally apply to interim and forecast year networks as well.

The roadway network is a GIS-based representation of the street and highway system in the NFR region as well as the expanded Ozone modeling region. It also contains information about non-motorized facilities, including on-street bicycle treatments and low-stress routes as well as multi-use paths. The network is utilized as:

- An input database containing roadway characteristics (such as facility type, number of lanes, area type, etc.);
- A foundation for the transit route system; and
- A data repository that can be used to store and view travel model results.

The roadway network is one of the foundational components of the travel model as it serves to represent the supply side of the travel demand/ transportation system relationship. As such, the establishment and review of detailed network attribute data was very important to the model's development.

The roadway network is structured to contain data for multiple timeframes. The roadway network prepared for the NFR Model contains the 2015 base year network as well as a list of planned and proposed roadway projects. The network also retains information about the 2012 year network to support back-casting as part of the model validation process. The network is designed to maintain information about planned and proposed roadway, transit, park-n-ride, and non-motorized projects, each associated with a year of completion. This allows the network to represent the 2015 base year, existing plus committed networks, plan forecast networks, interim horizon year networks, and any other network scenarios desired within a single network database.

What's New

Notable changes to the 2015 roadway networks include:

- Network contents have been updated to reflect 2015 base year conditions;
- Posted speed limits have been added to the network;
- Link speed models have been updated based on an analysis of speed limit and INRIX GPS speed data;
- Non-motorized facilities and a bicycle facility type have been added to the network;

- Area type has been removed from the input network and is instead stored only in the TAZ dataset;
- Area type definitions have been revised for consistency with other models in the state of Colorado, now increasing from the most dense to least dense area type;
- Toll, HOV, and managed lane coding procedures have been updated;
- Storage of roadway project information has been moved to a separate table and revised to include information about each roadway project; and
- Some changes to network field names have been made to improve clarity.

2.1 Roadway Network Structure

The NFR Model roadway network structure is designed to be a flexible data repository and to host input and output data required by the travel model. This section describes the network file structure and defines attributes populated on the network. Input attributes and some output attributes are discussed herein. Additional output variables created by subsequent model steps are discussed in the associated sections of this report.

Input network attributes used by the travel model include facility type, area type, number of lanes, speed limit, and direction of flow. Each of these variables is addressed in the sections that follow. Values for these attributes have been populated on the roadway network file for the year 2012 and 2015. The network is accompanied by a list of projects that can be combined to create scenario, interim year, and forecast year networks. This list of projects can be maintained and edited using an accompanying master network management system.

The roadway network contains a number of year-specific input fields, which are used to compute freeflow speed, travel time, and capacity on each link in the roadway network. Methods used to develop and compute these values are discussed and specific values are documented herein.

2.1.1 Input and Output Networks

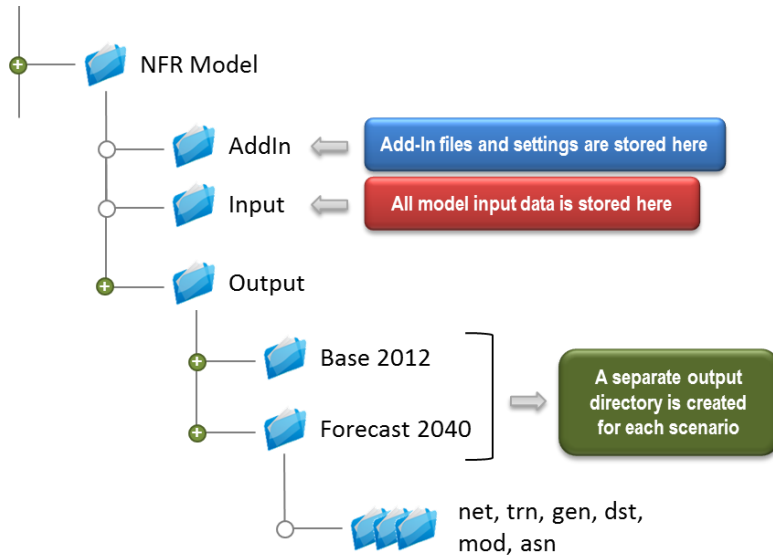
The roadway network file contains travel model input data and also acts as a repository for both intermediate (e.g., speed and capacity) and final (e.g., traffic volumes) model data. For this reason, a separate output model network is created for each model scenario. This output network is created by making a copy of the input network and then modifying this network to contain data and results specific to each model run. This copy of the roadway network is created and modified automatically by a network initialization step when the travel model is run.

The model's directory structure allows multiple model output directories to exist alongside a single input directory as shown in **Figure 2.1**. When the travel model is run, files located in the input directory are not modified by model macros. Instead, if a file is to be modified it is copied to an output directory and only the copy is modified. This approach has several benefits, including:

- All input files are located in one standardized location, making identification of files easy when edits are required;

- Because input files are not modified by the travel model macros, it is unlikely important data present within input files will be inadvertently overwritten by travel model macros; and
- All output files related to a particular model run are maintained in a single directory, minimizing confusion about which model scenario is represented by each file.

Figure 2.1 Example Model Run Directory Structure



2.2 Network Attributes

The roadway network contains input attributes listed in **Table 2.1**. Additional fields can be added to the network by MPO staff or other users as desired using standard tools available in the TransCAD software. Such fields will not be referenced by the travel model but can be used to aid in analysis of results.

In addition to link attributes, several attributes are included on the node layer of the roadway network file. Centroid nodes are identified by the ZONE attribute on the node layer. Node attributes are listed in **Table 2.2**.

Table 2.1 Input Network Link Fields

Field Name	Description	Comments
ID	TransCAD Unique ID	Maintained automatically by TransCAD
Length	Link Length in miles	Maintained automatically by TransCAD
Dir	Link Direction of Flow	Direction of Flow
Street_Name	Optional Field indicating street name	
Local_Name	Optional Field indicating alternate street name	
Dir_yyyy	Scenario-specific Direction Field	yyyy represents a two through four-digit year code (e.g., 2015, 2045) or the string BC12 (Backcast 2012) or Unc (Unconstrained)
FT_yyyy	Scenario-specific facility type (see Table 1.3 for definition)	
BIKEFT_yyyy	Bicycle facility type representing bicycle comfort index.	
AB/BA_LANE_yyyy	Scenario-specific directional number of through lanes (lanes that are used for parking in the off-peak periods are included in this value)	
SPEEDLIM_yyyy	Posted speed limit on the link. Blank speed limits are populated using defaults based on facility type and area type. Values were averaged based on length of each posted speed limit zone for segments with two or more posted speed limits.	
UNPAVED_yyyy	Links with a value of “1” in this field are indicated as being unpaved. Null or zero indicates a paved facility.	
TOLL_CODE_yyyy	Toll code matching the accompanying TollRates.bin table. Null or zero indicates no toll.	
TRUCK_PROHIB_yyyy	A value of “1” Indicates that medium and heavy trucks are prohibited on the link.	
TIMEPEN_yyyy	Link time penalty in minutes	This field should be left empty in most cases.
WALK_PROHIB	Links with a value of 1 in this field cannot be used for transit walk access/egress or for direct walk trips.	
TFOR_yyyy	Truck time factor override – if this field is empty (null), the lookup table will be used.	This factor is applied after application of link time penalties.
FFOR_yyyy	Freeflow speed override – if this field is empty (null), the lookup table will be used.	This field should be left empty in most cases.
CAPOR_yyyy	Capacity override – if this field is empty (null), the lookup table will be used.	
HOV_yyyy	A value of “2” indicates that the link is an HOV lane that permits vehicles with 2 or more occupants. A value of “3” indicates that the link is an HOV lane that permits vehicles with 3 or more occupants.	Managed or express lanes are coded using the TOLL_CODE_yyyy field and accompanying toll table, not with HOV_yyyy.
AB/BA_FBAM_yyyy	Scenario-specific fields used to hold speed feedback results. These fields are managed by the travel model interface.	
AB/BA_FBOP_yyyy		
NFR_SCRL	Indicates whether the link is on a screenline, and if so, which screenline	

Field Name	Description	Comments																
CARBON_M	Indicates whether the link is in the Fort Collins (1) or Greeley (2) non-attainment area (See note 1)																	
OZONE	A value of 1 Indicates links to be included in Ozone analysis. Links outside of the Northern Subarea are omitted. (See note 1)																	
SUB_REGION	<table border="1"> <thead> <tr> <th>Value</th> <th>Subregion</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>Rural/Other</td> </tr> <tr> <td>2</td> <td>Greeley</td> </tr> <tr> <td>3</td> <td>Fort Collins</td> </tr> <tr> <td>4</td> <td>Loveland / Berthoud</td> </tr> <tr> <td>5</td> <td>Larimer County (expanded area)</td> </tr> <tr> <td>6</td> <td>Weld County (expanded area)</td> </tr> <tr> <td>7</td> <td>Central I-25</td> </tr> </tbody> </table>	Value	Subregion	1	Rural/Other	2	Greeley	3	Fort Collins	4	Loveland / Berthoud	5	Larimer County (expanded area)	6	Weld County (expanded area)	7	Central I-25	Subregion identifiers were used for model validation and reasonableness checks, but to not reflect city limit or growth management area (GMA) details.
Value	Subregion																	
1	Rural/Other																	
2	Greeley																	
3	Fort Collins																	
4	Loveland / Berthoud																	
5	Larimer County (expanded area)																	
6	Weld County (expanded area)																	
7	Central I-25																	
COUNTY	Optional county name																	
NFRMPO	Identifies links within the MPO boundary																	
Expand	<p>Identifies links that are in the expanded ozone non-attainment region. (See note 1)</p> <p>1 = Links in the unexpanded area (includes the MPO area and areas to the north and south of the MPO)</p> <p>2 = External station connectors for the unexpanded area</p> <p>3 = All links in the expanded area</p>																	
RSC	Regionally Significant Corridor ID (See note 1)	This field is for reference and is not used by the travel model. It may not always be up to date.																
CUSTOM1	User specified subarea where CUSTOM1 = 1																	
CUSTOM2	User specified subarea where CUSTOM2 = 1																	
DO_NCHRP	A value of 1 indicates that NCHRP adjustment will be performed if all required data is available. If this value is null or zero, adjustment will not be performed even if all required data are present.																	
BASEVOL	Base year model volume on regionally significant corridors used to perform an NCHRP adjustment																	
EST_Count	Estimated count data used to perform an NCHRP adjustment if a validation count is not available																	
VAL_Count	Traffic count selected for use in validation																	
VAL_Year	Year validation count was taken	Validation year, month, notes, ID, and override fields are not required by the model but have been retained on the network for reference.																
VAL_Month	Month validation count was taken																	
VAL_Notes	Notes taken during validation process																	
VAL_MTruck	Classified counts: medium truck																	

Field Name	Description	Comments
VAL_HTruck	Classified counts: heavy truck	
VAL_TrkYear	Year truck validation count was taken	
VAL_trkMonth	Month truck validation count was taken	
Count_ID1/Count_ID2	Count ID used to match traffic count data to the network	
CountOverride	Manual count override values from manual review.	
PROJECT1/2/3	Project ID values for use with master network project identification	

Notes: 1. Geographic fields such as OZONE, CARBON_M, SUBREGION, and NFRMPO can become out of date after extensive network editing. These fields should be verified prior to performing analysis that relies on these fields.
 2. Additional fields not included in this table may be present on the network but are not referenced by the travel model.

Table 2.2 Input Network Node Fields

Field Name	Description	Comments
ID	Unique TransCAD ID	Maintained automatically by TransCAD. Note: The node ID value should be set to match the Zone number. This can be accomplished by either exporting the network file after modifying the ZONE field or running the Update Input Network utility available from the model interface.
ZONE	Traffic Analysis Zone Number	Populated only for centroid nodes (including external station nodes). Null for all non-centroid nodes.
Int_ID	Intersection ID (Optional)	Raw modeled turn movements will be saved for nodes on which a value is present. This ID may be synchronized with a Synchro network or other traffic database.
PROJECT1/2/3	Project ID values for use with master network project identification	
PNR_yyyy	Scenario specific park-n-ride nodes. A value of 1 indicates that a node is a park-n-ride.	yyyy represents a two through four-digit year code (e.g., 12, 40FC)
PULSE_yyyy	Transfer time override for scenario specific timed transfer nodes	

2.2.1 Direction of Flow

Direction of flow does not fit within the attribute management scheme as well as other variables. This is due to the requirement in the TransCAD software that direction of flow be maintained in the network field “Dir” at all times. While this fits within the process used to run the model, this requirement can cause difficulties when editing the network if not addressed. It is important to remember the following points if the direction of flow varies on a link in different year or alternative networks:

- To display directional arrows for a particular network year, fill the column “Dir” with the value from the appropriate attribute (e.g., Dir_2015).
- When editing route system files, it is helpful if the Dir field is filled with values using the appropriate year-specific Dir field (e.g., Dir_2045) prior to opening a route system for editing – especially if any transit routes utilize one-way segments.

Note these concerns are most important when the Dir attribute varies from year to year.

2.2.2 Expanded Model Area

The NFR Model includes the capability to model expanded portions of Larimer and Weld counties for purposes of ozone analysis. To accomplish this and to help maintain consistency between the primary travel model and the expanded travel model, the input roadway network includes the entire expanded model area. When running the model for the primary model area only, links in the expanded modeling area are removed from the output network by the travel model macros. Similarly, when running the model for the expanded area, external station links internal to the expanded area are removed from the network.

Roadway network links are retained or removed based on the *Expand* field in the roadway network file according to the rules listed below.

- **Expand = 1:** These links are in the primary model area and are also included in the expanded model. They are always retained.
- **Expand = 2:** These links are in the primary model area but are not included in the expanded model. They are deleted when running the expanded model. Expand is typically only set to 2 for external connectors that must be removed when running the expanded model.
- **Expand = 3:** These links are in the expanded model area, but not the primary model area. They are deleted when running the primary travel model.

2.2.3 Functional Classification / Facility Type

The functional classification of each roadway link reflects the system of streets and highways. The term “functional classification” has specific implications with regards to the administration of federal-aid highway programs, but travel model networks do not always adhere to these definitions. The facility type variable present in the travel model is similar to functional classification, but not necessarily consistent in all cases. The Facility Type (FT) variable on the roadway network is used to look up speed, capacity, and volume delay parameters. Facility type values used in the NFR Model are listed in **Table 2.3**. Base year facility type values in the updated model are shown in **Figure 2.2** through **Figure 2.6**.

Table 2.4 demonstrates the relationship between interstate, expressway, arterial, collector, and local facility types, and a description of each facility type follows.

Table 2.3 Facility Types

Value	Facility Type
1	Interstate
2	Expressway
3	Principal Arterial
4	Minor Arterial
5	Collector
6	Ramps
7	Frontage Road
8	Centroid Connector
9	Walk Access Connector
51	Transit Only
61	Non-Motorized Only

Figure 2.2 2015 Facility Type Designations (MPO Region)

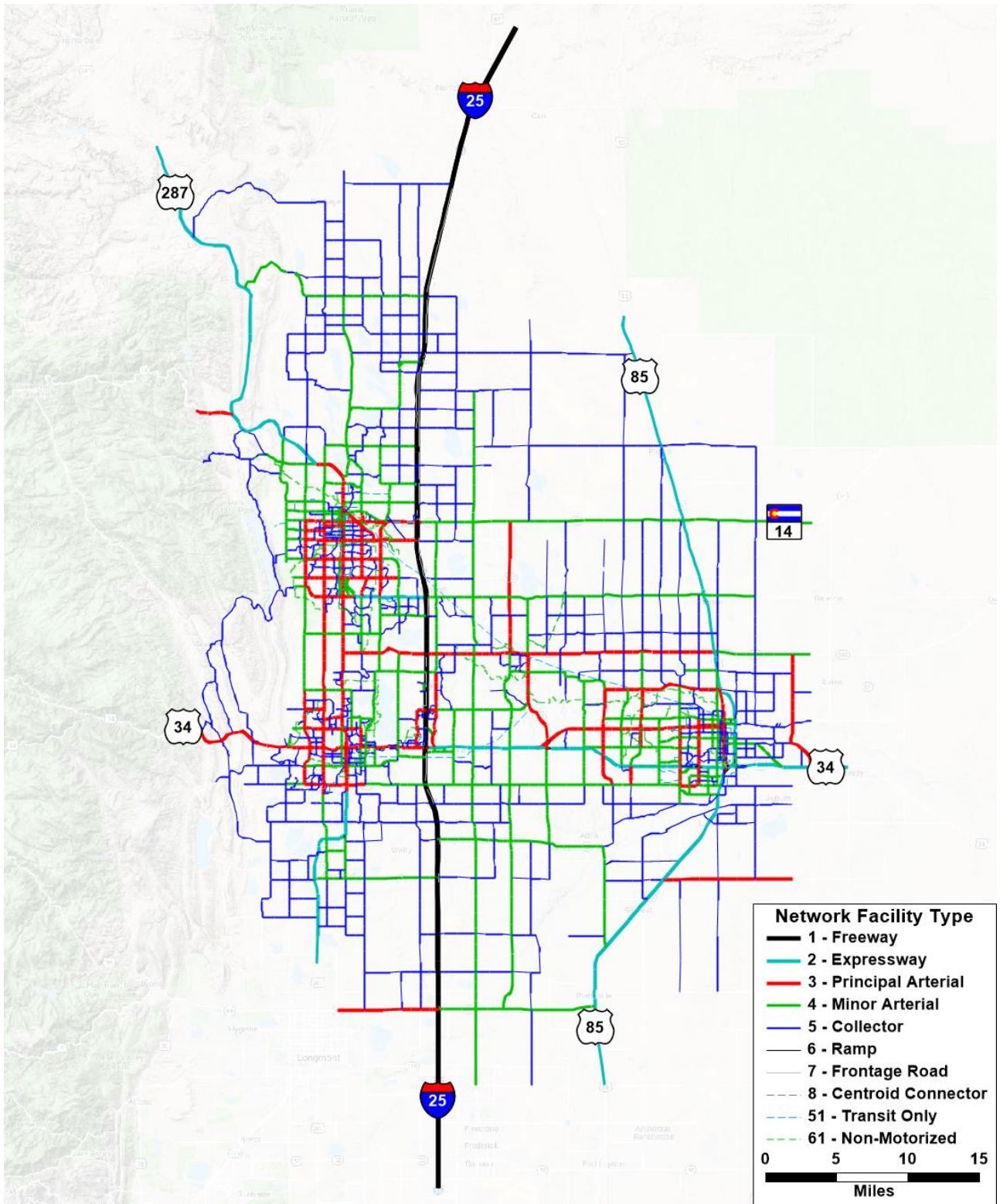


Figure 2.3 2015 Facility Type Designations (Fort Collins)

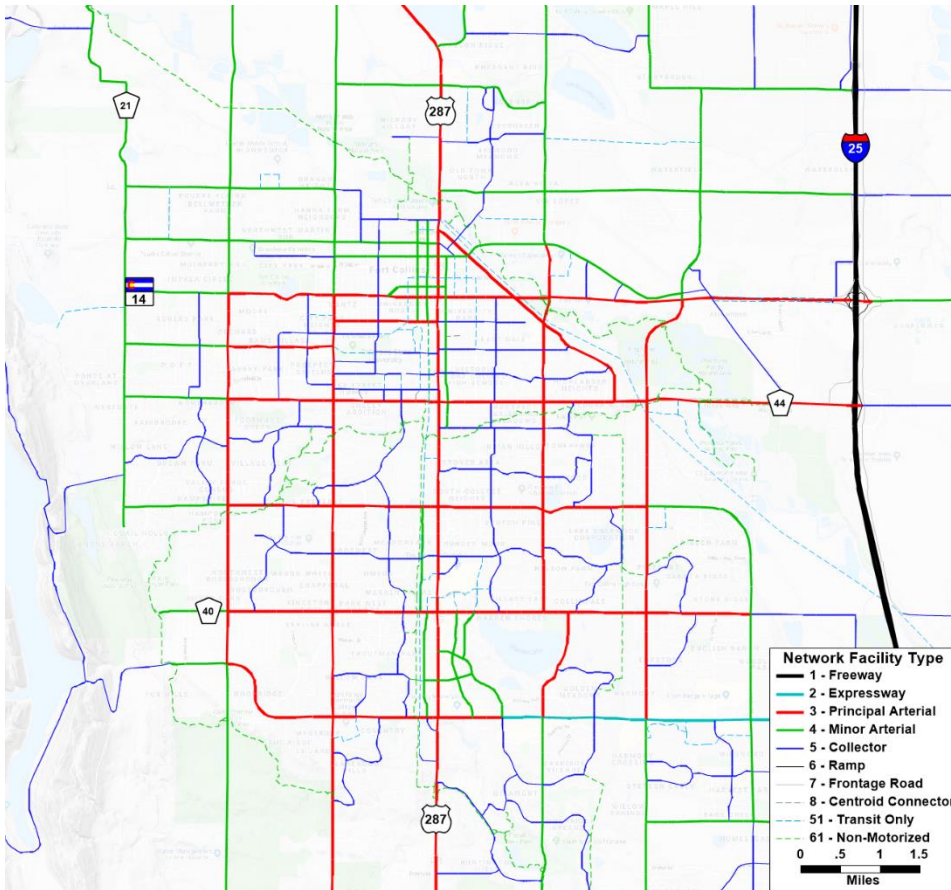


Figure 2.4 2015 Facility Type Designations (Greeley)

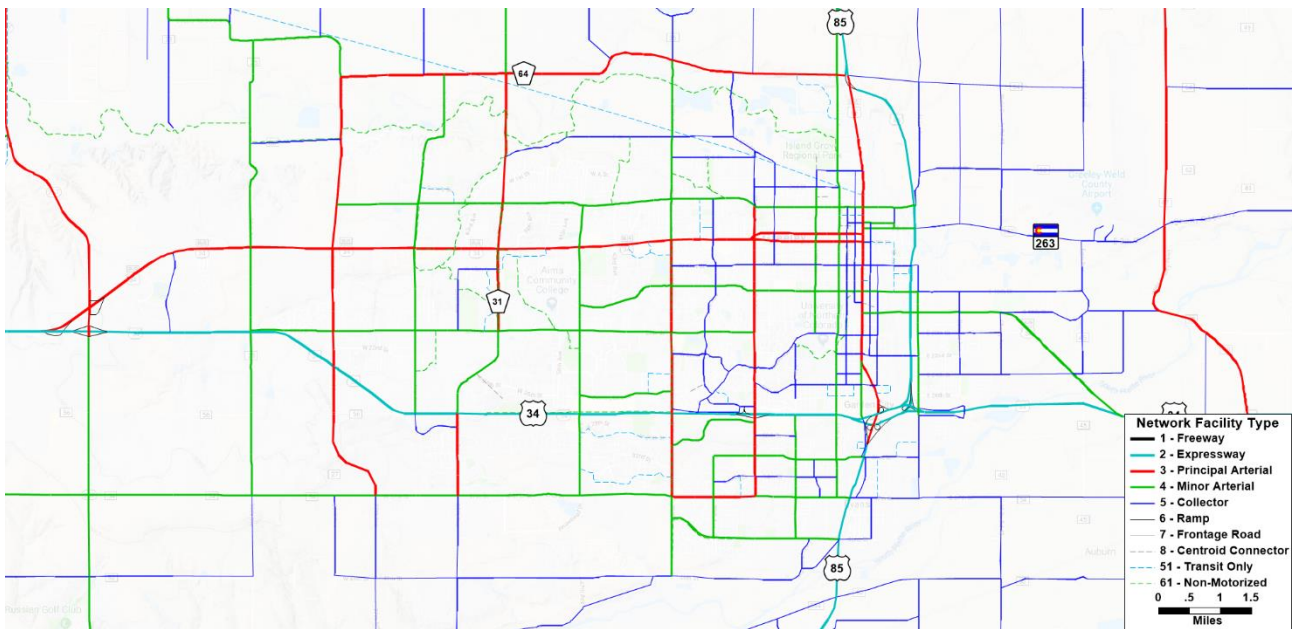


Figure 2.5 2015 Facility Type Designations (Loveland)

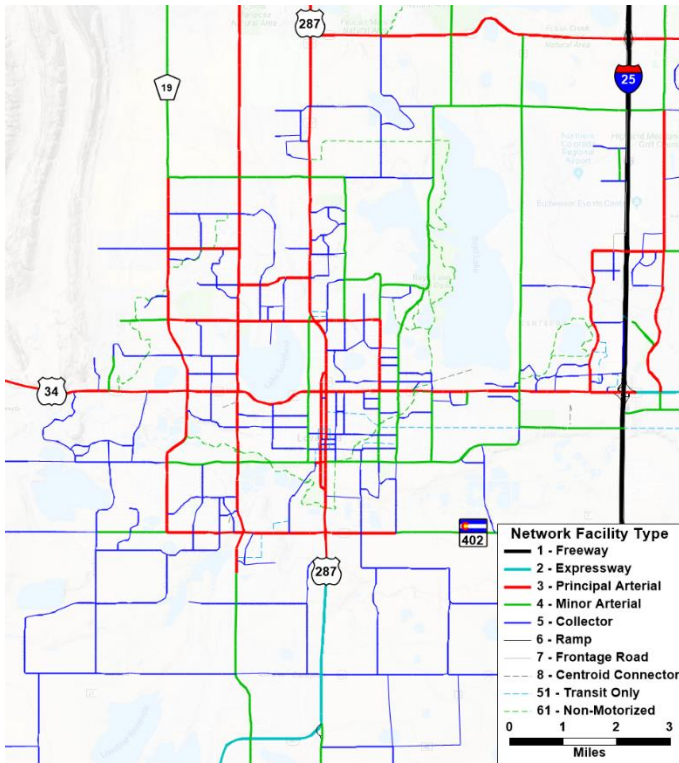


Figure 2.6 2015 Facility Type Designations (Expanded Area)

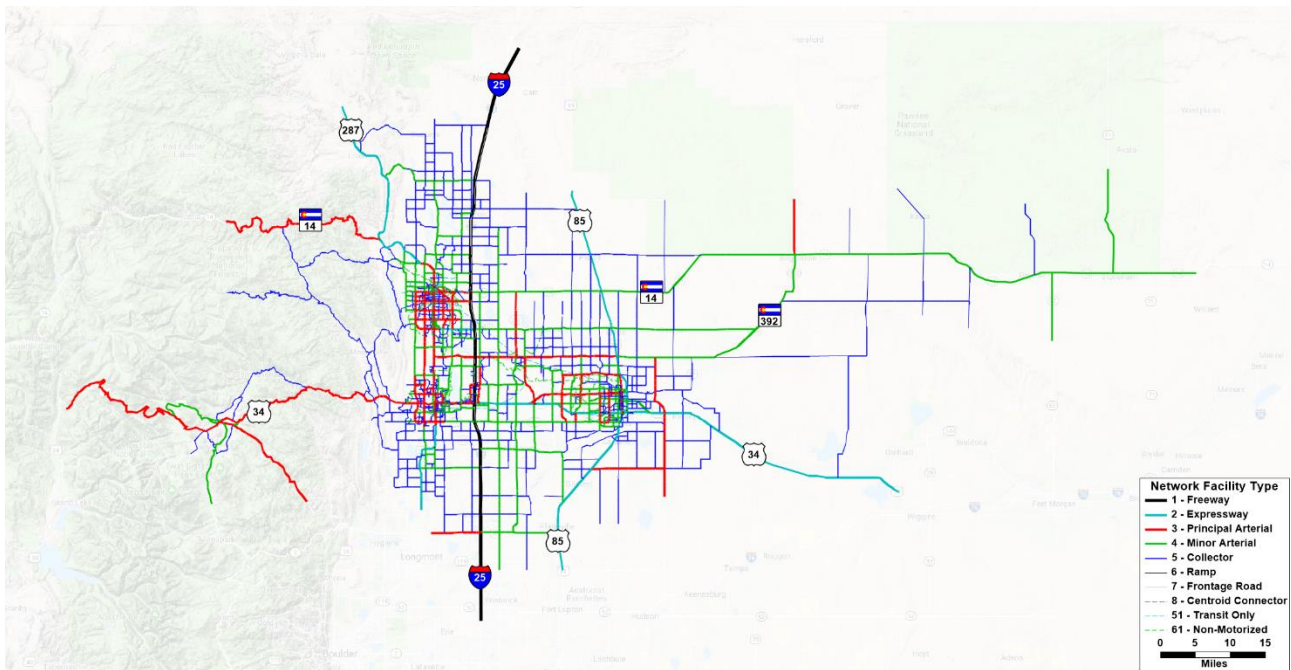


Table 2.4 Roadway Facility Type Hierarchy

	Interstate / Expressway	Principal Arterial	Minor Arterial	Collector	Local
Mobility	High				Low
Design Standards	High				Low
Speed	High				Low
Trip Type	Longer/ Regional				Local
Access	Full Control				Full Access
Road Type	Multi-Lane				2 Lane
Spacing	Varies	1 mile	1/4- 1/2 mile		

- **Interstate** – Freeways are divided, restricted access facilities with no direct land access and no at-grade crossings or intersections. Freeways are intended to provide the highest degree of mobility serving higher traffic volumes and longer-length trips. The only freeway included in the NFR Model is I-25.
- **Expressway** – Expressway facilities are sometimes classified as divided principal arterials but include many features common to freeways. Expressways use a higher level of access control than other arterials and may include grade-separated intersections. Expressways have higher speed limits than other principal arterials (e.g., 55 or 65 MPH), provide little or no direct access to local businesses, may have frontage roads or access roads, and limit signal spacing to at least ½ mile. Examples include sections of US 34 and US 85.
- **Ramp** – Ramps provide connections between freeways and other non-freeway roadway facilities. On freeway to non-freeway ramps, traffic usually accelerates or decelerates to or from a stop. Therefore, the freeflow speed on freeway to arterial ramps is often coded as much slower than the ramp speed limit.
- **Principal Arterial** – Principal arterials permit traffic flow through and within urban areas and between major destinations. These are important to the transportation system since they provide local land access by connecting major traffic generators, such as central business districts and universities, to other major activity centers. Principal arterials carry a high proportion of the total urban travel on a minimum of roadway mileage. They typically receive priority in traffic signal systems (i.e., have a high level of coordination and receive longer green times than other facility types). Divided principal arterials have turn bays at intersections, include medians or center turn lanes, and sometimes contain grade separations and other higher-type design features. State and US highways are typically designated as principal arterials unless they are classified as freeways.
- **Minor Arterial** – Minor arterials collect and distribute traffic from principal arterials and freeways to streets of lower classification and, in some cases, allow traffic to directly access destinations. They serve secondary traffic generators, such as community business centers, neighborhood shopping centers, multifamily residential areas, and traffic between neighborhoods. Access to land use activities is generally permitted, but should be consolidated, shared, or limited to larger-scale users. Minor arterials generally have slower speed limits than principal arterials, may or may not have medians and center turn lanes, and receive lower signal priority than other facility types (i.e., are only coordinated to the extent that principal arterials are not disrupted and receive shorter green times than principal arterials).

- **Collector Street** – Collectors provide for land access and traffic circulation within and between residential neighborhoods and commercial and industrial areas. They distribute traffic movements from these areas to arterial streets. Except in rural areas, collectors do not typically accommodate long through trips and are not continuous for long distances. The cross-section of a collector street may vary widely depending on the scale and density of adjacent land uses and the character of the local area. Left turn lanes sometimes occur on collector streets adjacent to non-residential development. Collector streets should generally be limited to two lanes, but sometimes have 4-lane sections.
- **Frontage Road** – Frontage roads are identified as facilities similar to minor arterial or collectors but serve a specific purpose in providing local access adjacent to a freeway or expressway.
- **Centroid Connector** – These facilities are the means by which the trip and other data at the traffic analysis zone (TAZ) level are attached to the street system. Centroid connectors are an approximate representation of local streets, which are not included in the travel model.

2.2.4 Bicycle Facility Type

Bicycle facility type defines the bicycle facilities available on the roadway network. Bicycle paths prioritize higher level facilities and are not allowed to use facilities where bicycles are prohibited. Bicycle facility is defined by the network variable BikeFT and is defined as shown in **Table 2.5**. Bicycle facilities include non-motorized facilities such as bike paths, which are coded with a roadway facility type value of 61.

Table 2.5 Bicycle Facility Type

Value	Bicycle Facility Type
1	Bike Trail / Multi-Use Path
2	Bike Lane
3	Bike Route, sharrow, or Bikeable Shoulder
4	Bikes Allowed, no special treatment
-1	Bikes prohibited

2.2.5 Area Type

Area type is an attribute assigned to each TAZ and roadway and is based on the activity level and character of the zone. Terminal times, speed-limit to freeflow speed conversion factors, roadway capacity, and volume-delay characteristics are dependent on area type. Area type is first defined at the TAZ level based on socioeconomic characteristics and then transferred to the roadway network

Area type values are maintained in the TAZ dataset for each model year. Area type is then transferred from the TAZ layer to the roadway network layer using an automated process. This process ensures that links along an area type boundary are assigned the denser area type, and also assigns consistent area type values to links within interchanges.

2.2.6 Link Speeds

Network speeds are used in the trip distribution model to distribute trips throughout the model area and in the trip assignment model to route traffic on the roadway network.

Link freeflow speeds represent average travel time, including intersection delay, needed to traverse the distance of a link with little or no traffic (i.e., no congestion effects). These speeds are generally similar to the speed limit and are calculated based on posted speed, facility type, and area type. Freeflow speeds are typically lower than the speed limit to account for intersection delay on arterials, collectors, and ramps.

The model's freeflow speeds are based on an analysis of speeds as represented by INRIX made available by CDOT for use by the NFRMPO. Freeflow speeds are based on data representing Tuesday, Wednesday, and Thursday for the month of September in 2015. Average observed speeds for every 15-minute period throughout the day are reported within the dataset. For the roadways that are within the MPO modeled area the average hourly speeds were recorded by facility type and area type for two different periods where speeds are typically uncongested: 10:00 AM to 11:00 AM and 2:00 AM to 3:00 AM. The maximum speed for each facility type / area type combination from these two time periods was then selected to represent typical freeflow conditions. This approach ensures that outliers within the dataset are removed.

The NFR model applies the freeflow speeds calculated from the INRIX data in two different ways depending on the availability of posted speed limit data. For links without a valid posted speed, freeflow speed is obtained from **Table 2.6**. These values are computed as the average freeflow speed based on the INRIX data. For links with a valid posted speed, freeflow speeds are calculated by multiplying posted speeds by the factors shown in **Table 2.7**. Freeflow speed factors were calculated for each facility type / area type combination as the average freeflow speed from the INRIX data divided by the average posted speed. For facility type / area type combinations that had no data, speeds from similar categories were used and are shaded in blue in the tables below. Frontage road speeds were set to match minor arterial speeds, since frontage roads were not present in the INRIX dataset.

For use in model estimation and for initial speed feedback iterations, a set of congested speed tables was also developed. These congested speed tables represent the AM peak hour, defined as 7:00 to 8:00 AM. The AM peak period is chosen because it reflects the time period in which the majority of production to attraction commute trips are made. Congested speed lookup tables and factor tables are shown in **Table 2.8** and **Table 2.9**.

Table 2.6 Default Freeflow Speed Lookup Table

	Facility Type	CBD (1)	Commercial (2)	Urban (3)	Suburban (4)	Rural (5)
1	Freeway	75	75	75	75	75
2	Expressway	23.1	24.9	26.7	48.8	52.6
3	Principal Arterial	23.1	24.9	26.7	34.4	41.2
4	Minor Arterial	26.1	26.1	26.1	30.5	34.2
5	Collector	19.4	19.4	19.4	26	42.7
6	Ramp	41	41	41	54.9	54.9
7	Frontage Road	26.1	26.1	26.1	30.5	34.2
8	Centroid Connector	25	25	25	30	35
9	Walk Connector	2.5	2.5	2.5	2.5	2.5
51	Transit Link	15	15	18	18	18
61	Non-Motorized Link (Walk)	2.5	2.5	2.5	2.5	2.5
61	Non-Motorized Link (Bike)	12.0	12.0	12.0	12.0	12.0

Source: CS Analysis of INRIX data, adjusted during model calibration and validation.

Notes: Shaded cells indicate use of speeds from similar categories. Reasonable speeds have been assumed for centroid connectors, walk connectors, transit links, and non-motorized links.

Table 2.7 Posted Speed to Freeflow Speed Factor Lookup Table

	Facility Type	CBD (1)	Commercial (2)	Urban (3)	Suburban (4)	Rural (5)
1	Freeway	1	1	1	1	1
2	Expressway	0.84	0.84	0.9	0.96	0.96
3	Principal Arterial	0.84	0.84	0.9	0.96	0.96
4	Minor Arterial	0.8	0.85	0.9	0.96	0.96
5	Collector	0.7	0.7	0.7	0.71	0.96
6	Ramp	1	1	1	1	1
7	Frontage Road	0.8	0.85	0.9	0.96	0.96
8	Centroid Connector	1	1	1	1	1
9	Walk Connector	1	1	1	1	1
51	Transit Link	1	1	1	1	1
61	Non-Motorized Link	1	1	1	1	1

Source: CS Analysis of INRIX data, adjusted during model calibration and validation.

Note: Shaded cells indicate use of factors from similar categories. Ramps speeds initially calculated with factors greater than 1 were set to 1. Freeflow speeds are assumed to match the speed limits (if present) on centroid connectors, walk connectors, transit links, and non-motorized links.

Table 2.8 Default Congested Speed Lookup Table

	Facility Type	CBD (1)	Commercial (2)	Urban (3)	Suburban (4)	Rural (5)
1	Freeway	67.6	67.6	67.6	67.6	69.3
2	Expressway	25.8	25.8	25.8	44	42.2
3	Principal Arterial	17.6	17.6	21.6	26.1	32.6
4	Minor Arterial	20.2	20.2	20.2	23.9	30.5
5	Collector	14	14	14	21.3	37
6	Ramp	39.6	39.6	39.6	52.7	52.7
7	Frontage Road	20.2	20.2	20.2	23.9	30.5
8	Centroid Connector	25	25	25	30	35
9	Walk Connector	2.5	2.5	2.5	2.5	2.5
51	Transit Link	15	15	20	25	30
61	Non-Motorized Link (Walk)	2.5	2.5	2.5	2.5	2.5
61	Non-Motorized Link (Bike)	12.0	12.0	12.0	12.0	12.0

Source: CS Analysis of INRIX data, adjusted during model calibration and validation.

Notes: Shaded cells indicate use of speeds from similar categories. Congestion is not modeled on centroid connectors, walk connectors, transit links, and non-motorized links.

Table 2.9 Posted Speed to Congested Speed Factor Lookup Table

	Facility Type	CBD (1)	Commercial (2)	Urban (3)	Suburban (4)	Rural (5)
1	Freeway	0.9	0.9	0.9	0.9	0.92
2	Expressway	0.57	0.57	0.57	0.82	0.69
3	Principal Arterial	0.56	0.56	0.56	0.56	0.58
4	Minor Arterial	0.57	0.57	0.57	0.58	0.58
5	Collector	0.47	0.47	0.47	0.54	0.79
6	Ramp	1	1	1	0.99	0.99
7	Frontage Road	0.57	0.57	0.57	0.58	0.58
8	Centroid Connector	1	1	1	1	1
9	Walk Connector	1	1	1	1	1
51	Transit Link	1	1	1	1	1
61	Non-Motorized Link	1	1	1	1	1

Source: CS Analysis of INRIX data, adjusted during model calibration and validation.

Note: Shaded cells indicate use of factors from similar categories. Ramps speeds initially calculated with factors greater than 1 were set to 1. Congested speeds are assumed to match the speed limits (if present) on centroid connectors, walk connectors, transit links, and non-motorized links.

2.2.7 Link Capacities

Capacity constrained traffic assignment requires roadway capacity values on each network link. The model uses link capacity to measure congestion and to determine route diversion due to slower travel speeds associated with increasing congestion. This is accomplished through volume-delay equations that are further documented in **Section 11.2.1**. The approach to developing link capacities remains unchanged from those used in the 2012 base year model.

In the model, per-lane capacity values are retrieved from a lookup table based on the facility type and area type of each link in the roadway network. This approach eliminates opportunities for error in defining capacities at the link level and enforces consistent application of capacity values. These hourly lane capacities are used in combination with the number of lane information present on the network to define hourly directional capacity.

The Highway Capacity Manual¹ (HCM) provides guidance on the definition of roadway capacity. HCM provides link-level capacity guidelines for freeways and rural highways but does not provide detailed link-level capacity guidelines for urban and suburban collector and arterial streets. Therefore, HCM intersection capacity was used in place of link capacity to develop capacities for these other facilities.

Freeways

Capacity guidelines for freeways and expressways are provided in Chapters 21 and 23 of the HCM in the form of unadjusted or ideal per-lane capacities based on freeflow speed. These capacities must then be adjusted for the conditions listed below.

- **Heavy Vehicle Adjustment Factor** – The heavy vehicle adjustment factor accounts for passenger car equivalents (PCE) for trucks, buses, and recreational vehicles. HCM recommends default values of 10 percent heavy vehicles in rural areas and five percent heavy vehicles in non-rural areas unless additional data is available. Because the NFR Model applies volume delay functions using PCE volumes, the heavy adjustment factor has not been applied.
- **Driver Population Factor** – The driver population factor represents the familiarity of drivers with roadway facilities. Because the model represents traffic on a typical weekday when school is in session, normal driver familiarity is assumed. Driver population factors are typically used for weekend conditions or in areas with a high amount of tourist/recreational activity. This value was set to 1.0 for all links in the NFR model, including links in Estes Park.

Peak Hour Factor – A peak hour factor (PHF) represents the variation of traffic volumes within one hour. Default values of 0.88 for rural area types and 0.92 for non-rural area types were applied².

HCM suggests adjusting flow rate (traffic volume) according to equation (1).

$$V_p = \frac{V}{(PHF \cdot N \cdot f_{hv} \cdot f_p)} \quad (1)$$

¹ Highway Capacity Manual. Transportation Research Board, 2000.

² HCM 2000, p. 13-11

Where:

- V_p = 15-min passenger equivalent flow rate (pc/hr/ln)
- V = hourly volume (veh/hr)
- PHF = peak-hour factor
- N = number of lanes
- f_{hv} = heavy-vehicle adjustment factor
- f_p = driver population factor

For travel model application, it is more practical to adjust capacity than vehicle flow rate. This eliminates the need to adjust vehicle trip tables prior to and subsequent to traffic assignment. By replacing V_p with ideal capacity (C_I) and V with link capacity (C), Equation (1) can be used to adjust ideal capacity to effective link capacity. Furthermore, it is useful to consider capacity on a per lane (veh/hr/ln) basis, allowing number of lane calculations to be applied at the link level. The resulting Equation (2) was used to compute per lane capacity for freeways and expressways.

$$C = C_I \cdot PHF \cdot f_{HV} \cdot f_P \quad (2)$$

Where:

- C_I = Ideal (unadjusted) capacity (pc/hr/ln)
- C = link capacity (veh/hr)
- PHF = peak-hour factor
- F_{HV} = heavy-vehicle adjustment factor
- f_P = driver population factor

Ideal capacities defined in HCM³ according to selected freeflow speed values are shown in **Table 2.10**, along with adjusted capacities computed using Equation (2). Adjusted capacities have been rounded to 100 vehicles per hour. These calculations result in a lower capacity on rural freeways than on suburban and urban freeways due to the difference in peaking factors associated with rural facilities. In practice, rural freeways in the NFR region appear to have peaking factors that allow for capacity values comparable to those in urban and suburban areas.

Table 2.10 Ideal and Adjusted Capacities for Freeways and Expressways based on HCM 2000

Facility Type	Area Type	Freeflow Speed (mph)	Ideal Capacity	PHF	FHV	FP	Adjusted Capacity
Freeway	Rural	70	2,400	0.88	1	1	2,100
Freeway	Suburban	70	2,400	0.92	1	1	2,200
Freeway	Urban	65	2,350	0.92	1	1	2,200

Note: Capacity values are upper limit LOS E capacities in vehicles per hour per lane.

³ HCM 2000, p. 23-5

Collectors and Arterials

For arterial and collector streets, the HCM recommends identifying capacity on an intersection basis, with the intersection having the lowest capacity determining overall arterial link capacity. The link capacity at each intersection can be computed using Equation (3a)⁴.

$$c = S_0 \cdot N \cdot f_w \cdot f_{hv} \cdot f_g \cdot f_p \cdot f_{bb} \cdot f_a \cdot f_{LU} \cdot F_{LT} \cdot F_{RT} \cdot F_{Lpb} \cdot F_{Rbp} \cdot PHF \cdot g/C \quad (3a)$$

Where:

- c = capacity
- S_0 = base saturation flow per lane (pc/h/ln) – assumed at 1900
- N = number of lanes in lane group (intersection approach lanes, not mid-block lanes)
- f_w = adjustment factor for lane width– assumed at 1.0
- F_{HV} = adjustment factor for heavy vehicles in traffic stream assumed at 1.0
- f_g = adjustment factor for approach grade – assumed at 1.0
- f_p = adjustment factor for a parking lane and parking activity – assumed at 1.0
- f_{bb} = adjustment factor for blocking effect of local busses – assumed at 1.0
- f_a = adjustment factor for CBD area type
- f_{LU} = adjustment factor for lane utilization – assumed at 0.95
- f_{LT} = adjustment factor for left turns in lane group – assumed at 1.0
- f_{RT} = adjustment factor for right turns in lane group – assumed at 1.0
- f_{Lpb} = pedestrian adjustment factor for left-turn movements – assumed at 1.0
- f_{Rpb} = pedestrian-bicycle adjustment factor for right turn movements – assumed at 1.0
- PHF = peak-hour factor – assumed at 0.92
- g/C = effective green time per cycle

The equations above account for details not practical to maintain in a regional travel model. Therefore, a number of adjustment factors can be assumed constant or set to 1.0 for all cases. Some variables which have been set to 1.0, such as lane width, parking, turns, bus blocking, and pedestrian and bicycle effects are instead captured in the area type adjustment. Other variables can be approximated based on facility type and area type. Additionally, a regional travel model must rely on the number of through lanes on each link, rather than the number of approach lanes at each intersection. This can be addressed by an intersection widening factor that varies by facility type and accounts for the presence of left and right turn lanes at intersection approaches.

Equation (3a) can be simplified to Equation (3b) for use in a regional travel modeling context. Assumed values for adjustment factors which vary by facility type and area type are shown in **Table 2.11**, along with resulting capacity values.

⁴ HCM 2000, p. 30-5

$$c = S_0 \cdot N_t \cdot f_a \cdot f_{LU} \cdot PHF \cdot \frac{g}{C} \cdot F_{iw} \quad (3b)$$

Where:

- c = capacity
- S_0 = base saturation flow per lane (pc/h/ln) – assumed at 1900
- N_t = number of through (mid-block) lanes, excluding center turn lanes
- f_a = adjustment factor for area type
- f_{LU} = adjustment factor for lane utilization – assumed at 0.95
- PHF = peak-hour factor – assumed at 0.92
- g/C = effective green time per cycle
- F_{iw} = adjustment factor for intersection widening

Table 2.11 Link Capacity Adjustment Factors and Resulting Capacity

FT	AT	f_a	g/C	f_{iw}	Capacity
Principal Arterial	CBD	0.76	0.45	1.30	740
	Urban	0.95	0.45	1.30	920
	Suburban	0.99	0.45	1.30	960
	Rural (Expressway)	0.97	0.55	1.30	1,200
Minor Arterial	CBD	0.76	0.45	1.15	650
	Urban	0.95	0.42	1.15	760
	Suburban / Rural	0.99	0.42	1.15	790
Collector	CBD	0.75	0.45	1.05	590
	Urban	0.95	0.41	1.05	680
	Suburban / Rural	0.99	0.41	1.05	710

Note: Capacity values are upper limit LOS E capacities in vehicles per hour per lane.

Resulting Capacity Model

The calculations in **Table 2.11** provide capacity values which can be applied based on facility type, area type, and number of lanes. These capacities served as a starting point for model development but were adjusted during the model validation process. Resulting hourly lane capacities are shown in **Table 2.12**. For centroid connectors, walk access links, and transit local links, capacity values of 10,000 or less indicate congestion is not represented on these links.

Table 2.12 Roadway Capacities (vehicles per hour per lane, upper-limit LOS E)

Facility Type	CBD (1,2)	Urban (3)	Suburban (4)	Rural (5)
1 Freeway	2,100	2,100	2,100	2,200
2 Expressway	1,100	1,200	1,200	1,200

Facility Type	CBD (1,2)	Urban (3)	Suburban (4)	Rural (5)
3 Principal Arterial	740	920	960	1,162
4 Minor Arterial	650	760	790	956
5 Collector	590	680	710	850
6 Ramp	650	750	800	800
7 Frontage Road	590	680	710	850
8 Centroid Connector	10,000	10,000	10,000	10,000
9 Walk Access Connector	10,000	10,000	10,000	10,000
51 Transit Link	n/a	n/a	n/a	n/a
61 Non-Motorized Link	n/a	n/a	n/a	n/a

Note: Capacity values are upper limit LOS E capacities in vehicles per hour per lane.

Off-Peak Capacities

Although hourly capacity is useful for most applications, the traffic assignment model requires separate mid-day off-peak capacity. Both mid-day and off-peak capacity are calculated by multiplying the number of hours in the time period by the hourly capacity. The mid-day capacity represents 6 hours, while the off-peak capacity represents 12 hours.

2.2.8 Toll and HOV Coding

Tolling is indicated on the highway network using a toll code which identifies a specific set of per-mile toll rates and/or flat cost toll values at specified locations. In typical application, tolls are specified as either per-mile (e.g., \$0.05/mile for long segments), or flat rate (e.g., a \$2.50 toll at a toll plaza or access link). The toll code is associated with a separate input file that contains detailed toll values by vehicle class. This approach minimizes the number of toll fields that must be maintained on the network, simplifying network management. Fields present in the toll table are defined in **Table 2.13**. However, since the NFR Model does not feature any toll facilities in the base year, toll functionality is only present in forecast year networks.

Table 2.13 Toll Lookup Table Fields

Field Name	Table Header
TOLL_CODE	Toll type code matching toll code on highway network
[AM/MD/PM/OP]_TOLLVAL_[DA/SR2/SR3]	Toll value for each time period and vehicle class
[AM/MD/PM/OP]_TOLLRATE_[DA/SR2/SR3]	Toll rate per mile for each time period and vehicle class

2.2.9 Bicycle Facility Type

The NFR Model includes a bicycle facility type, which reflects the type of bicycle treatment on each link in the network. The bicycle facility type is based on the concept of a bicycle comfort index, with some facilities being more comfortable for bicyclists than others. The bicycle facility types are listed in **Table 2.14**. In addition, the network includes a non-motorized link facility type. This facility type represents paths, trails, and connections that are open to non-motorized travel but not open to vehicles. Bicycle facility type as defined on the 2015 base year network are shown in **Figure 2.7** through **Figure 2.11**.

Table 2.14 Bicycle Facility Type Definitions

Bicycle Facility Type	Description
1	Bike trails / mixed use paths
2	Bike lanes
3	Bike routes / bikeable shoulders
4	No specific treatment, but bikes allowed
-1	Bikes prohibited

Figure 2.7 Bicycle Facility Types (MPO Region)

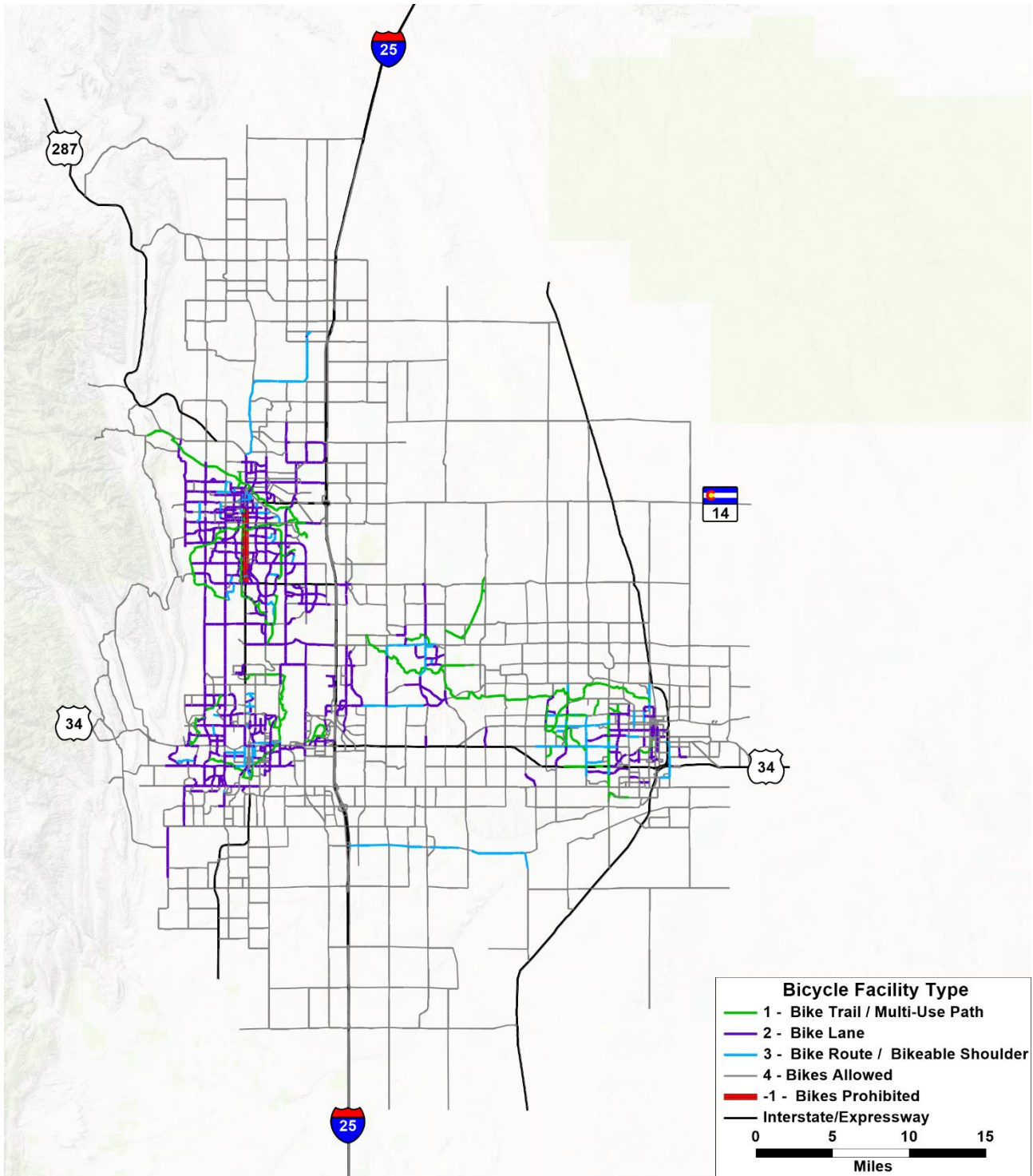


Figure 2.8 Bicycle Facility Types (Fort Collins)

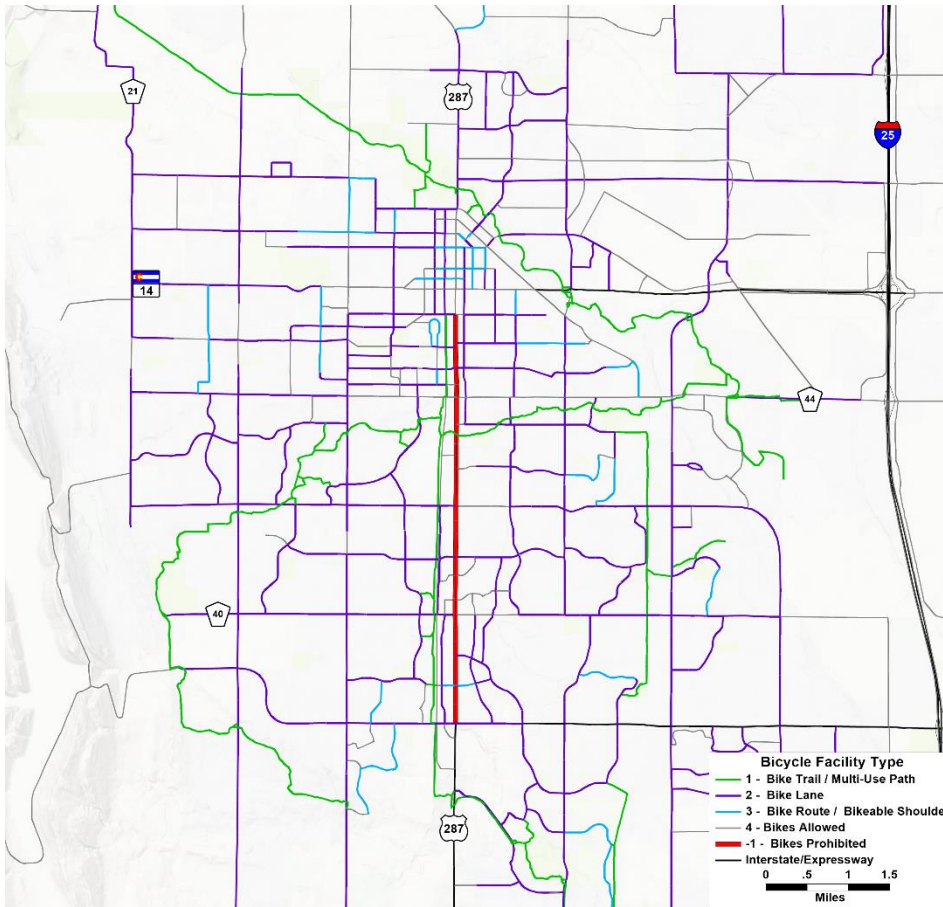


Figure 2.9 Bicycle Facility Types (Greeley)

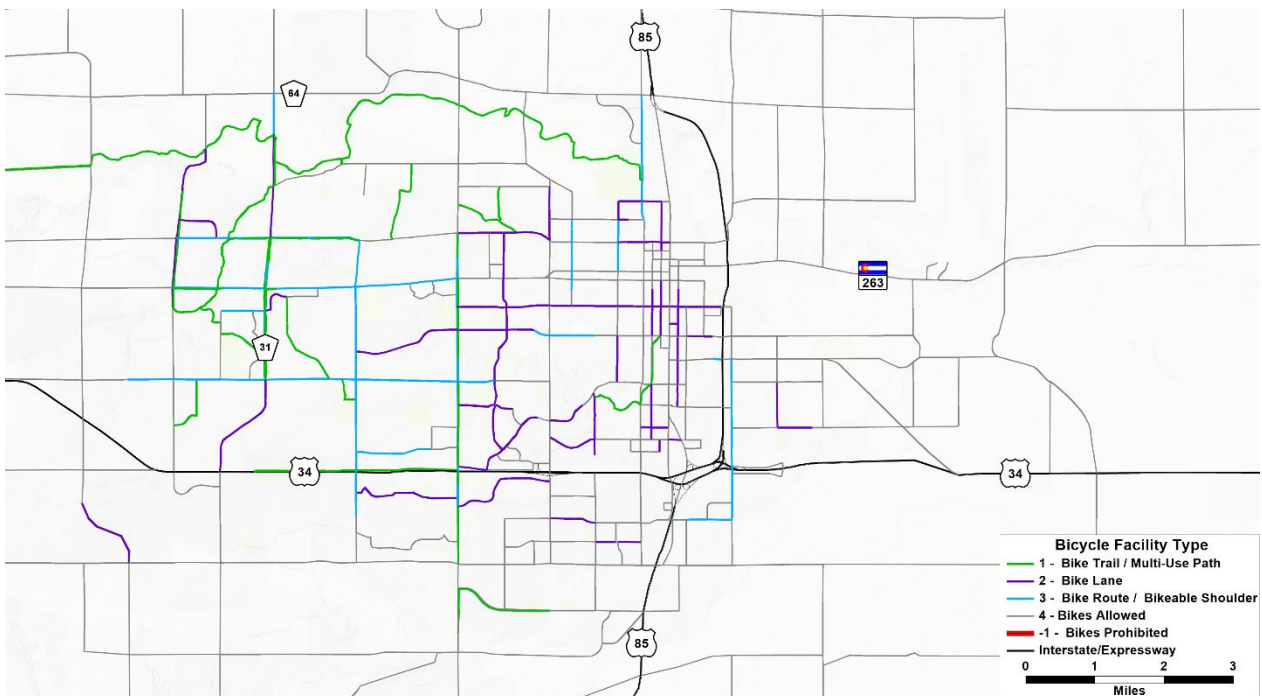


Figure 2.10 Bicycle Facility Types (Loveland)

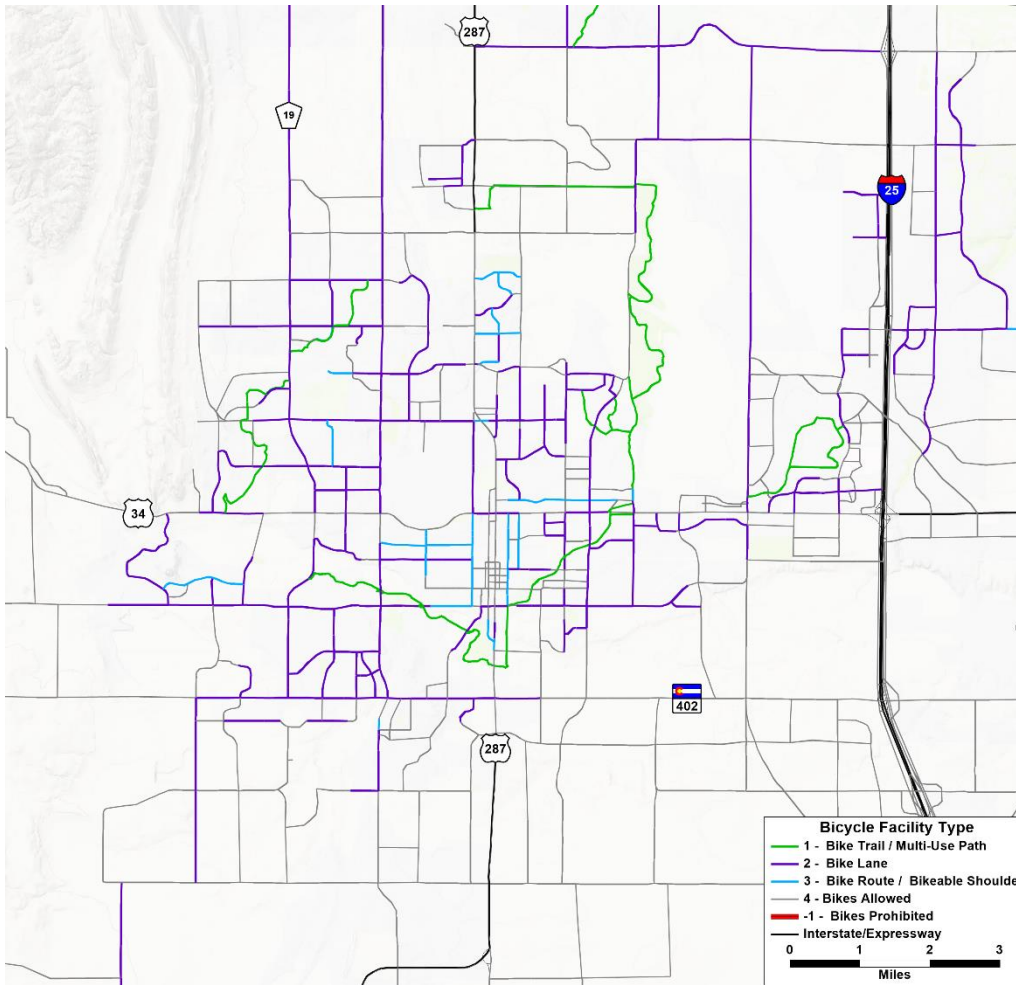
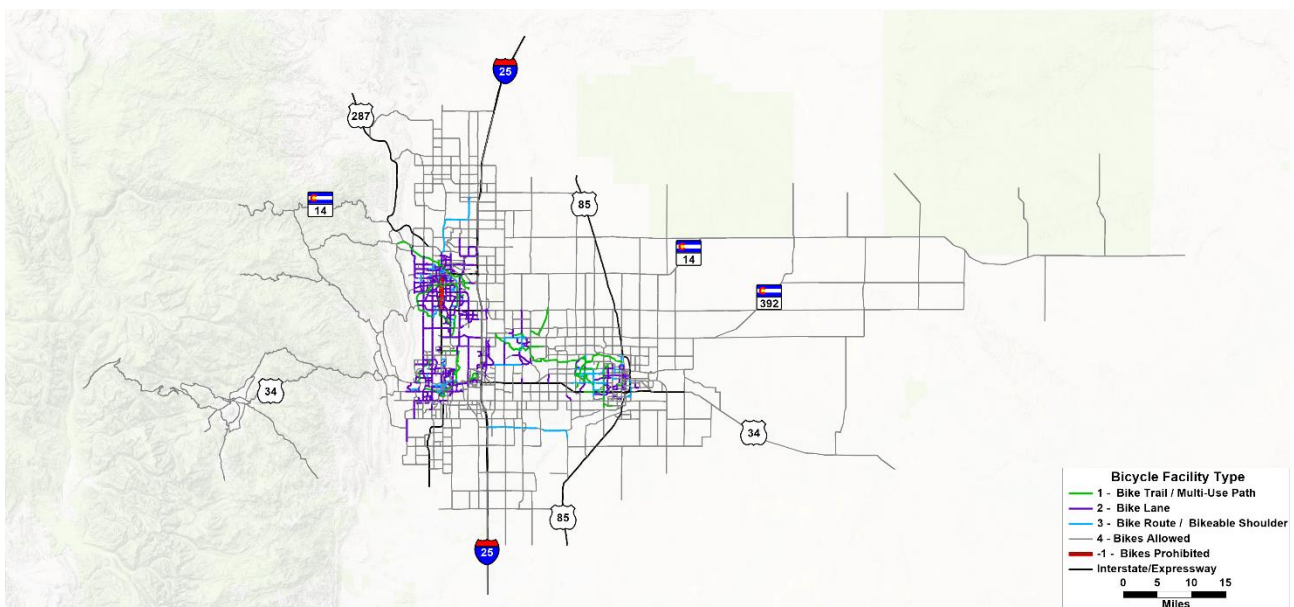


Figure 2.11 Bicycle Facility Types (Expanded Model Area)



2.2.10 Rutable Network

Many functions in TransCAD require the creation of a routable network file, identified by a “.net” extension. For the NFR Model, the path building/skimming and traffic assignment procedures require a routable network. A routable network is also required when editing transit route systems. Routable network files store link length, turn penalty information, and travel time information for each link. Specific turn prohibitions are initially stored in a separate file referenced when creating the routable network. An appropriate routable network file is created during automated network initialization.

The routable network file contains information about centroid connectors to prevent pathbuilder and traffic assignment algorithms from routing trips through centroids. The model automatically creates a selection of centroid nodes and identifies nodes as centroids in the routable network file.

3.0 Transit Network

The travel model uses transit networks to build the shortest paths between each zone pair for transit trips. The resulting shortest paths are used as inputs to the mode choice model. The NFR Model uses information stored on the roadway network layer, including congested travel times, and a TransCAD route system to represent the transit networks. For transit pathbuilding, the NFR Model uses the “Pathfinder” method provided by the TransCAD software.

What’s New

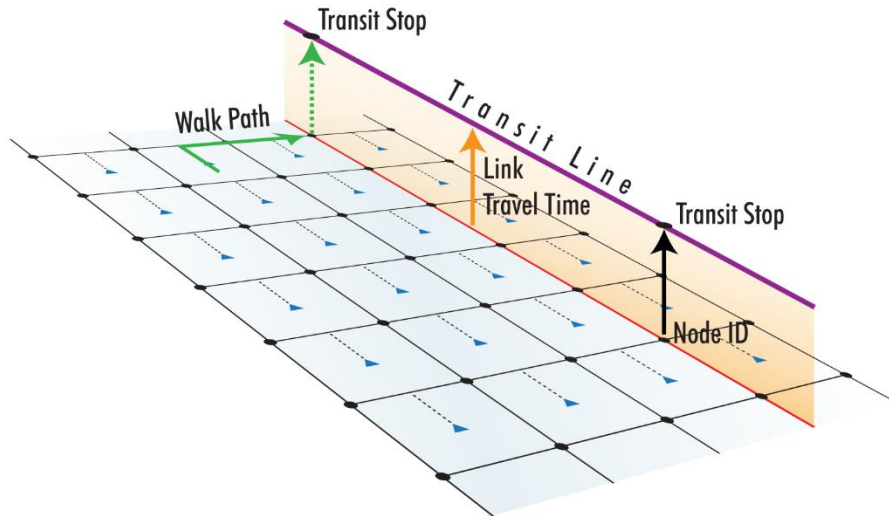
The following updates have been made to the transit networks for the 2015 model update:

- Transfort and City of Loveland Transit (COLT) routes have been updated based on 2015 service;
- Greeley-Evans Transit (GET) routes have been updated to represent a 2016 restructuring of the system;
- The inter-regional Bustang route has been added to the route system in 2015 (FLEX was already included in the 2012 route system, and Bustang was in previous forecast year route systems);
- The transit pathbuilding networks have been updated to use the multi-class network management available in TransCAD 8; and
- Some simplification and refinement of fields, procedures, and mode identifiers has been conducted.

3.1 Transit / Roadway Linkage

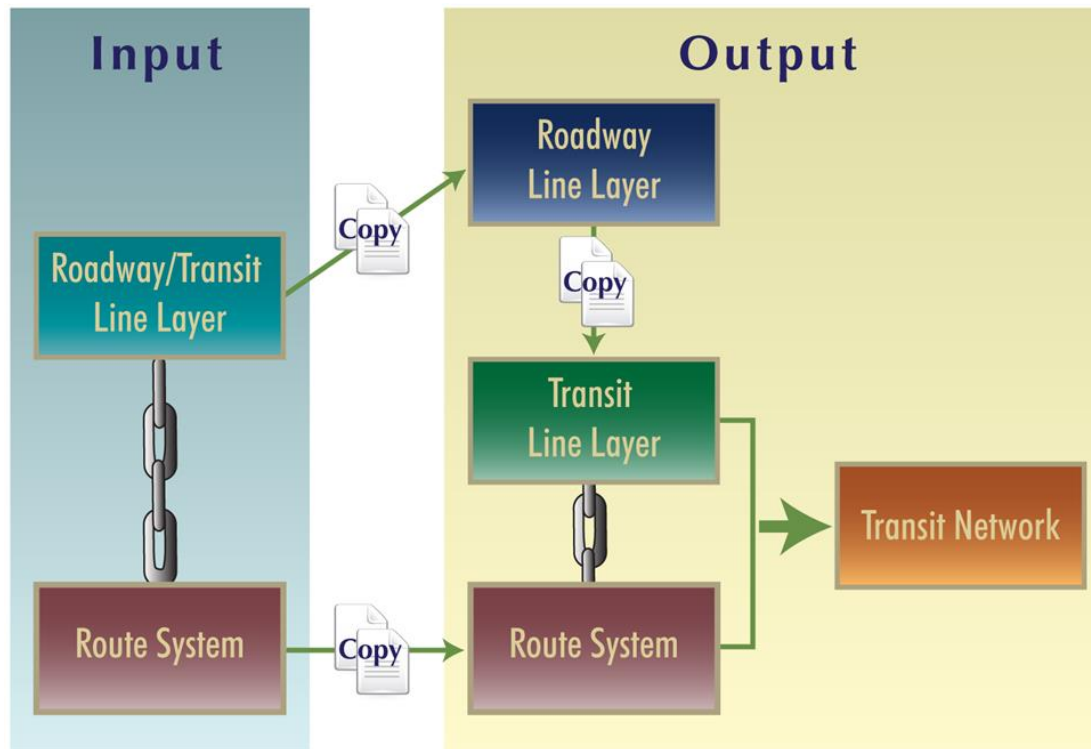
Transit networks in TransCAD are made up of two separate but connected layers: the transit route system and the transit line layer. Information from these two layers is combined as shown in **Figure 3.1** to allow representation of walk, drive, and in-vehicle components of a transit trip. Because these layers are connected, information on the transit line layer, such as link travel times and centroid data, is available to the route system; however, this also requires the roadway and transit networks to be maintained in a manner that prevents them from becoming inconsistent with each other.

Figure 3.1 Connections between the Route System and Transit Line Layer



To enforce consistency between roadway and transit line layers, the model input dataset consists of only one roadway geographic file (roadway/transit line layer). When the travel model is run, separate copies of this layer are made for use in roadway and transit modeling. The roadway line layer includes information such as link capacity and travel time, as described in the **Section 2.2**. The transit line layer includes all information present on the roadway line layer, as well as transit and walk speed. The transit line layer also includes additional automatically generated walk access links. The transit line layer and route system are combined to create a complete transit network. **Figure 3.2** illustrates the process of separating the input roadway/transit line layer into separate roadway and transit line layers. Since transit routes in this environment are coded over roadway links with unique IDs, any change to the input roadway/transit line layer requires modification of the route system.

Figure 3.2 Roadway and Transit Line Layer Processing



3.2 Transit Route System

Transit routes and stops are represented within the TransCAD route system. Contents of the route system are based on schedule data from transit operators in the region.

3.2.1 Route System Attributes

Each route is represented as a unique feature in the route system layer. Like the line layer, the route system layer includes attributes for each feature. These attributes contain route-specific information such as route name, operator, and headway. Notably absent from the list of route system attributes is travel time. The TransCAD model computes stop-to-stop travel time using attributes on the underlying link layer rather than attributes stored directly on the route system. A list of route attributes is included as **Table 3.1**.

Table 3.1 Route Attributes

Field Name	Description	Comments
Route_ID	TransCAD Unique ID	Maintained automatically by TransCAD
Route_Name	Short descriptive route name	Unique route name used for route identification
Side	Indicates the side of the street for use in display	This field should contain the value "R" for all routes.
Route_Number	Route number assigned by transit agency	This field is optional and not referenced by the model macros.

Field Name	Description	Comments
Notes	Optional field for storage of notes	This field can be useful to track or monitor route system editing activities.
Fare	Indicates the fare used in pathbuilding and mode choice	This value represents the average fare paid by non-university students. Cost for 2015 fares are adjusted to reflect 2010 dollars by applying a ratio of CPI factors.
InitPen	Initial boarding penalty used in calibration of bus, regional bus, and BRT modes	This field is set to zero for all routes. Included for special use cases and sensitivity testing.
Ridership	Average observed daily ridership in 2015	This field is included for validation purposes and is not used directly by the model. It does not need to be present on future year route systems.
Expand	Indicates if route is in the primary modeling area or the expanded model area.	1 = Primary model area 3 = Expanded model area
PK_Headway	Peak route headway	These fields are modified by the model macros and should not be edited manually.
OP_Headway	Off-peak route headway	
PK_Headway_yyyy	Scenario-specific peak route headway	yyyy represents a two through four-digit year code (e.g., 2015, 2045) or a scenario-specific code (e.g. S1)
OP_Headway_yyyy	Scenario-specific off-peak route headway	
Agency	Name of operating agency	
Mode	Transit Mode ID	See Table 3.3 .
Dwell	Stop dwell time	Stop dwell time has been set to zero for all routes, as dwell time is incorporated in the transit speed assumptions.

Route Headways

The headway for each transit route is calculated separately for peak and off-peak time periods. For identification of transit headway, peak time period is approximate, roughly 7:00 AM through 9:00 AM and 3:30 PM through 6:30 PM.

Transit Fares

Transit fares are specified for each route in 2010 dollars but have been defined at the operator level for the 2015 base year. Transit fares entered on the route system should account for the average fare paid for each complete trip. Transit fares must account for a mix of riders using cash fares, standard monthly passes, and discounted or free monthly passes. CSU student passes should not be included in the average, as the model makes a separate assumption that all transit travel by students to and from CSU and UNC is free of charge. Average fares included in the 2015 base year route system are shown in **Table 3.2**.

Table 3.2 2015 Transit Fares

Operator	Fare
CDOT (Bustang)	\$7.88
City of Loveland Transit (COLT)	\$0.66
Estes Park Free Shuttle	\$0.00
Greeley/Evans Transit (GET)	\$0.39
Transfort	\$0.27

Transit Modes

The NFR Model features three primary types of transit service: local bus, interregional express bus, and premium transit. Premium transit can represent BRT service similar to the existing MAX route or can be used to represent proposed rail service. Each mode is coded with a separate Mode value, allowing different speed, in-vehicle travel time weights, and other attributes to be specified at the mode level. Mode values available in the NFR Model are specified in **Table 3.3**. In addition, the line layer is populated with a Mode field having a value of 99 on all non-transit links available for walk or drive access.

Transit routes are coded directly on roadway links and may also use local streets that are not included in the roadway model. These transit-only streets or lanes are coded using the *Transit Link* facility type, 51. Transit links are not available for use by vehicles, even though they may represent local streets. Local streets are represented by centroid connectors in the roadway networks.

Portions of the MAX BRT line use an exclusive guideway that is not open to autos. These portions of the MAX BRT line also use the *Transit Link* facility type, but in this case to represent the guideway links. As with local streets used by buses, the fixed guideway is not available in the model for vehicular use. Transit speeds on the fixed guideway can be set based on schedule data, as they are not affected by increasing congestion. Portions of the MAX BRT line that run in mixed flow traffic are coded similarly to local bus and experience congestion effects of increasing traffic in forecast year models.

Table 3.3 Transit Network Mode Values

Mode ID	Mode Description
1	Local Bus
10	Local Bus coordinated with premium transit (not used, included for special use cases and sensitivity testing)
20	Express / Interregional Bus
30	Premium Transit: Bus Rapid Transit (BRT) or rail
99	Walk or Drive Access

Transit Stops

The transit route system includes transit stop locations coded at all locations where transit access may be possible. For local bus routes, transit stops were not coded based on actual stop locations, rather they are designed to represent good access to all routes. For MAX BRT, FLEX service, and Bustang, stops are coded based on actual stop locations. Transit stops for future non-local transit routes, including the Poudre Express, are coded based on existing plans or best practices.

Routes can only be boarded or alighted at stops. To facilitate a connection to the transit line layer, all transit stops must be coded to coincide with a distinct node on the input roadway network. Furthermore, only one stop can be coded per direction, per route, per node. Attributes maintained on the route stop layer are listed in **Table 3.4**.

The TransCAD route system structure does not require transit stops to be located at nodes on the transit line layer. However, when the transit network processing model step is performed, each transit stop is matched to the closest node on the transit line layer. If the route system contains stops that cannot be matched to nodes, the model will fail to run.

Table 3.4 Route Stop Attributes

Field Name	Description	Comments
ID	TransCAD Unique ID	These fields are all maintained automatically by TransCAD and are read-only.
Route_ID	ID of the route associated with the stop	
Pass_Count	Used to associate a stop with one of multiple times a route passes a particular node.	
Milepost	Distance from the route starting point	
STOP_ID	Unique stop ID (identical to ID)	
Dwell	Stop dwell time	Dwell time is set to zero for all stops.
NearNode	Identifies the ID of the node on the network layer that matches the route stop	This field is filled automatically when the model is run.

3.2.2 Base Year Transit Routes

Figure 3.3 and **Figure 3.4** show the base year 2015 transit routes.

Figure 3.3 Base Year Transit Routes (MPO Area)

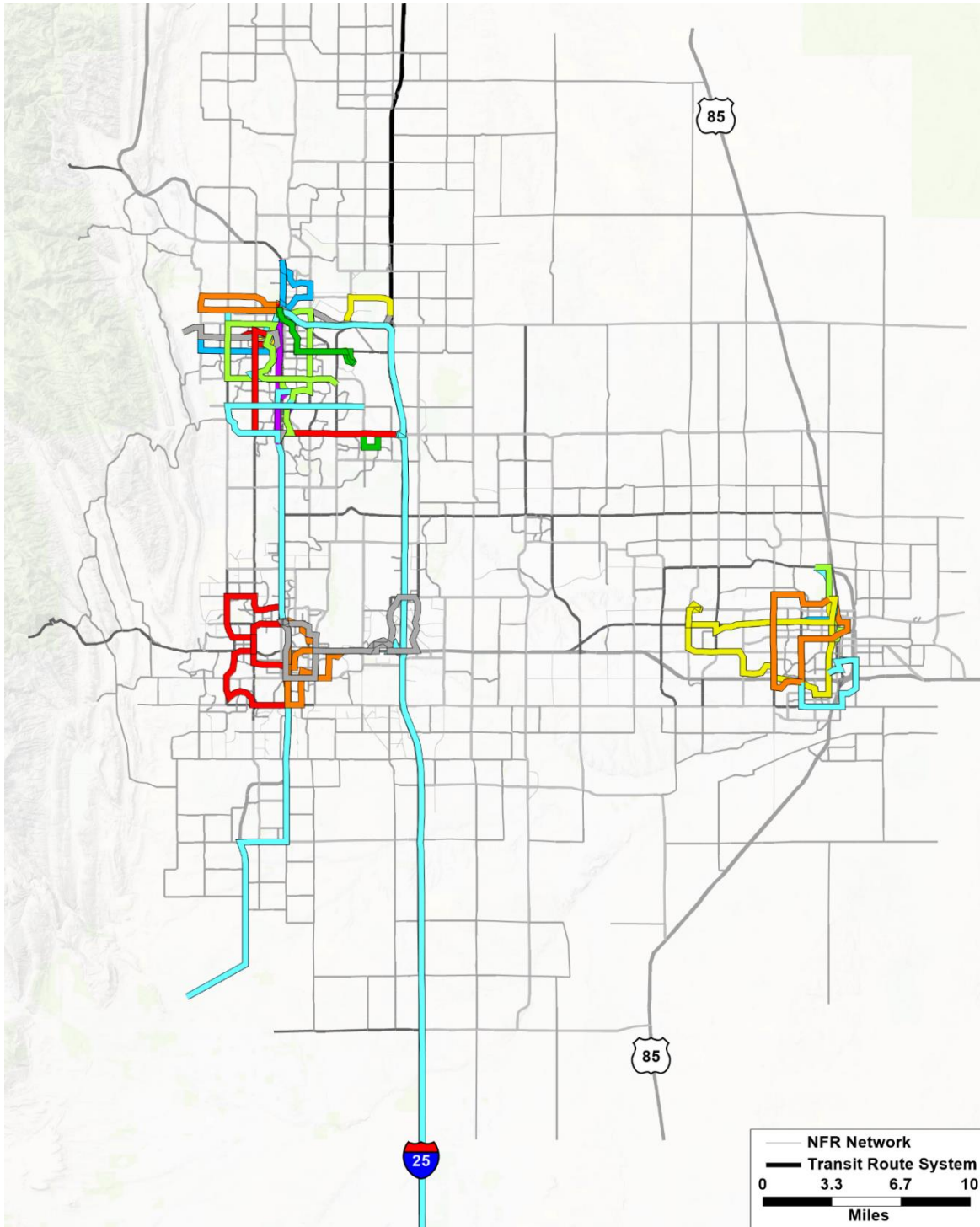
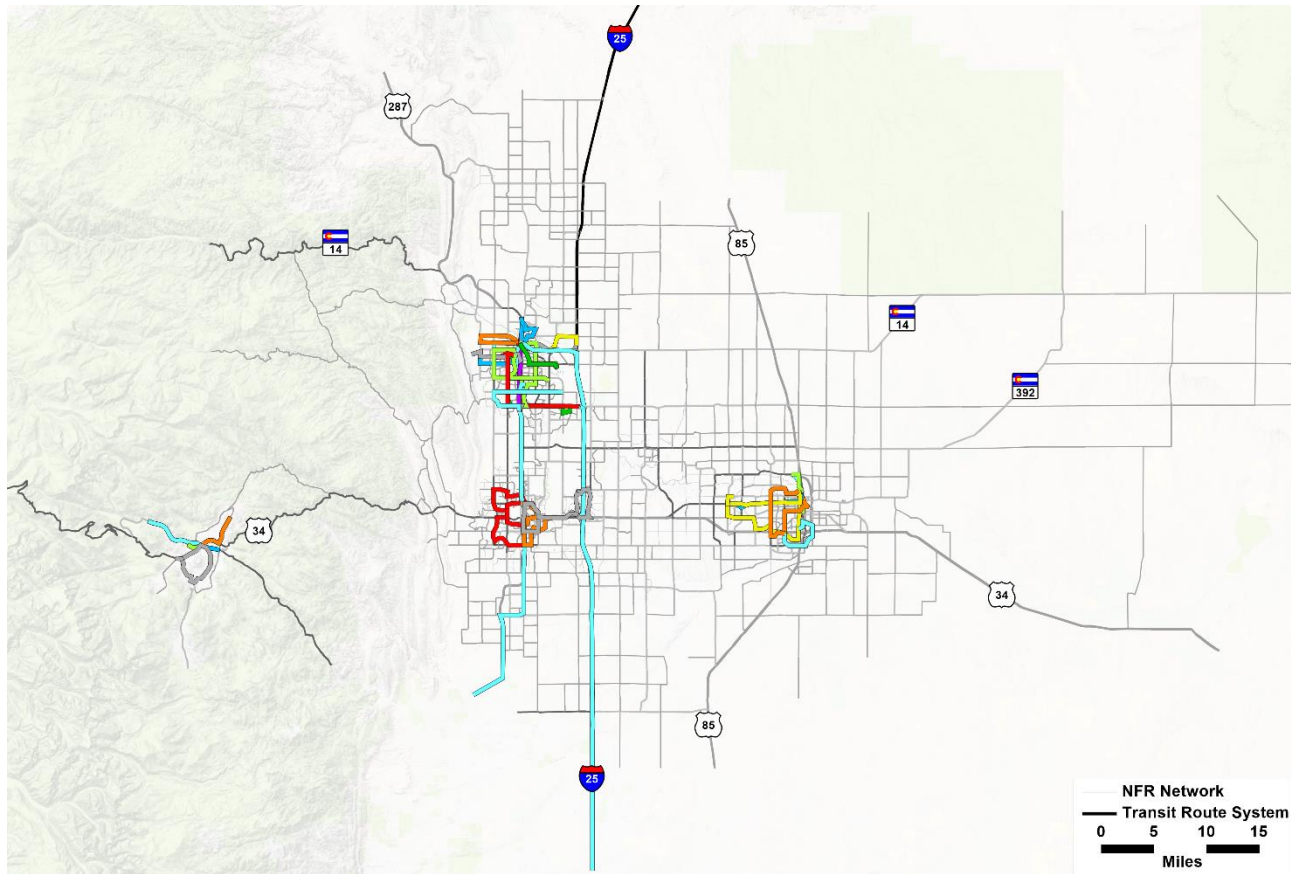


Figure 3.4 Base Year Transit Routes (Expanded Model Area)



3.3 Transit Line Layer

Some transit variables are maintained on a copy of the roadway network rather than the route system, allowing for interaction between the roadway and transit networks. Transit travel time is calculated as a function of vehicle travel time on each link. The transit line layer also provides a connection between TAZ centroids and route stops. This connection is provided in the form of centroids, roadway links, non-motorized links, and walk access/egress links and the roadway network.

3.3.1 Transit Travel Time

Transit travel time is computed by multiplying congested travel time by a calibrated transit time factor. This factor represents the observed difference between transit route times and congested network times. Transit time factors are based on a regression analysis comparing published times to congested model network travel times for each transit route.

During roadway and transit network processing, the fields listed in **Table 3.5** are populated with data required for transit and non-motorized modeling. When running speed feedback, the model calculates transit speeds based on the congested speeds resulting from speed feedback.

Table 3.5 Key fields in Transit Line Layer

Field Name	Description	Comments
AB_OPTRTIM	Off-peak period transit time	Based on the off-peak link time resulting from speed feedback
BA_OPTRTIM		
AB_PKTRTIM	Peak period transit time	Based on the AM congested link time resulting from speed feedback
BA_PKTRTIM		
AB_OPTRSPD	Off-peak period transit speed	Calculated based on link time and length (for reference only)
BA_OPTRSPD		
AB_PKTRSPD	Peak period transit speed	
BA_PKTRSPD		
WALK_TIME	Walk travel time	Used for transit walk access
Mode	Non-transit mode field	Used to identify links that can be used for walk access/egress

3.3.2 Walk Access and Egress

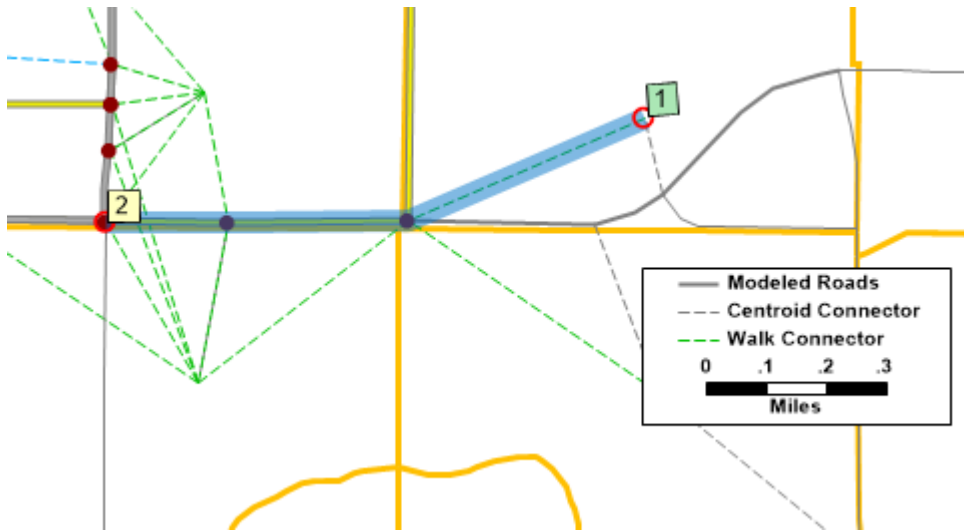
The transit line layer also represents the connection between TAZ centroids and transit route stops. Except for park-n-ride trips, all transit trips must start and end on foot⁵. Several approaches are available for representing walk access to transit in TransCAD:

- **Direct Walk Links:** A set of walk access/egress links provides a direct connection between each TAZ centroid and all transit stops within a specified distance.
- **Roadway Network Walk Links:** Walk access and egress occurs using the roadway network, including centroid connectors and most roadways. Walk access cannot occur on links where walk access is prohibited, such as freeway links. In cases where transit facilities are adjacent to freeways it is important to accurately represent walk access connectivity, which may include walk links crossing the freeway that represent tunnels and/or bridges.
- **Combined Walk Links and Roadway Network:** Walk access links are created between transit stops and immediately adjacent TAZs. Centroid connectors, walk access links, and the roadway network are used to facilitate walk access and egress for TAZs not immediately adjacent to transit stops.

The NFR Model connects TAZs to transit stops using the combined walk access link and roadway network approach. This approach allows representation of direct access to transit stops adjacent to TAZs while representing the increased walk distance to and from zones near, but not directly adjacent, to transit stops. An example walk access path from a centroid to a specified transit stop that uses both access links and roadway links is shown in **Figure 3.5**.

⁵ Bicycle access and egress to transit is not modeled explicitly but is instead modeled as walk access and egress.

Figure 3.5 Example Walk Access Path



The TransCAD model implements this methodology by automatically drawing walk links from each stop to TAZ centroids within a ¼-mile radius. Walk access links are created in the transit line layer but are not present in the roadway line layer. A facility type value of nine prevents use of walk access links by vehicles.

A walk speed of three mph is assigned to all links on which walk access is permitted. This walk speed is used to compute a walk time in minutes. For example, a walk time of five minutes would be assigned to a link 1/4 mile in length.

3.3.3 Walk Access/Egress Adjustment

Walk access and egress times generated in the pathbuilding process represent the walk time to/from the zone centroid to the transit stop used by the trip maker. Consistent network coding practices ensure this value is reasonable, and more importantly consistent, for all zones with access to transit. During model application, walk times are adjusted to represent varying walk access and egress times for different portions of each TAZ.

Walk access and egress times are segmented into short (less than ¼ mile), medium (less than ¾ mile), and long (over ¾ mile) distance from transit. The 25-minute walk time used for transit trips in the long market segment effectively eliminates walk access to transit from portions of zones further than ¾ of a mile from a transit stop. The model computes access and egress times for each market segment included in a zone. The rules outlined below are used to compute walk access and egress times by market segment.

- If a zone falls completely within one market segment, walk times are read directly from the network.
- If a zone falls in two or more market segments, the following procedure is used:
 - The minimum walk times specified for each market segment in **Table 3.6** are used; and
 - For each zone pair, if the stop on the first route is not the closest stop to the zone centroid, the distance between the stop and the closest stop is added to the minimum walk time. This prevents the

model from assuming an unreasonably short walk time in cases where the route used for a path does not make use of the closest stop to a zone.

Table 3.6 Minimum Walk Access/Egress Times by Market Segment

Market	Minimum Walk Time
Short	2.5 minutes
Medium	7.5 minutes
Long	25 minutes

3.3.4 Timed Transfers

At most locations, transfer wait time is computed as one-half the headway of the route being boarded. However, some routes are timed to provide quick transfers at transfer centers. The NFR Model applies a lower transfer time at these locations using a pulse transfer time value stored on the node layer. Positive values specified in the node field PULSE_yyyy will override the default transfer time for all transfers occurring at a node.

3.3.5 Drive Access

The transit network connects TAZs to route stops to represent transit trips made using a park-n-ride. Drive access connectivity is only provided in the direction from TAZs to route stops. The model allows trips from a production zone to a park-n-ride, but not from a park-n-ride to an attraction zone. This prevents drive egress trips due to the mode choice and transit modeling convention that transit pathbuilding and assignment is performed in *Production/Attraction* format rather than *Origin/Destination* format. By following this convention, it is possible to limit drive access to transit to the production (or home) end of each trip. Because transit riders do not typically have access to a vehicle at the attraction (or non-home) end of a trip, transit egress is limited to the walk mode.

Drive access to transit is provided using centroid connectors and roadway links. Zone to park-n-ride travel times are computed using peak and off-peak travel times on the roadway network. Drive access is only provided to specially designated park-n-ride nodes, identified by populating the *PNR_yyyy* field on the input network node layer with a number 1.

3.4 Transit Pathbuilding

Transit networks are built in the TransCAD software for use with the Pathfinder transit shortest path method. The Pathfinder method is unique to the TransCAD software and builds paths using a weighted generalized cost approach. Each component of a transit trip is converted into a common unit, allowing application of different weights to each trip component. Pathfinder weights have been set for consistency with coefficients in the mode choice model.

The Pathfinder evaluates possible transit paths between each zone pair and identifies the path with the lowest generalized cost. Path components considered by the Pathbuilder setup in the NFR Model are listed along with pathbuilding weights in **Table 3.7**.

Table 3.7 Transit Pathbuilding Weights

Variable	Description	Weight
Walk Access Time	Time spent walking from the production TAZ centroid to the transit stop (for walk access trips only)	2
Drive Access Time	Time spent driving from the production TAZ centroid to a park-n-ride (for drive access trips only)	1
Drive Access Cost	Auto operating cost associated with drive access (for drive access trips only)	1
Drive Access Terminal Time	Terminal time at the production TAZ consistent with that for an auto trip (for drive access trips only)	2
Initial Wait Time (Short)	Time spent waiting for the first bus to arrive, computed as one-half of the route headway. The short component of the initial wait time includes a wait up to 7.5 minutes	2*
Initial Wait Time (Long)	Initial wait time exceeding 7.5 minutes	1*
In-Vehicle Travel Time	Time spent riding or waiting in a transit vehicle	1
Transfer Wait Time	Time spent walking between stops for a transfer (if applicable)	2
Transfer Walk Time	Time spent walking between stops for a transfer (if applicable)	2
Transfer Penalty Time	Additional transfer penalty (calibration parameter)	2
Egress Walk Time	Time spent walking from the transit stop to the attraction TAZ centroid	2
Fare	Transit fare paid for the trip	1

Note: Travel time variables are converted for consistency with cost variables using the value of time documented in the mode choice model specification.

* Weighted initial wait time is computed for each route based on the combined short and long wait times. The transit network weight is set to 1 for initial wait time. Transit shortest path matrices are post-processed to represent unweighted short and long initial wait time.

4.0 TAZs

Traffic analysis zones (TAZ) are geographic boundaries that contain socioeconomic data used as the foundation for trip-making in the travel model. The TAZ layer is formatted as a polygon layer and is based on US Census Block geography. The size and number of TAZs in a particular area is primarily driven by the density of development but planned or expected future development also plays a role. Developed areas require a greater number of smaller zones, while rural un-developed areas are represented with larger zones. TAZs are attached to the roadway networks using zone centroids and centroid connectors that allow travelers access to the transportation system by simulating local and neighborhood streets.

TAZs are ideally but not always sized and shaped to provide a relatively homogeneous amount and type of activity within each zone. TAZ delineations traditionally follow the natural and manmade boundaries that tend to segregate different land uses. These boundaries include water features, bridges, roads, railroads, and other lines that form logical boundaries. Jurisdictional and Census boundaries often do not make for good TAZ delineations because they can be arbitrary in relation to the needs of the model; but they are usually desirable for data development and reporting functions.

What's New

The TAZ layer, along with centroid connectors, for the 2015 base year NFR Model has been updated and recreated. The updated zone system is loosely based on the traffic analysis zones developed for the 2012 model, with updates being made with the following considerations:

- Compatibility with Census Block and Tract boundaries;
- TAZ activity density;
- Zone size proportional to roadway network density;
- Area type consistency with other models in Colorado;
- Addition of a new Commercial area type, replacing the distinction between Fort Collins and other CBD; and
- Lessons learned from past applications of the model for local planning agencies, including matching GMA boundaries to the extent possible and reducing the size of TAZs in rural areas to provide manageable areas of analysis for local staff.

In addition, the following updates have been made to the model in accessing and working with the TAZ layer and TAZ data.

- Fields on the TAZ layer have been further minimized, allowing TAZ data to be stored in a separate table; and
- Socioeconomic data formats have been updated to read information produced by UrbanCanvas.

4.1 TAZ System Summary

The 2015 TAZ layer is based directly on aggregations of 2010 Census Block boundaries. Updated zone boundaries also take the 2012 TAZ layer into account, maintaining existing zones where appropriate. In some cases it was necessary to split Census Blocks into separate zones, but this was avoided when possible. **Figure 4.1** and **Figure 4.2** show the updated zone system, compared to the previous zone system, for the expanded and unexpanded regions.

Numbering of updated zones is non-sequential. Zones that remain consistent with 2012 definitions generally use the same zone number as the 2012 layer. In cases where zones were changed significantly, multiple zones were merged into a single zone, or one zone was split into multiple zones, new zones numbers were used. These new zone numbers were chosen so that they do not match numbering of unrelated zones from the 2012 TAZ layer.

The TAZ layer is contained in a TransCAD geographic file and is a required input to the travel model. A listing of required fields in the TAZ geographic file can be found in **Table 4.1**. By design, the geographic file contains minimal data, with most information stored in separate tables that can be joined to the geographic file. While it is possible to add additional information to the TAZ layer for analysis or record keeping purposes, it is recommended that socioeconomic data and other model input data not be stored directly in the TAZ layer to avoid confusion about where the travel model expects data to be located.

Table 4.1 Data Dictionary for NFR Model TAZ file

NFRMPO_TAZ.dbd Fields	Description
ID	Unique TransCAD identifier
Area	Total TAZ area (square mile)
TAZ	TAZ number
Expand	1=unexpanded; 3=expanded

Figure 4.1 TAZ Boundary Changes (Expanded)

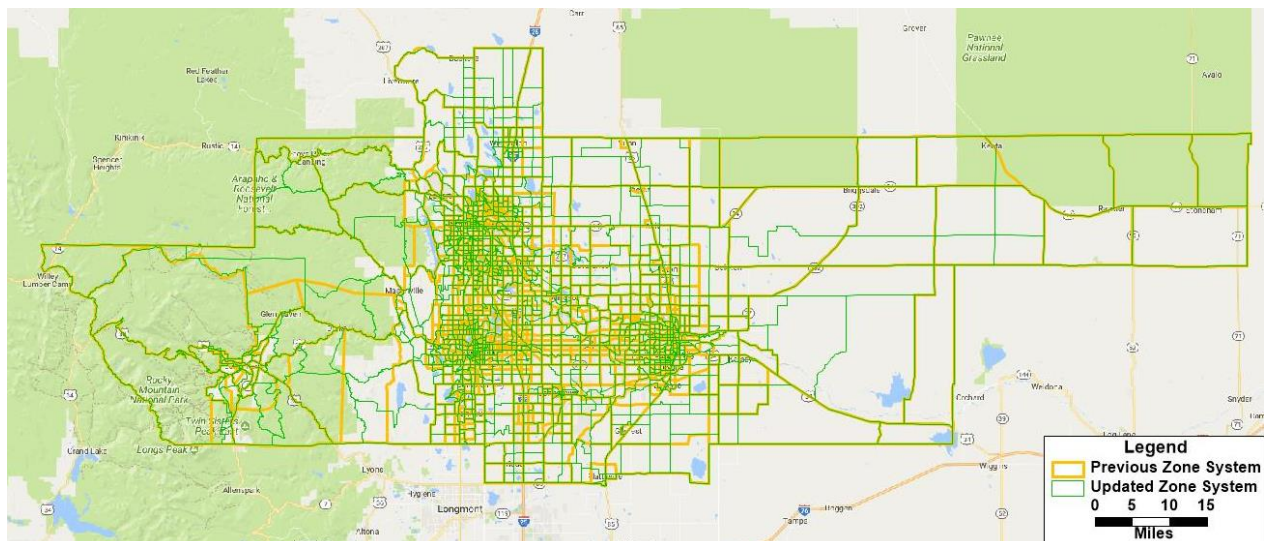
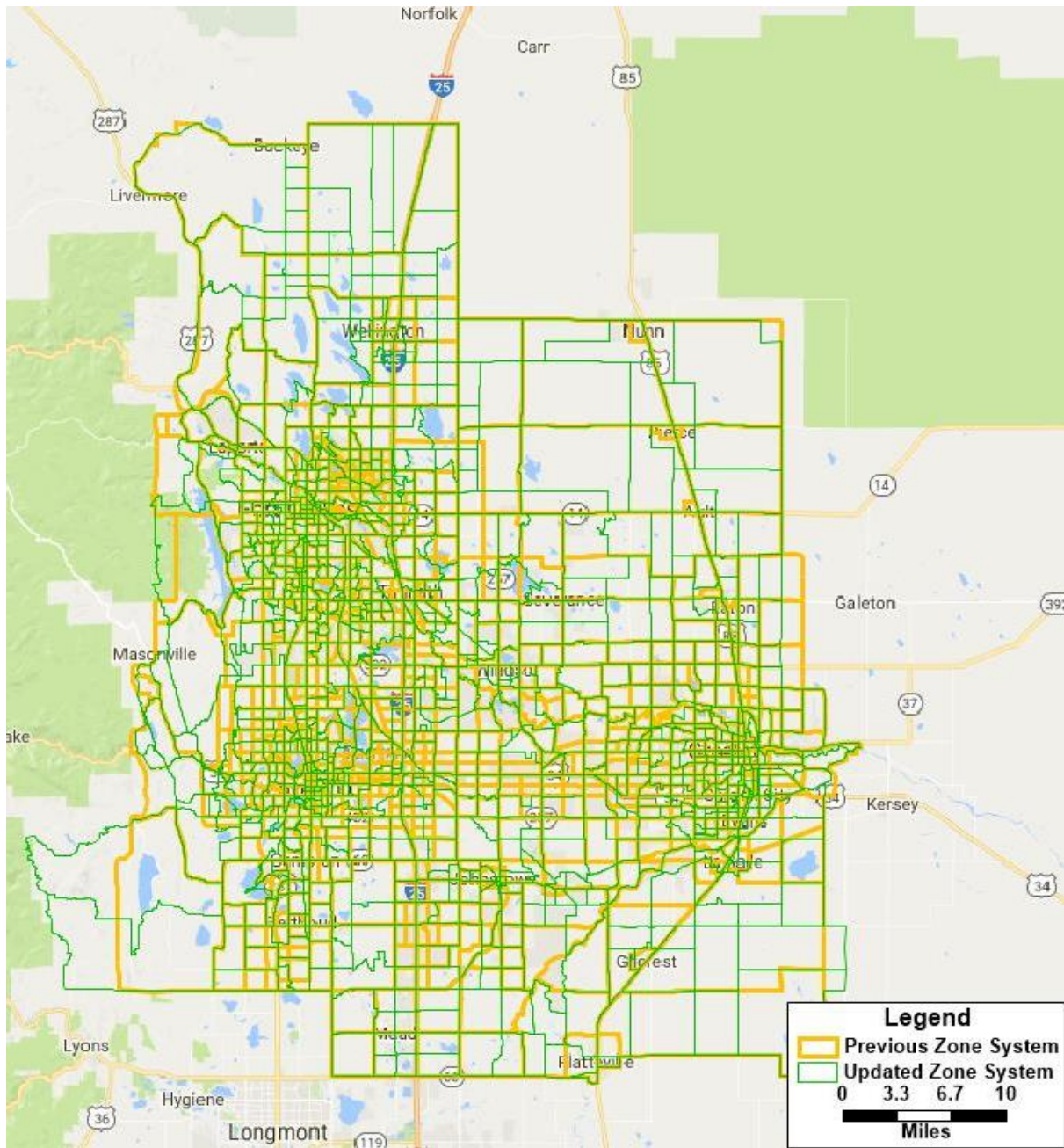


Figure 4.2 TAZ Boundary Changes (Unexpanded)



The updated zone system totals 1,205 TAZs, an addition of 173 TAZs. A comparison of descriptive statistics of the updated zone system, in comparison the previous zone system, is provided in **Table 4.2**.

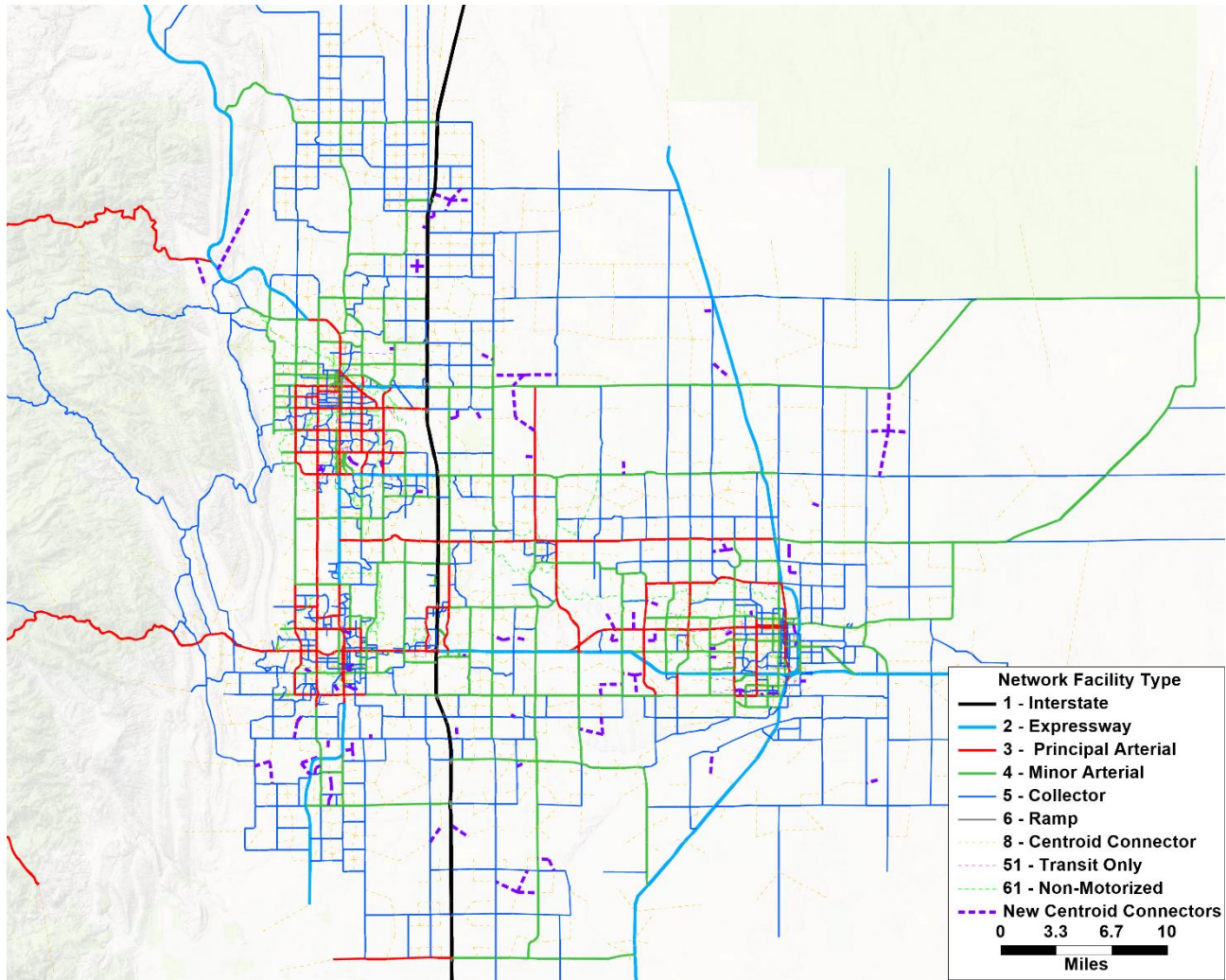
Table 4.2 Distribution of Year 2012 and 2015 TAZs

TAZs	2012 Base Year Zones			Updated 2015 Base Year Zones		
	Unexpanded	Expanded	Total	Unexpanded	Expanded	Total
Total number of TAZs	961	71	1,032	1,103	102	1,205
Average Size (Square Mile)	1.19	27.64	3.01	1.04	19.12	2.6
Average Number of Households	190	139	187	174	110	168
Maximum Number of Households	2,135	558	2,135	1,901	623	1,901
Average Household Density (Households per Square Mile)	608	77	572	716	72	662
Maximum Household Density	5,688	806	5,688	8,379	895	8,379
Standard Deviation of Household Density	936	171	914	1,118	182	1,086
Average Employment	269	116	258	248	76	234
Maximum Employment	7,146	1,059	7,146	5,559	1,033	5,559
Average Employment Density (Jobs per Square Mile)	1,198	111	1,123	1,271	77	1,170
Maximum Employment Density	38,578	1,505	38,578	55,079	1,468	55,079
Standard Deviation of Employment Density	3,280	231	3,179	3,990	229	3,832

Note: Household and employment statistics for 2015 exclude university zones.

Centroid connectors were also revised in the network in order to better reflect access to and from the new TAZs. **Figure 4.3** shows the locations of the new centroid connectors added during initial network development. Further updates to centroid connectors were made during model validation.

Figure 4.3 New Centroid Connectors



4.2 Zone Attributes and Socioeconomic Data

Attributes for each TAZ are stored in a separate table that can be joined to the geographic file. The data table also includes additional records for external stations, which are not included in the TAZ layer. The table contains the fields listed in **Table 4.3**, but does not include TAZ-level socioeconomic data. Socioeconomic data is input to the travel model separately using data files produced by the NFRMPO 2010 Land Use Allocation Model (LUAM) developed with UrbanCanvas.

Table 4.3 Zone Attributes

ZoneData.bin Fields		Description
TAZ	TAZ number	
AT	Area Type 1=CBD; 2=Commercial; 3=Urban; 4=Suburban; 5=Rural	
Subregion	Subregion ID Number	
Expand	1=unexpanded; 3=expanded	
Custom1	Custom area 1 for summary report	
Custom2	Custom area 2 for summary report	
External	1=external station, blank= internal zone record	
Univ	1=CSU, 2=UNC	
ModelArea	1=Unexpanded and Expanded area 3=Expanded Only	
Park8	Average daily parking costs (\$)	
Park8_STD	Average daily parking costs for students in university zones (\$)	
Park8_FAC	Average daily parking costs for faculty in university zones (\$)	
Park2	Average 2-hour parking costs (\$)	

4.2.1 Area Type

Area type is an attribute assigned to each TAZ and roadway and is based on the activity level and character of the zone. Terminal times, speed-limit to freeflow speed conversion factors, roadway capacity, and volume-delay characteristics are dependent on area type. Area type is first defined at the TAZ level based on socioeconomic characteristics and then transferred to the roadway network.

Area type is an attribute that can and should vary with time. Therefore, it is important area type definitions are specified in a manner which can be updated for future conditions based on available forecast data. While area type definitions based on external information, such as corridor characteristics (e.g., commercial vs. residential) or the U.S. Census urbanized area boundary are useful in defining existing area type, this information is not very useful in defining future year area types. Area type definitions are specified so area type forecasts can be developed using forecast socioeconomic data. Area types used in the NFR Model include central business district (CBD), commercial, urban, suburban, and rural as shown in **Table 4.4**.

Zones identified as CBD areas were retained from the previous version of the model but have been modified slightly during model calibration and validation. Initial identification of non-CBD area types was done at the

TAZ level by applying the area type criteria shown in **Table 4.4** to non-CBD zones based on the 2015 socioeconomic dataset.

After the initial criteria were applied, a manual smoothing process was used to determine base year area type designation for each zone. This was accomplished by overlaying the model TAZ structure on aerial photography obtained from Google Maps. The initial area types were then adjusted to:

1. Fill in holes and gaps in contiguous commercial, urban, and suburban areas;
2. More accurately define existing land uses based on local knowledge; and
3. More accurately define the transition between commercial, urban, suburban, and rural area types through a visual evaluation of the aerial photography and roadway layers.

Changes in zone density between 2012 and 2015 were then evaluated. Area type values were adjusted for zones experiencing a significant increase in density due to either socioeconomic growth or redefinition of zone boundaries. The resulting area type values are shown in **Table 4.4**. **Figure 4.4** through **Figure 4.8** show the resulting base year area type designations.

Area type for forecast and interim year datasets was determined by identifying zones that experienced an increase in activity density crossing one of the thresholds shown in **Table 4.4**. Interim and forecast year area type was then smoothed to eliminate gaps and holes in contiguous commercial, urban, and suburban areas.

Table 4.4 Area Type Designations

Area Type	Population/ Sq. Mile	Employment/ Sq. Mile
1 CBD	n/a	n/a
2 Commercial	n/a	< 7,000
3 Urban	4,000 +	4,000 – 7,000
4 Suburban	300 – 3,999	300 – 3,999
5 Rural	0 - 299	0 – 299

Note: For each TAZ, the most dense non-CBD area type is applied for which at least one of the criteria is met.

Figure 4.4 Base Year Area Type (Expanded Model Area)

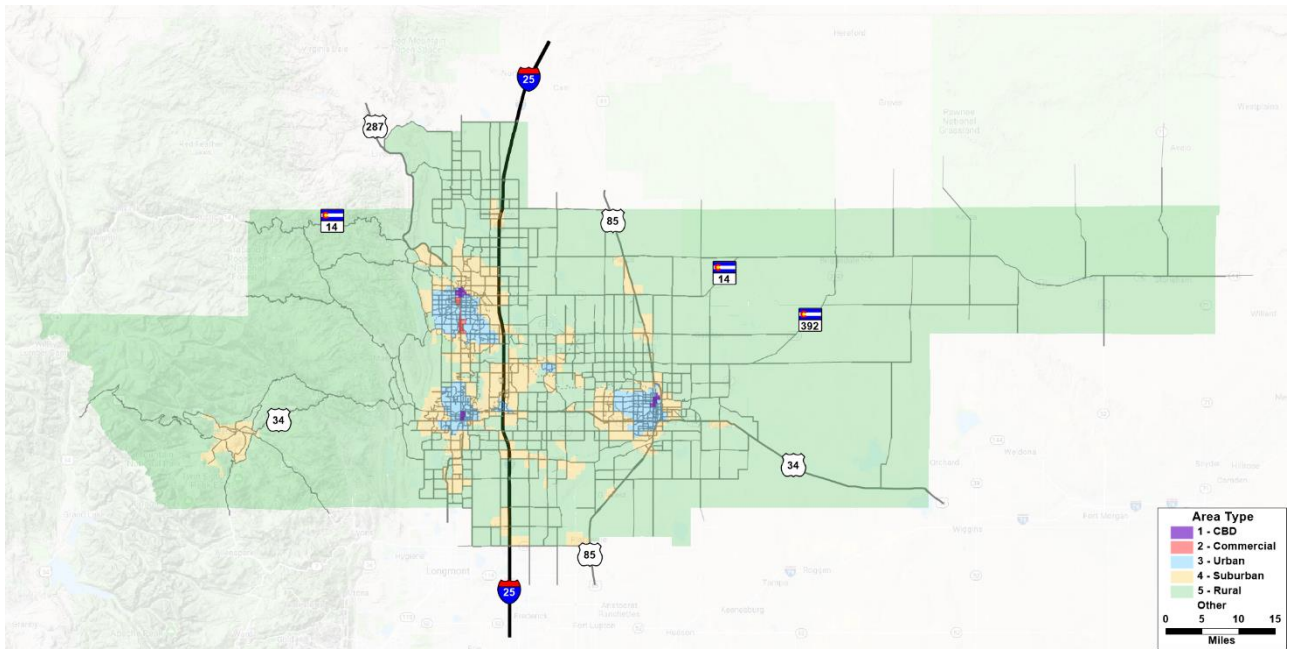


Figure 4.5 Base Year Area Type (Unexpanded MPO Region)

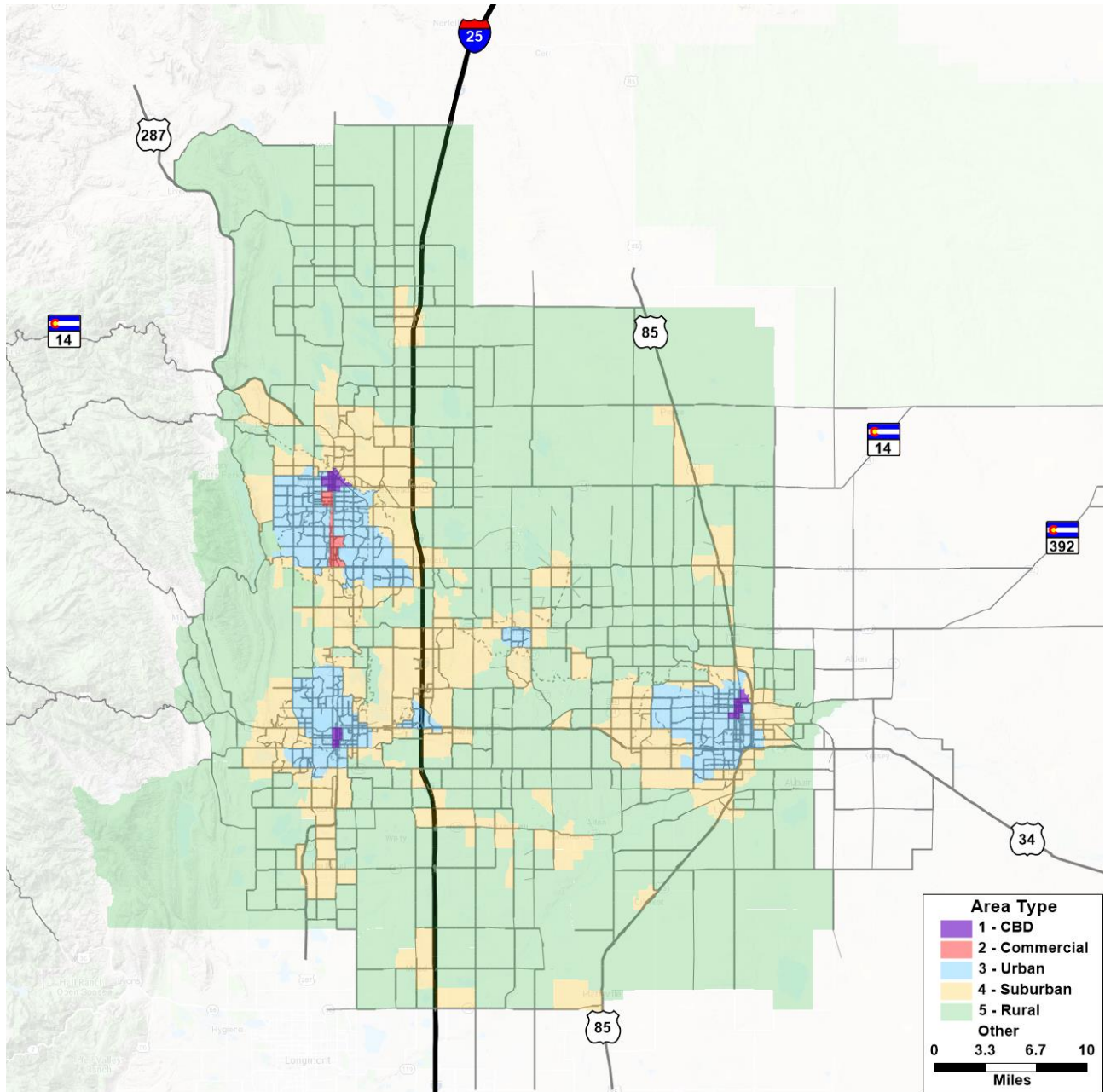


Figure 4.6 Base Year 2015 Area Type Designations (Fort Collins)

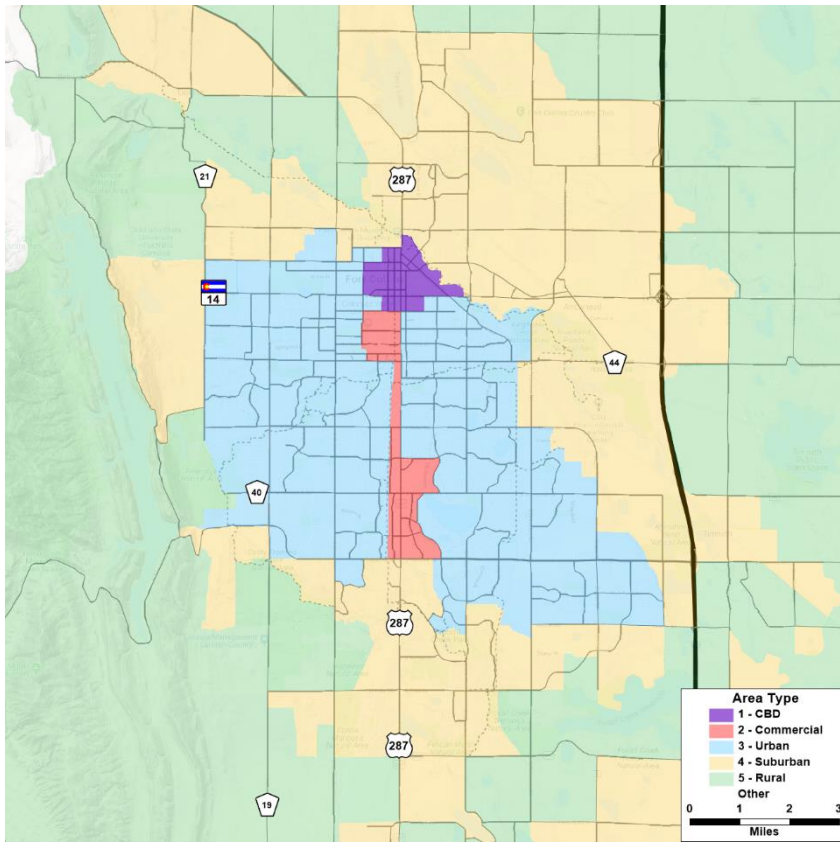


Figure 4.7 Base Year 2015 Area Type Designations (Greeley)

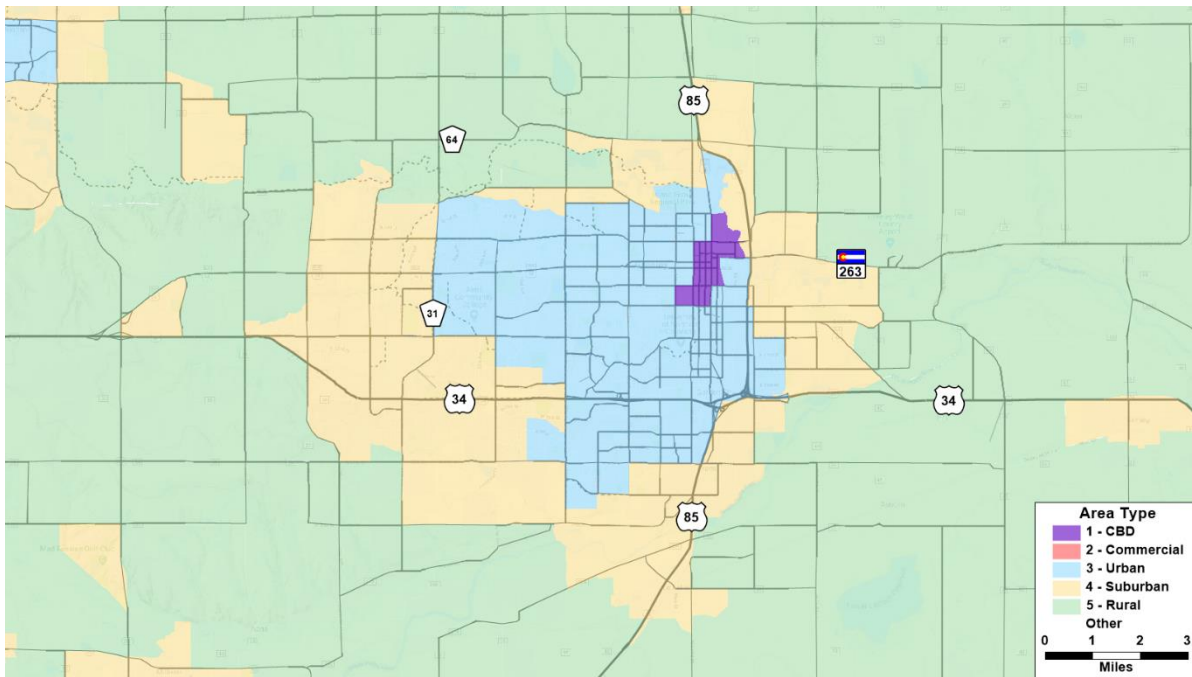
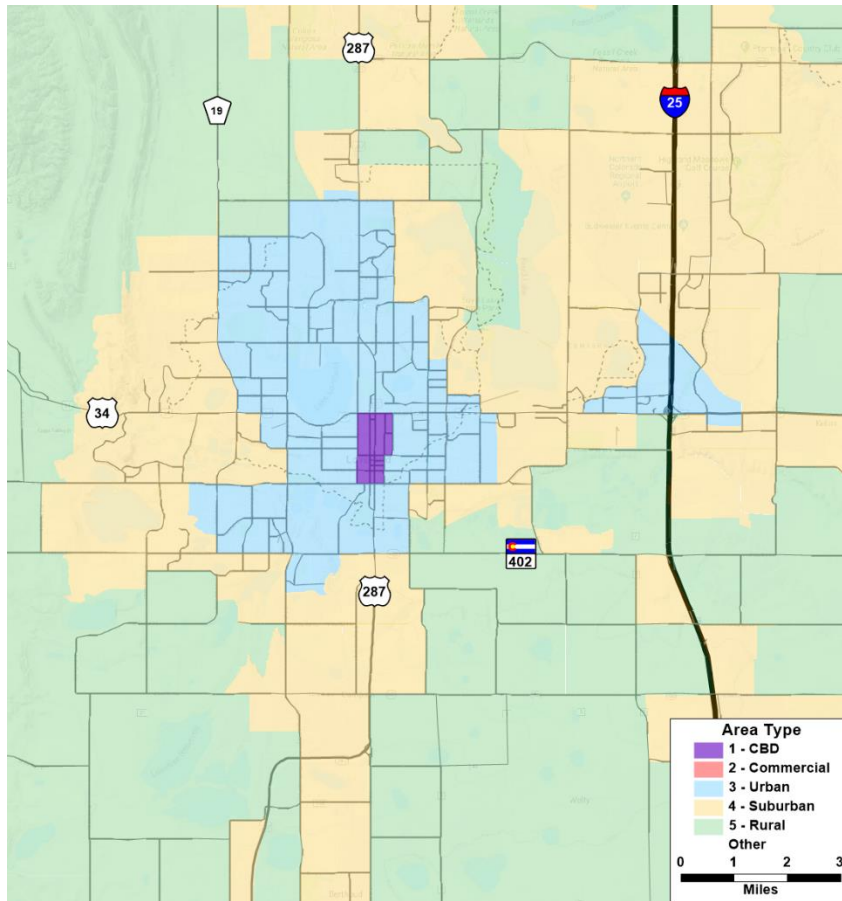


Figure 4.8 Base Year 2015 Area Type Designations (Loveland)



4.2.2 Parking Costs

The TAZ layer includes four types of parking costs:

- Average daily parking costs;
- Average daily parking costs for students in university zones;
- Average daily parking costs for faculty in university zones; and
- Average 2-hour parking costs (assumed to be free everywhere in the NFR modeling area for 2015.).

For the average daily parking costs, parking costs are only observed for downtown Fort Collins. An inventory of parking rates was available for monthly parking costs as well as advanced-purchase monthly parking costs, as shown in **Table 4.5**. A weight was applied to each parking lot cost to better represent an average parking cost (lots with many spaces were weighted higher and vice versa). **Table 4.5** summarizes these parking lot rates and the assumed weight for each. Multiplying the costs by the respective weights and dividing by an assumed average of 20 workdays per month yields a range of \$2.06 to \$1.59 per day, in 2015

dollars. Since all costs in the model are reflected in 2010 dollars, a Consumer Price Index⁶ (CPI) for 2015 and 2010 was applied to adjust the 2015-dollar parking costs to costs in 2010 dollars (88.5% of 2015 dollars). The final average daily parking costs for Fort Collins for 2015 is \$1.50, which is consistent with the 2012 assumptions.

Table 4.5 Fort Collins Average Daily Parking Costs

Description	Monthly	Advance	Weight
Civic Center Garage Covered-Parking	\$50	\$40	0.3
Civic Center Garage Roof-Top	\$30	\$20	0.1
Old Town Garage Covered-Parking	\$50	\$40	0.3
Old Town Garage Roof-Top	\$30	\$20	0.1
Firehouse Alley All-Parking	\$60	\$50	0.1
Mason Lot	\$43	\$33	0.2
Oak/Remington Lot	\$37	\$27	0.2
Jefferson Lot	\$31	\$21	0.2
Canyon Lot	\$30	\$20	0.2
Average Cost (monthly)	\$41.29	\$31.29	
Average Cost (daily)	\$2.06	\$1.56	
CPI Ratio (2010 dollars / 2015 dollars)	0.8852	0.8852	
2015 Average Daily Parking Costs for 2015 in 2010 dollars	\$1.83	\$1.39	
Assumed Parking Costs for Fort Collins	\$1.50		

Parking for Colorado State University (CSU) students is available at a few different rates. Similar to the process for developing average daily parking costs for downtown Fort Collins, parking rates were inventoried and weights were applied to reflect the relative availability of these parking passes, as shown in **Table 4.6**. Parking passes are available on an annual basis, and an assumption of 161 school days⁷ per year was used to estimate an average daily parking cost. Adjusting the 2015 parking costs to 2010 dollars, the overall average daily parking costs for CSU students for 2015 is \$2.64, as shown in **Table 4.6**.

Parking costs for CSU faculty cost \$600 per year. An assumption of 215 workdays⁸ per year was used to estimate an average daily parking cost. Adjusting the 2015 parking costs to 2010 dollars, the average daily parking costs for CSU students for 2015 is \$2.47, as shown in **Table 4.7**.

For the University of Northern Colorado (UNC), average daily parking costs were estimated in the same way as CSU parking costs, as shown in **Table 4.8** and **Table 4.9**.

⁶ A Consumer Price Index (CPI) is an index of the variation in prices paid by typical consumers for retail goods and other items. Information about the CPI for Colorado in 2010 and 2015 was obtained from the Bureau of Labor Statistics (<https://www.bls.gov/cpi/>).

⁷ School days exclude weekends, holidays, summer, and days when CSU is not in session.

⁸ Work days exclude weekends, holidays, and days when CSU is not in session.

Table 4.6 CSU Student Average Daily Parking Costs

Description	Cost	Weight
Permit for CSU students who split the cost of the permit to carpool and park designated carpool space (annual)	\$552	0.6
Permit for CSU staff, faculty, or students to park only in the Moby Arena lot (annual)	\$412	0.3
Permit for CSU staff, faculty, or students to park only in the Research Blvd lot (annual)	\$258	0.1
Average cost (annual)	\$481	
Average number of school days per year	161	
Average cost (daily)	\$2.99	
CPI Ratio (2010 dollars / 2015 dollars)	0.8852	
2015 Average Daily Parking Costs for 2015 in 2010 dollars	\$2.64	

Table 4.7 CSU Faculty Average Daily Parking Costs

Description	Cost
Permit for regular CSU staff and faculty members (annual)	\$600
Average number of workdays per year	215
Average cost (daily)	\$2.79
CPI Ratio (2010 dollars / 2015 dollars)	0.8852
2015 Average Daily Parking Costs for 2015 in 2010 dollars	\$2.47

Table 4.8 UNC Student Average Daily Parking Costs

Description	Cost
Permit for UNC student (annual)	\$285
Average number of school days per year	161
Average cost (daily)	\$1.77
CPI Ratio (2010 dollars / 2015 dollars)	0.8852
2015 Average Daily Parking Costs for 2015 in 2010 dollars	\$1.57

Table 4.9 UNC Faculty Average Daily Parking Costs

Description	Cost
Permit for regular CSU staff and faculty members (Annual)	\$320
Average number of workdays per year	215
Average cost (daily)	\$1.49
CPI Ratio (2010 dollars / 2015 dollars)	0.8852
2015 Average Daily Parking Costs for 2015 in 2010 dollars	\$1.32

5.0 External Travel

In addition to internal-internal trips that occur entirely within the modeling area, the model must also include external travel from outside of the region. Trips with one end inside the modeling area and the other outside of the area are called Internal-External (IE) and External-Internal (EI) trips. Through trips, or External-External (EE) trips, are those which pass through the modeling area without stopping (or with only short convenience stops). External travel is modeled explicitly at the external stations where roadways cross the model boundary.

What's New

The following provides an overview of what has changed in modeling external travel for the updated model:

- Traffic volumes have been updated based on traffic count data collected between 2013 and 2017;
- Six external stations have been added: Weld County Parkway South, WCR-89 North, WCR-390 North, WCR-129 North, SH-71 North, and Weld County Parkway South (expanded);
- External station assumptions have been validated using Location Based Services (LBS) data obtained from StreetLight data⁹; and
- The spreadsheet-based external trip model has been migrated to GISDK, streamlining the process of updating external station input assumptions.

5.1 External Station Locations

The 19 external stations used when running the model for the MPO only are shown in **Figure 5.1**. When running the model for the larger expanded area necessary for ozone conformity analysis, some external stations become internal to the travel model. Additionally, some new external stations are present in the expanded modeling area. External stations present in the expanded model network are shown in **Figure 5.2**. As is evident in these figures, external stations for the MPO modeling area are numbered in the 3000 range, with external stations present only in the expanded model being numbered in the 4000 range.

⁹ CDOT obtained StreetLight Data to support refinement of the commercial vehicle portion of the model for a study of mobility in Northern Colorado.

Figure 5.1 External Station Locations (MPO Modeling Area)

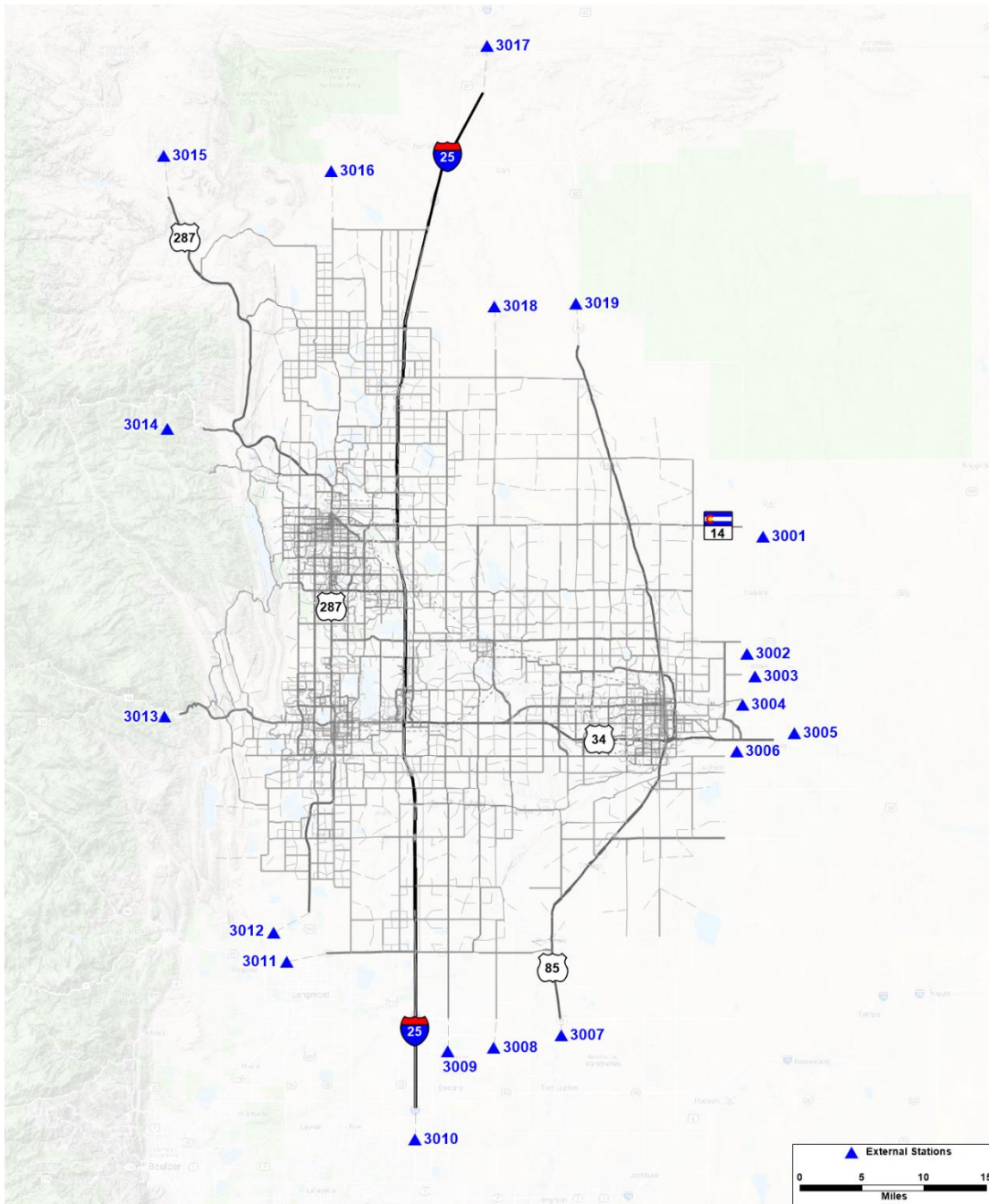
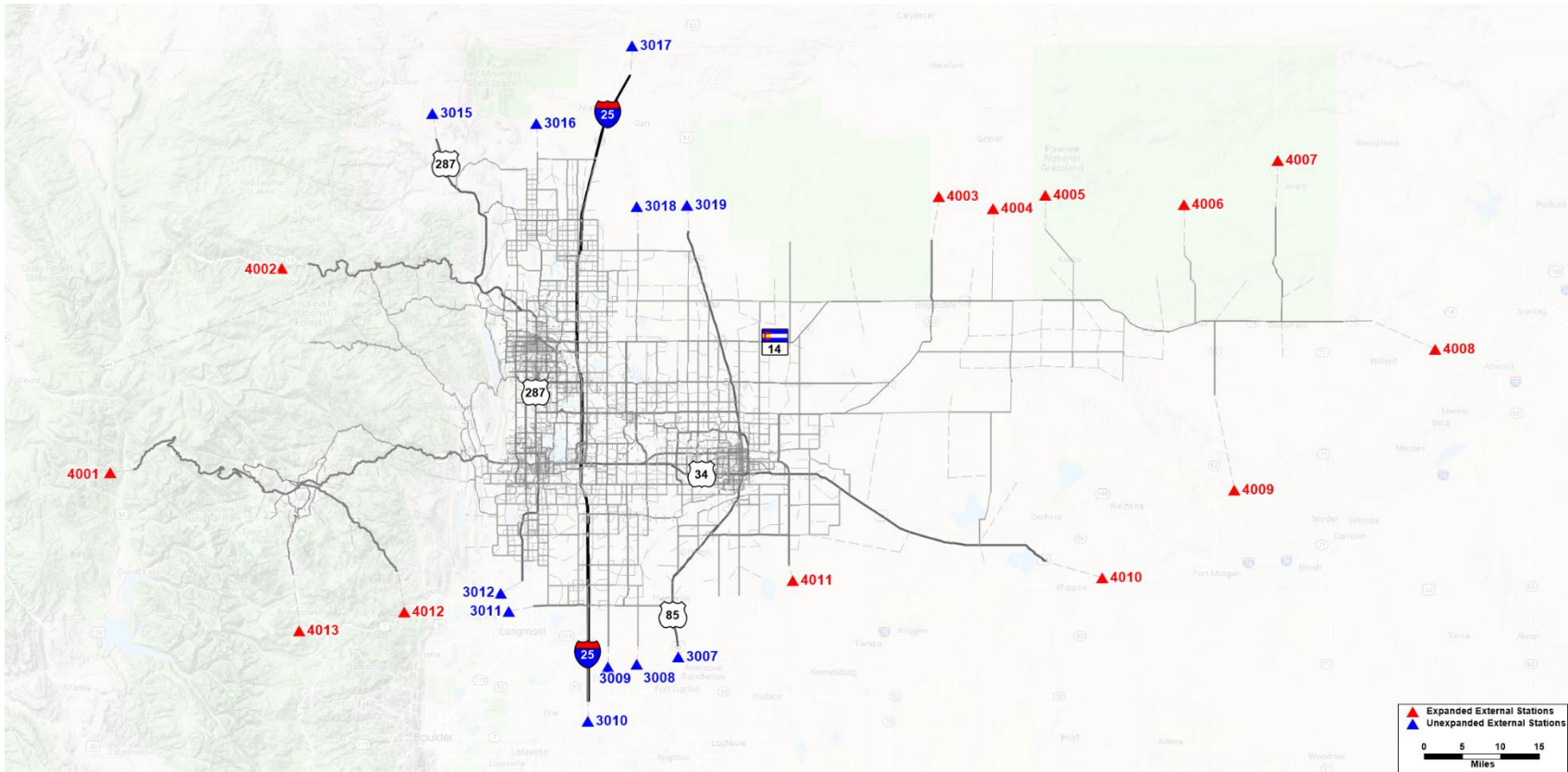


Figure 5.2 External Station Locations (Expanded Modeling Area)



5.2 Base Year External Travel

5.2.1 External Station Volumes

The first step in estimating external travel for the model was to determine the average weekday traffic at each location in the base year. Traffic count data for all external stations were obtained. Since some counts represented annual average daily traffic, they were adjusted as needed to represent an average weekday in March, April, September, October, and November. This was necessary because the travel model is designed to represent an “average weekday when school is in session.”

The next step was to determine the split between the EE and IE/EI trips at each external station. Auto and truck trips were split into through and IE/EI trips. The splits were calculated using the 2006 North Front Range External Travel Study and are shown in **Table 5.1**. Only a few external stations are assumed to carry a significant number of EE auto trips; however, a larger number of stations have a significant number of through truck trips. For the MPO modeling area, external stations have been numbered as zones 3001 through 3019. For the expanded area, several internal stations were removed and new external stations numbered 4001 through 4013 were added. This numbering approach simplifies identification of external stations and allows for easier zone splits as necessary for focused internal area modeling.

Table 5.1 External Travel Assumptions

External Station ID	Location	2015 Total Volume (Vehicles)	Auto EE %	Medium Truck EE %	Heavy Truck EE %
3001	SH-14 East*	1,625	0%	20%	20%
3002	SH-392 East*	2,649	0%	0%	20%
3003	CR-64 East*	56	0%	0%	20%
3004	SH-263 East*	3,715	0%	0%	20%
3005	US-34 East*	14,488	1.78%	2%	2%
3006	Weld County Pkwy South*	5,937	0%	0%	0%
3007	US-85 South	24,939	1.57%	1%	50%
3008	CR-19 South	1,480	0%	0%	0%
3009	CR-13 South	4,844	0%	0%	0%
3010	I-25 South	88,781	20.00%	20%	49%
3011	SH-66 West	26,182	50.00%	50%	56%
3012	US-287 South	23,285	0.60%	10%	12%
3013	US-34 West*	5,511	3.91%	7%	23%
3014	SH-14 West*	1,333	1.58%	7%	23%
3015	US-287 North	7,311	14.59%	67%	68%
3016	CR-15 North	250	0%	0%	0%
3017	I-25 North	24,719	17.51%	55%	74%
3018	CR-19 North	63	0%	0%	0%

External Station ID	Location	2015 Total Volume (Vehicles)	Auto EE %	Medium Truck EE %	Heavy Truck EE %
3019	US-85 North	3,007	3.28%	4%	52%
4001	US-34 west expanded	3,437	3.86%	0%	0%
4002	SH-14 west expanded	1,513	1.65%	0%	52%
4003	SH-392 north expanded	860	0%	0%	0%
4004	WCR-89 North	635	1.16%	1%	17%
4005	WCR-390 North	538	1.16%	1%	17%
4006	WCR-129 North	563	1.16%	1%	17%
4007	SH-71 North	1,024	1.16%	1%	17%
4008	SH-14 east expanded	1,502	0%	0%	49%
4009	SH-52 east expanded	964	0%	0%	0%
4010	US-34 east expanded	3,818	1.8%	1%	50%
4011	Weld County Pkwy South expanded	5,637	0%	0%	0%
4012	US-36 west expanded	8,513	0%	0%	0%
4013	SH-7 west expanded	3,130	0%	0%	0%

* External stations 3001, 3002, 3003, 3004, 3005, 3006, 3013, and 3014 are only used when running the Model for the MPO, excluding the expanded area.

5.2.2 Internal-External and External-Internal Trips

IE/EI trips processed in the travel model use the internal trip purposes described in **Section 6.3**. Trips with productions at the external station are EI trips, while trips with attractions at the external station are IE trips. Previous model development efforts separated IE/EI trips directionally based on an analysis of directional traffic counts in the AM and PM peak periods. This model update utilized Location Based Services (LBS) data. Review of LBS data confirmed that the share of Denver area productions and attractions that travel to/from the NFR is consistent with the previous assumptions based on traffic count analysis. Therefore, the IE/EI trip allocation assumptions remain unchanged from previous model versions. The resulting allocation of trips into the IE and EI categories is shown in **Table 5.2**.

Table 5.2 IE/EI Trip Allocation

External Station Type	% IE (Attraction external to the NFR)	% EI (Production external to the NFR)
Denver Connections (3006 through 3012)	60%	40%
All Other Stations	40%	60%

IE and EI trips were also allocated to trip purposes using information from the Front Range Travel Counts household travel survey. The North Front Range portion of the survey was combined with the DRCOG portion of the survey to identify the breakdown of trips between the NFR and DRCOG regions by trip

purpose. For external trips to other areas, it was only possible to consider trips produced in the NFR region, as the household survey did not include households making trips into the modeling area. The resulting allocations by trip purpose are shown in **Table 5.3**. These assumptions remain unchanged from the previous version of the model.

Table 5.3 Distribution of IE and EI Trips by Purpose

Trip Purpose	IE/EI Trips
Home-based Work (HBW)	30.1%
Home-based Shopping (HBS)	8.4%
Home-based Other (HBO)	37.7%
Work-based Other (WBO)	7.3%
Other-based Other (OBO)	16.5%
TOTAL	100%

5.2.3 External-External Trips

The external to external trip process applies the percent share of EE trips at each external station to traffic counts, as well as input seed matrices. The model applies an iterative proportional fitting process that estimates an EE trip matrix that best matches the number of external trips at each based on a seed matrix that provides some information about the relative likelihood for various external to external zone trips. For example, base year data shows the highest number of EE trips occurring between the north and the south I-25 external stations. The seed matrix reflects these travel patterns, and the model will account for these propensities.

For external station forecasting, the model requires traffic volume forecasts at each external station. These forecasts are likely to be obtained from the CDOT statewide travel model. Other assumptions, such as through trip shares and the through trip seed matrix can also be adjusted if statewide modeling exercises suggest this is appropriate.

Seed Matrices

EE seed matrices for autos, medium trucks, and heavy trucks are based on the *2006 North Front Range External Travel Study*. Significant EE trips only occur at a subset of external stations. As previously discussed, external trip totals are derived from total traffic volumes and observed external trip percentages.

Over the course of a day, the total number of EE trips at each external station is assumed to be equal for both directions (inbound trips = outbound trips). This means the daily directional number of EE trips at each external station is equal to half the total EE trips at the station. These totals are used to adjust the observed distribution of EE trips in 2006 to represent 2015 or forecast conditions. The adjustment was performed using an iterative proportional factoring process. These assumptions remain unchanged from the previous version of the model. The resulting through trips for autos, medium trucks, and heavy trucks (the base year EE trip tables from the previous model update) are shown in **Table 5.4** through **Table 5.6** and are used as seed matrices for EE trips in the 2015 base year model.

For the expanded area, the exercise was repeated, but with a different set of external stations. These assumptions remain unchanged from the previous version of the model. EE trip tables for the expanded modeling area are shown in **Table 5.7** through **Table 5.9**.

Table 5.4 Daily EE Auto Seed Matrix (MPO Region)

ID	Location	3005	3007	3010	3011	3012	3013	3014	3015	3017	3019	Total
		US-34 East	US-85 South	I-25 South	SH-66 West	US-287 South	US-34 West	SH-14 West	US-287 North	I-25 North	US-85 North	
3005	US-34 East	0	30	19	12	5	18	0	1	4	7	96
3007	US-85 South	30	0	26	36	0	3	1	1	2	11	110
3010	I-25 South	19	26	0	697	23	91	3	329	1,320	15	2,523
3011	SH-66 West	12	36	697	0	1	2	0	4	24	0	776
3012	US-287 South	5	0	23	1	0	28	1	2	1	0	61
3013	US-34 West	18	3	91	2	28	0	0	1	16	0	159
3014	SH-14 West	0	1	3	0	1	0	0	3	1	0	9
3015	US-287 North	1	1	329	4	2	1	3	0	1	0	342
3017	I-25 North	4	2	1,320	24	1	16	1	1	0	0	1,369
3019	US-85 North	7	11	15	0	0	0	0	0	0	0	34
Total		96	110	2,523	776	61	159	9	342	1,369	33	5,478

Note: External stations where EE travel is not modeled are excluded from this table.

Table 5.5 Daily EE Medium Truck Seed Matrix (MPO Region)

ID	Location	3001	3005	3007	3010	3011	3012	3013	3014	3015	3017	3019	Total
		SH-14 East	US-34 East	US-85 South	I-25 South	SH-66 West	US-287 South	US-34 West	SH-14 West	US-287 North	I-25 North	US-85 North	
3001	SH-14 East	0	0	0.1	4.3	0	0.9	0	0	0	6.1	0.0	11.4
3005	US-34 East	0	0	0.0	0.6	0	0.1	0	0	0	0.9	0.0	1.6
3007	US-85 South	0.1	0.0	0	0	0.2	0.8	0.0	0.0	3.4	14.9	0.1	19.5
3010	I-25 South	6.0	0.9	0	0	7.7	35.2	0.1	0.1	156	683	4.3	892
3011	SH-66 West	0	0	0.4	17.2	0	0	0	0	0	0	0	17.6
3012	US-287 South	0	0	1.3	58.7	0	0	0.0	0.0	2.0	1.0	0.0	63.1
3013	US-34 West	0	0	0.0	0.3	0	0.1	0	0	0	0	0	0.4
3014	SH-14 West	0	0	0.0	0.1	0	0.1	0	0	0	0	0	0.2
3015	US-287 North	0.9	0.1	3.5	161	0	2.0	0	0	0	0	0.0	168
3017	I-25 North	10.4	1.5	15.6	713	0	1.0	0	0	0	0	0	741
3019	US-85 North	0.1	0.0	0.1	4.5	0	0.0	0	0	0.0	0	0	4.7
Total		17.5	2.5	21.0	960	7.8	40.2	0.2	0.1	161	706	4.5	1,920

Note: External stations where EE travel is not modeled are excluded from this table.

Table 5.6 Daily EE Heavy Truck Seed Matrix (MPO Region)

ID	Location	3001	3002	3003	3004	3005	3007	3010	3011	3012	3014	3015	3017	3019	Total
		SH-14 east	SH-392 east	CR-64 East	CR-64 East	US-34 east	US-85 south	I-25 south	SH-66 west	US-287 south	SH-14 west	US-287 North	I-25 north	US-85 north	
3001	SH-14 E	0	0	0	0	0	0.0	0.1	0	0	0	0.1	0.4	0.0	0.6
3002	SH-392 E	0	0	0	0	0	0.1	0.2	0	0	0	0.2	1.3	0.1	1.8
3003	CR-64 E	0	0	0	0	0	0.0	0.0	0	0	0	0.0	0.0	0.0	0.0
3004	SH-263 E	0	0	0	0	0	0.1	0.3	0	0	0	0.2	1.3	0.1	1.9
3005	US-34 E	0	0	0	0	0	0.0	0.0	0	0	0	0.0	0.2	0.0	0.3
3007	US-85 S	0.0	0.1	0.0	0.1	0.0	0	0	0.2	1.0	0.0	50.6	464	29.7	546
3010	I-25 S	0.2	0.5	0.0	0.5	0.1	0	0	0.9	4.4	0.0	222	2,039	131	2,399
3011	SH-66 W	0	0	0	0	0	0.2	0.9	0	0	0	0	0	0	1.1
3012	US-287 S	0	0	0	0	0	1.0	4.6	0	0	0.0	7.2	1.5	0.1	14.3
3014	SH-14 W	0	0	0	0	0	0.0	0.0	0	0.0	0	0	0	0	0.0
3015	US-287 N	0.1	0.3	0.0	0.3	0.0	55.1	242	0	5.2	0	0	0	0.2	303
3017	I-25 N	0.9	2.5	0.0	2.5	0.5	462	2,030	0.2	0.3	0.0	0	0	0	2,499
3019	US-85 N	0.1	0.2	0.0	0.2	0.0	29.6	130	0.0	0.0	0.0	0.0	0	0	160
Total		1.2	3.4	0.0	3.5	0.6	548	2,408	1.2	11.0	0.0	281	2,509	161	5,928

Note: External stations where EE travel is not modeled are excluded from this table.

Table 5.7 Daily EE Auto Seed Matrix (Expanded Area)

ID	Location	3007	3010	3011	3012	3015	3017	3019	4001	4002	4010	Total
		US-85 south	I-25 south	SH-66 west	US-287 south	US-287 north	I-25 north	US-85 north	US-34 west	SH-14 west	US-34 east	
3007	US-85 south	0	34	0	37	1	2	12	14	2	9	111
3010	I-25 south	34	0	49	711	329	1,340	16	36	4	6	2,525
3011	SH-66 west	37	711	1	0	3	20	0	0	0	3	775
3012	US-287 south	0	49	0	1	4	2	0	0	2	3	61
3015	US-287 north	1	329	4	3	0	1	0	2	2	0	342
3017	I-25 north	2	1,339	2	20	1	0	0	2	1	1	1,368
3019	US-85 north	12	16	0	0	0	0	0	5	0	2	35
4001	US-34 west	14	36	0	0	2	2	5	0	0	4	63
4002	SH-14 west	2	4	2	0	2	1	0	0	0	0	11
4010	US-34 east	9	6	3	3	0	1	2	4	0	0	28
Total		111	2,524	61	775	342	1,369	35	63	11	28	5,319

Note: External stations where EE travel is not modeled are excluded from this table.

Table 5.8 Daily EE Medium Truck Seed Matrix (Expanded Area)

ID	Location	3007	3010	3011	3012	3015	3017	3019	4002	4008	4010	Total
		US-85 south	I-25 south	SH-66 west	US-287 south	US-287 north	I-25 north	US-85 north	SH-14 west	SH-14 east	US-34 east	
3007	US-85 south	0	0	0.2	0.8	3.4	14.9	0.1	0.0	0.1	0.0	19.5
3010	I-25 south	0	0	7.7	35.2	156	683	4.3	0.1	6.0	0.9	892
3011	SH-66 west	0.4	17.2	0	0	0	0	0	0	0	0	17.6
3012	US-287 south	1.3	58.7	0	0	2.0	1.0	0.0	0.0	0	0	63.0
3015	US-287 north	3.5	161	0	2.0	0	0	0.0	0	0.9	0.1	168
3017	I-25 north	15.6	713	0	1.0	0	0	0	0	10.4	1.5	741
3019	US-85 north	0.1	4.5	0	0.0	0.0	0	0	0	0.1	0.0	4.7
4002	SH-14 west	0.0	0.1	0	0.1	0	0	0	0	0	0	0.2
4008	SH-14 east	0.1	4.3	0	0.9	0	6.1	0.0	0	0	0	11.4
4010	US-34 east	0.0	0.6	0	0.1	0	0.9	0.0	0	0	0	1.6
Total		21.0	960	7.8	40.1	161	706	4.5	0.1	17.5	2.5	1,920

Note: External stations where EE travel is not modeled are excluded from this table.

Table 5.9 Daily EE Heavy Truck Seed Matrix (Expanded Area)

ID	Location	3007	3010	3011	3012	3015	3017	3019	4002	4008	4010	Total
		US-85 south	I-25 south	SH-66 west	US-287 south	US-287 north	I-25 north	US-85 north	SH-14 west	SH-14 east	US-34 east	
3007	US-85 south	0	0	0.2	1.0	50.6	464	29.7	0.0	0.0	0.0	546
3010	I-25 south	0	0	0.9	4.4	222	2,039	131	0.0	0.2	0.1	2,398
3011	SH-66 west	0.2	0.9	0	0	0	0	0	0	0	0	1.1
3012	US-287 south	1.0	4.6	0	0	7.2	1.5	0.1	0.0	0	0	14.3
3015	US-287 north	55.1	242	0	5.2	0	0	0.2	0	0.1	0.0	303
3017	I-25 north	462	2,030	0.2	0.3	0	0	0	0.0	0.9	0.5	2,494
3019	US-85 north	29.6	130	0.0	0.0	0.0	0	0	0.0	0.1	0.0	160
4002	SH-14 west	0.0	0.0	0	0.0	0	0	0	0	0	0	0.0
4008	SH-14 east	0.0	0.1	0	0	0.1	0.4	0.0	0	0	0	0.6
4010	US-34 east	0.0	0.0	0	0	0.0	0.2	0.0	0	0	0	0.3
Total		548	2,408	1.2	11.0	280	2,506	161	0.0	1.2	0.6	5,917

Note: External stations where EE travel is not modeled are excluded from this table.

5.2.4 Auto Occupancy Rates

The inputs to the external travel model are number of vehicles at each external station. However, these vehicles need to be linked to person trips in trip distribution. In addition, it is important to separate external trips into auto occupancy classes to properly account for express lanes that offer discounted or free travel to high occupancy vehicles. This requires input of auto occupancy shares at each external station. The external travel model inputs include fields for percent of vehicles by vehicle class: drive alone, shared ride 2, and shared ride 3+. Without recent observed data for auto occupancy at each of these external stations, the Colorado Statewide Travel Model, StateFocus, was used to calculate the share of vehicles by vehicle class assigned at each NFR Model external station. The results were reasonable and were used as input values to the 2015 NFR Model; these values are documented in **Table 5.10**. In the case that an external station was not included in StateFocus, average values of 88%, 8%, and 4% were assumed for drive alone, shared ride 2, and shared ride 3+, respectively.

Table 5.10 Auto Occupancy at External Stations

External Station ID	Location	Percent Drive Alone	Percent Shared Ride 2	Percent Shared Ride 3+
3001	SH-14 East	86%	10%	4%
3002	SH-392 East	88%	8%	4%
3003	CR-64 East	88%	8%	4%
3004	SH-263 East	85%	10%	4%
3005	US-34 East	85%	10%	5%

External Station ID	Location	Percent Drive Alone	Percent Shared Ride 2	Percent Shared Ride 3+
3006	Weld County Pkwy South	86%	10%	4%
3007	US-85 South	86%	9%	4%
3008	CR-19 South	85%	11%	5%
3009	CR-13 South	86%	11%	4%
3010	I-25 South	88%	8%	4%
3011	SH-66 West	87%	9%	4%
3012	US-287 South	87%	9%	4%
3013	US-34 West	95%	4%	1%
3014	SH-14 West	86%	7%	7%
3015	US-287 North	88%	8%	4%
3016	CR-15 North	88%	8%	4%
3017	I-25 North	88%	8%	4%
3018	CR-19 North	88%	8%	4%
3019	US-85 North	88%	8%	4%
4001	US-34 west expanded	88%	8%	4%
4002	SH-14 west expanded	89%	8%	4%
4003	SH-392 north expanded	82%	12%	6%
4004	WCR-89 North	88%	8%	4%
4005	WCR-390 North	88%	8%	4%
4006	WCR-129 North	88%	8%	4%
4007	SH-71 North	88%	8%	4%
4008	SH-14 east expanded	93%	5%	2%
4009	SH-52 east expanded	96%	3%	1%
4010	US-34 east expanded	91%	6%	3%
4011	Weld County Pkwy South expanded	86%	10%	4%
4012	US-36 west expanded	92%	6%	2%
4013	SH-7 west expanded	88%	8%	4%

5.2.5 External Transit

The NFR Model is set up to account for external transit. External transit trips are accounted for in a manner similar to external vehicle trips, the number of trips crossing the model boundary must be specified as an input value. In the 2015 base year, the FLEX route connecting Fort Collins, Loveland, and Longmont and the Bustang route connecting Fort Collins, Loveland, and Denver are included as an external transit connector. Because specific data was unavailable, assumptions about trip direction and the share of trips exiting the region were required. External transit assumptions shown in Table 5.11 reflect the total Bustang ridership, as the Bustang service in 2015 only allows travel between the NFR and Denver. Trips staying within the NFR region are not allowed on Bustang as operated in 2015. The FLEX external station assumptions only

represent part of the total FLEX ridership, as this route serves trips within the region as well as between the NFR and Longmont.

Table 5.11 External Transit Assumptions

	Trips	% Productions	% External	External P	External A
Bustang	206	90%	90%	21	185
FLEX	221	60%	70%	88	133

While external transit trip-ends are specified, internal ends of these trips are allocated by the mode choice model. When a transit volume is specified at an external station, the mode choice model is run for all zone pairs connected to the external station. The resulting trips generated by the mode choice model are then scaled to match the specified external station volume. This approach allocates external transit trips to zones that are most accessible by transit.

To model external transit, the input data and route system coding conventions listed below must be met.

- External Transit Values must be specified in the external station table. Values are provided separately for external transit productions (i.e., transit productions located outside of the NFR) and external transit attractions.
- The route system must include a transit route that connects to the external station node. The route must travel along the external station connector to connect directly to the external station. In addition, the route system must contain a route stop at the external station node.

5.3 External Travel Forecasting

Unlike internal growth, the model cannot forecast external station volumes based on model inputs such as zone data and transportation networks. When running the travel model in a forecast year condition, external station volumes must be increased to account for future growth, with forecast external station volumes specified as model inputs. Two possible approaches for forecasting external travel growth are applying external station growth rates based on historical count data (consistent approach with the previous model) or applying future year forecast data from the newly developed StateFocus. NFR Model forecast volumes are based on StateFocus 2045 volumes at the external stations, for locations that are included in the statewide model and that show reasonable results. For external stations that are not included the StateFocus network or that have unreasonable growth rates, 2045 external station volumes were extrapolated based on growth rates assumptions retained from the 2012 NFR Model.

5.3.1 Extrapolation of Observed Growth Rates

External station forecast volumes can be developed using historical traffic count data to develop a linear or compound annual growth rate model. Different growth rates can be applied to each external station based on past growth along with local knowledge about expected growth outside of the model boundary. Previously, annual growth rates at each external station were calculated based on the 20-year growth factor obtained from the CDOT Traffic Data Explorer. This approach was retained for forecasting external station growth for a small subset of external stations, as noted in Table 5.12.

5.3.2 Colorado Statewide Travel Model

To obtain forecast external station volumes, base and forecast year traffic volumes were obtained from the statewide model. Furthermore, the DRCOG model was also evaluated for this same purpose and applied where its forecasts were more reasonable than the Statewide Model. This allowed calculation of growth rates that were applied to the base year volumes to generate external station forecast volumes. **Table 5.12** presents the resulting 2045 external station volumes.

Table 5.12 2045 External Station Volumes

External Station ID	Location	2015 Volume	2045 Volume	CAGR	CAGR Source
3001	SH-14 East	1,625	1,642	0.03%	Statewide Model
3002	SH-392 East	2,649	3,645	1.07%	2012 BY NFRMPO Model
3003	CR-64 East	56	137	3.03%	Statewide Model
3004	SH-263 East	4,148	5,950	1.21%	Statewide Model
3005	US-34 East	14,488	21,445	1.32%	Statewide Model
3006	Weld County Pkwy South	5,937	9,601	1.62%	Statewide Model (nearby stations)
3007	US-85 South	24,939	40,332	1.62%	Statewide Model
3008	CR-19 South	1,480	3,771	3.17%	Statewide Model
3009	CR-13 South	4,844	9,481	2.26%	Statewide Model
3010	I-25 South	88,781	148,791	1.74%	DRCOG Model
3011	SH-66 West	24,184	35,735	1.31%	Statewide Model
3012	US-287 South	23,285	33,758	1.25%	Statewide Model
3013	US-34 West	5,511	9,570	1.86%	Statewide Model
3014	SH-14 West	1,333	1,802	1.01%	Statewide Model
3015	US-287 North	7,311	9,524	0.89%	Statewide Model
3016	CR-15 North	250	496	2.31%	Statewide Model
3017	I-25 North	24,719	39,875	1.61%	Statewide Model
3018	CR-19 North	63	123	2.26%	2012 BY NFRMPO Model
3019	US-85 North	3,007	7,900	3.27%	Statewide Model
4001	US-34 west expanded	3,437	5,701	1.70%	Statewide Model
4002	SH-14 west expanded	1,513	2,158	1.19%	Statewide Model
4003	SH-392 north expanded	860	2,121	3.05%	Statewide Model
4004	WCR-89 North	635	1,145	1.98%	Statewide Model (nearby stations)
4005	WCR-390 North	538	970	1.98%	Statewide Model (nearby stations)
4006	WCR-129 North	563	1,015	1.98%	Statewide Model (nearby stations)
4007	SH-71 North	1,024	1,847	1.99%	Statewide Model (nearby stations)
4008	SH-14 east expanded	1,502	2,068	1.07%	Statewide Model

External Station ID	Location	2015 Volume	2045 Volume	CAGR	CAGR Source
4009	SH-52 east expanded	964	1,352	1.13%	Statewide Model
4010	US-34 east expanded	3,818	7,902	2.45%	Statewide Model
4011	Weld County Pkwy South expanded	5,637	9,116	1.62%	Statewide Model
4012	US-36 west expanded	8,513	11,390	0.98%	Statewide Model
4013	SH-7 west expanded	3,130	6,600	2.52%	2012 BY NFRMPO Model

Source: CAGR = Compound Annual Growth Rates

*Forecasted volumes at external station 3009 were based on DRCOG model volumes.

**Growth rates for external stations 3006 and 4004-4007 were based on the growth rates of nearby stations.

6.0 Trip Generation

Trip generation is the first phase of the traditional four-step travel demand modeling process. It identifies trip ends (productions and attractions) that correspond to places where activities occur, represented by socioeconomic data (households and employment). Trip generation estimates productions and attractions by trip purpose for each TAZ, then balances trips at the regional level so total productions and attractions are equal. In some cases, production and attraction allocation sub-models are applied to better represent the geographic distribution of trip-ends. The resulting productions and attractions by trip purpose and TAZ are subsequently used by the Trip Distribution model to estimate zone-to-zone travel patterns.

The primary data source for estimating trip productions and attractions is the North Front Range portion of the Front Range Travel Counts Household Survey. Since the survey is household-based, it provides excellent information with regard to household trip-making. The survey is especially well suited for estimating trip production rates. The survey also provides good information for estimating trip attraction rates based on participant employment type and attraction place information.

6.1 Socioeconomic Input Data

Trip generation requires household and employment data at the TAZ level. This information is produced by the NFRMPO's UrbanCanvas land use allocation model. UrbanCanvas produces discrete household and job data, geographically located at the Census Block level. The household dataset includes detailed information including household size, income, and number of workers. The employment dataset includes 2-digit North American Industry Classification System (NAICS) codes which can be used to classify employment into the categories used by the trip generation model.

6.1.1 Household Classifications

The trip generation model requires household information classified by two pairs of variables: the first pair being household income vs. size, and the second pair being household income vs. workers. Household sizes are categorized into 1-person households through 5+ person households. Number of resident workers is categorized into 0-worker households through 3+ worker households. Income groups are classified as shown in **Table 6.1**. Because the model is based on 2010 Census data and the household survey was conducted in approximately 2010, income groups are specified in 2010 dollars.

Table 6.1 Income Group Definitions

Income Group	Income Range
Low	\$29,999 and lower
Medium	\$30,000 - \$99,999
High	\$100,000 and higher

Source: NFR 2012 Base Year Regional Travel Model.

6.1.2 Employment Types

The trip generation model utilizes four employment categories. Each of these categories is defined by a set of NAICS codes present in the disaggregate jobs data produced by UrbanCanvas. Employment type groupings are specified in **Table 6.2**, and have generally been retained from the 2012 base year model.

Table 6.2 Employment Type Groupings

NAICS Code	Description	Employment Type
11	Agriculture, Forestry, Fishing and Hunting	Basic / Industrial
21	Mining, Quarrying, and Oil and Gas Extraction	Basic / Industrial
22	Utilities	Basic / Industrial
23	Construction	Basic / Industrial
31		Basic / Industrial
32	Manufacturing	Basic / Industrial
33		Basic / Industrial
42	Wholesale Trade	Basic / Industrial
44	Retail Trade	Retail
45		Retail
48	Transportation and Warehousing	Basic / Industrial
49		Basic / Industrial
51	Information	Service
52	Finance and Insurance	Service
53	Real Estate and Rental and Leasing	Service
54	Professional, Scientific, and Technical Services	Service
55	Management of Companies and Enterprises	Service
56	Administrative and Support and Waste Management and Remediation Services	Service
61	Educational Services	Service
62	Health Care and Social Assistance	Medical
71	Arts, Entertainment, and Recreation	Service
72	Accommodation and Food Services	Retail
81	Other Services (except Public Administration)	Service
92	Public Administration	Service

Source: NFR 2012 Base Year Regional Travel Model, US Census list of NAICS Codes (<https://www.census.gov/cgi-bin/sssd/naics/naicsrch?chart=2017>).

6.1.3 Aggregation and Geographic Processing

UrbanCanvas operates at the Census Block level, but the travel model requires data at the traffic analysis zone (TAZ) level. Many TAZs consist of one or more discrete Census Blocks, but some Census Blocks have been split amongst two or more separate zones. The travel model processes discrete block-based household and job data and aggregates household and job records to TAZs. This procedure requires a correspondence table that identifies the TAZ in which each block is located. In cases where Census Blocks have been split, the correspondence table identifies the proportion of households and employment to be allocated to each zone based on aerial imagery of existing development, along with analysis of zoning, future land use, and developable land area. The result of this process is a TAZ-level table that specifies the number of jobs by type and households by cross-classification category in each zone.

6.1.4 Zone Level Input Data

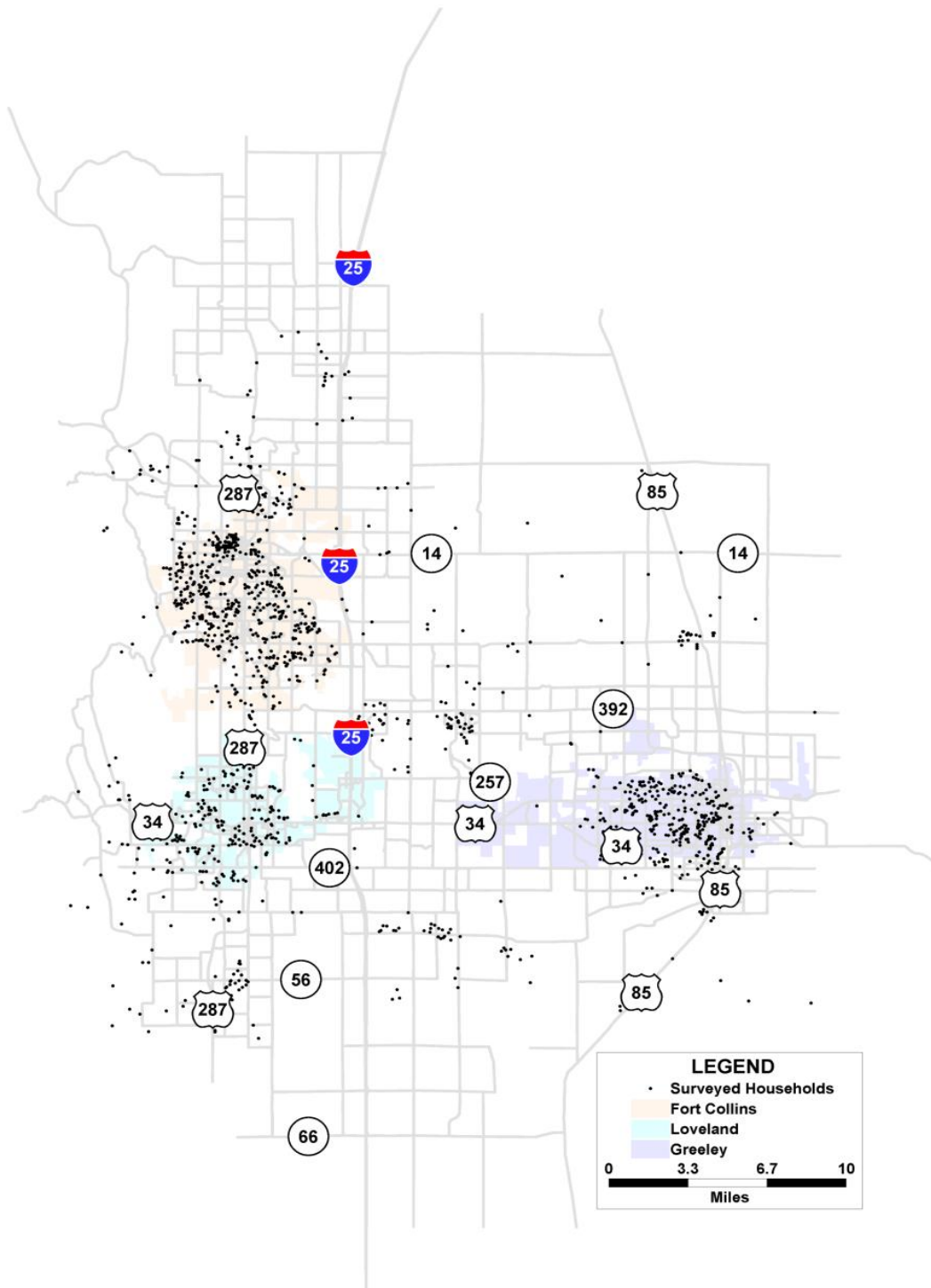
In addition to data produced by UrbanCanvas, the travel model requires K-12 school enrollment data in all applicable TAZs and the number of lodging units for TAZs in the Estes Park area. School enrollment in 2015 is from the National Center for Education Statistics (NCES) and includes all K-12 public schools. New schools planned as of 2018 were included in forecast year datasets. Forecasted enrollment for interim years and the 2045 out year was pulled from district enrollment forecasts, where available, and supplemented with the county-level growth projections developed by the State Demography Office (SDO) for the population aged 17 and under. This information is input to the model directly at the TAZ level.

6.2 Front Range Travel Counts Household Survey

The MPOs and COGs along the Front Range collaborated to conduct a household survey for the entire Front Range between 2010 and 2012. The North Front Range portion of the survey had a total of 2,125 households participate in the survey with 1,505 households providing complete travel data for one assigned day. Household socioeconomic data gathered in this survey includes information on household size, income, vehicle ownership, employment status of each household member, and housing unit type. The survey also collected information about each trip made by members of all participating households, including trip time, mode, activity at each trip-end, and vehicle occupancy. The survey was conducted among randomly selected households using telephone recruitment followed by a diary mail out. A telephone interview was used to collect travel diary information. Households surveyed are shown in **Figure 6.1**.

The survey consultant performed basic quality control of survey data and geocoded all household and trip-end locations in the survey database. The survey process and results are summarized in *Front Range Travel Counts: NFRMPO Household Survey (April 2010)* published by survey consultant NuStats.

Figure 6.1 Front Range Travel Counts– Participating Household Locations



Source: NFR 2012 Base Year Regional Travel Model Documentation.

6.2.1 Survey Weighting and Expansion

The household travel survey provided by the survey consultant included weights for each household. These weights account for probability of selection and adjust for over or under-representation of households by socioeconomic categories. After reviewing household survey totals by socioeconomic categories, it was determined adjustments to the initial weighting factors were required.

To ensure the weighted household data is representative of the regional population, household weights were revised so the weighted distribution of households by household size, number of workers, income, lifecycle, and auto ownership are consistent with distributions obtained from the US Census Bureau. Target distributions were obtained from the American Community Survey (ACS) Public-Use Microdata Samples (PUMS) dataset.

Household weights were adjusted using an iterative proportional fitting (IPF) process. This process iteratively adjusted household weighting factors based on the following five socioeconomic categories:

- Low, medium, and high income;
- Household size (1, 2, 3, 4, or 5+ persons per household);
- Household worker (0, 1, 2, 3+ workers per household);
- Lifecycle stage (Adult non-student non-working, adult non-student working, adult student, and household with children); and
- Auto ownership (0, 1, 2, 3+ vehicles per household).

Following the factoring process, household weights were normalized so the sum of weighted households is equal to the number of participating households. It was also necessary to expand the data to be consistent with the regional household total. A data expansion factor was calculated as the ratio of the total households in each subregion to the total weighted households from the Household Survey. The resulting weighting and expansion factors are shown in **Table 6.3**.

Table 6.3 Household Expansion Factors by Sub-region

Sub-Region	Average Weighting Factor	Expansion Factor
Fort Collins	1.06	103
Greeley	0.81	157
Loveland	0.91	141
Central I-25	1.00	158
Rest of Region	1.38	84
Average Factor	1.00	122

Source: NFR 2012 Base Year Regional Travel Model Documentation.

6.3 Trip Purpose

Trip purpose is used in travel models to categorize various types of trips with similar characteristics, such as trip rates, trip length, and auto occupancy. A separate set of trip generation rates has been developed for each individual trip purpose.

The trip purposes from the previous NFR Model have been expanded to include a home-based school trip purpose for this model update. The specific trip purposes in the NFR Model include:

- **Home-Based Work (HBW):** Commute trips between home and work.
- **Home-Based University (HBU):** Trips between home and university locations (e.g., Colorado State University) for school related purposes by people not employed by the university.
- **Home-Based Shop (HBS):** Trips between home and retail locations for the purpose of shopping.
- **Home-Based School (HBSc):** Trips between home and K-12 school locations for students in these schools.
- **Home-Based Other (HBO):** All other trips that have one end at home.
- **Work-Based Other (WBO):** Work-related trips without an end at home.
- **Other-Based Other (OBO):** Trips with neither an end at home nor a work-related purpose.
- **Lodging-Based Other (LBO):** Trips made by visitors, based at a lodging establishment (Estes Park area only, not included in the household travel survey).
- **Medium Trucks (MTRK):** Medium-heavy truck trips (FHWA Vehicle classes 5-7)
- **Heavy Trucks (HTRK):** Heavy truck trips (FHWA Vehicle classes 8-12)

Survey data was processed to identify 14,631 unique weekday trips reported by survey participants. Survey respondents were asked to report their primary activity at each place visited during the course of one day. These primary activities were used to categorize each trip into one of the purposes used in the travel model, resulting in the total number of trips by each purpose shown in **Table 6.4**, with trips by day of travel shown in **Table 6.5**. Trip purposes were identified based on the origin and destination activity for each trip using the relationship shown in **Table 6.6**. Certain origin/destination trip activity combinations, such as home to home, have been designated as N/A and dropped from the trip rate analysis. Such occurrences were exceedingly rare and did not have a significant impact on overall trip rates. Home-Based University (HBU) trips were not analyzed as part of the survey analysis, since these trips were developed based on the cordon count data collected at Colorado State University and the University of Northern Colorado.

Table 6.4 Weighted and Expanded Trips by Trip Purpose

Trip Purpose	Weekday Trip Records	Weighted & Expanded Trips	Percent of Total
HBW	2,460	259,380	14.9%
HBS	1,850	230,190	13.2%
HBS _c	1,152	160,667	9.21%
HBO	4,530	565,071	32.4%
WBO	1,331	125,887	7.22%
OBO	3,278	400,929	23.0%
N/A	30	2,337	0.13%
Total	14,631	1,744,461	100%

Source: NFR 2012 Base Year Regional Travel Model Documentation, updated by CS to include HBS_c trips and reduce HBO trips.

Table 6.5 Weighted and Expanded Trips by Day of Week

Day of Week	Trip Records	Weighted & Expanded Trips	Percent of Total
Monday	3,149	386,650	22.16%
Tuesday	2,481	342,107	19.61%
Wednesday	3,416	459,186	26.32%
Thursday	2,693	257,839	14.78%
Friday	2,892	298,678	17.12%
Total	14,631	1,744,461	100.00%

Source: NFR 2012 Base Year Regional Travel Model Documentation.

Table 6.6 Trip Purpose Definitions Based on Reported Activity

From Activity\To Activity	Working at home/Other home activities	Work/Work activities	Business related	Shopping/ Drive Thru/ Dining Outside Home	Attending Class or other School Activities	All Other
Working at home/Other home activities	N/A	HBW	HBW	HBS	HBS _c *	HBO
Work/Other work activities	HBW	N/A	WBO	WBO	WBO	WBO
Business related	HBW	WBO	WBO	WBO	WBO	WBO
Shopping/ Drive Thru/ Dining Outside Home	HBS	WBO	WBO	OBO	OBO	OBO
Attending Class or other School Activities (K-12)	HBS _c *	OBO	WBO	OBO	OBO	OBO
All Other	HBO	OBO	WBO	OBO	OBO	OBO

Source: NFR 2012 Base Year Regional Travel Model Documentation, updated by CS to include HBS_c trips.

6.4 Production Rates

Production rates for the NFR Model are based on a detailed analysis of household survey data. Past experience and analysis of survey data has shown trip production rates are generally sensitive to a measure of household size, as well as to a measure of wealth such as income or auto ownership. The decision to vary trip rates by income instead of auto ownership has been retained from previous versions of the model.

An analysis of trip rates by household size and separately by number of workers shows non-work trips tend to vary uniformly by household size. Conversely, work trips tend to vary more consistently by number of household workers. Therefore, non-work trip rates are defined based on household size, while work trip production rates vary by number of household workers.

6.4.1 Income Groups

The survey places each household into a set of fairly detailed income groups. Although useful, there are not sufficient records in the dataset to retain all seven groupings as income categories. Furthermore, analysis of person trip rates for each of the categories suggests aggregation to three income groups: low, medium, and high, as shown in **Table 6.7**. Note that during model validation, the income categories were adjusted based on

Table 6.7 Household Person Trip Production Rates by Income Category

Income Group (Model)	Income Category (Survey)	HBW	HBS	HBO & HBSc	WBO	OBO	All Purposes
Low	\$0 - \$14,999	0.61	0.74	2.00	0.46	1.99	5.80
	\$15,000 - \$19,999	0.59	0.67	2.10	0.30	0.75	4.40
	\$20,000 - \$29,999	1.96	1.53	1.56	0.44	1.23	6.72
Medium	\$30,000 - \$39,999	1.74	0.96	2.94	0.80	1.91	8.35
	\$40,000 - \$49,999	1.82	1.11	4.19	0.67	2.01	9.81
	\$50,000 - \$59,999	1.92	1.23	5.07	1.02	4.30	13.54
	\$60,000 - \$74,999	2.60	0.92	4.90	0.88	2.23	11.54
	\$75,000 - \$99,999	2.44	1.25	5.87	1.06	3.01	13.62
High	\$100,000 - \$134,999	2.06	1.25	5.36	1.07	2.65	12.39
	\$135,000 - \$149,999	2.52	1.48	3.19	1.84	2.30	11.32
	\$150,000 - More	2.38	1.27	4.10	1.06	1.56	10.37
Not Included in Analysis	Not Reported	1.88	1.58	4.10	0.96	2.40	10.92

Source: NFR 2012 Base Year Regional Travel Model Documentation, updated to reflect revised income categories.

6.4.2 Cross-classified Production Rates

Cross-classified trip rates are computed as the mean number of trips per household for each combination of household income and household size/worker category. However, a sufficient number of samples are not available for each combination. A review of mean trip rates, trip rate standard deviations, and trip rate confidence intervals resulted in the grouping of some income and household combinations with small sample sizes and similar trip rates. These grouped production rates are applied to each combination within the group for use in the model. The resulting person trip rates by purpose are shown in **Table 6.8** through **Table 6.13**.

Table 6.8 Trip Production Rates – HBW

	0-worker	1-worker	2-worker	3+ worker	All Workers
Low	0.00	0.79	2.35	2.98	2.04
Medium	0.00	1.10	2.35	2.98	2.14
High	0.00	1.27	2.35	3.06	2.23
All Incomes	0.00	1.05	2.35	3.01	2.14

Source: NFR 2012 Base Year Regional Travel Model Documentation.

Table 6.9 Trip Production Rates – HBS

	1-person	2-person	3-person	4-person	5-person	All Sizes
Low	0.44	1.38	0.66	1.72	2.08	1.06
Medium	0.53	1.40	1.16	1.72	2.08	1.73
High	0.74	1.40	1.16	1.72	2.08	2.02
All Incomes	0.57	1.39	0.99	1.72	2.08	1.71

Source: NFR 2012 Base Year Regional Travel Model Documentation.

Table 6.10 Trip Production Rates – HBSc

	1-person	2-person	3-person	4-person	5-person	All Sizes
Low	0.00	0.22	2.60	1.37	3.73	0.67
Medium	0.00	0.22	1.18	2.23	3.73	0.93
High	0.00	0.06	1.18	2.23	3.73	1.13
All Incomes	0.00	0.15	1.33	2.18	3.75	0.93

Source: CS analysis of household travel survey data.

Table 6.11 Trip Production Rates – HBO

	1-person	2-person	3-person	4-person	5-person	All Sizes
Low	1.15	1.93	1.43	4.02	5.10	1.60
Medium	1.15	2.00	3.17	4.97	6.25	2.64
High	1.40	2.16	3.17	4.97	11.13	3.43
All Incomes	1.22	2.07	2.98	4.86	8.34	2.80

Source: NFR 2012 Base Year Regional Travel Model Documentation, updated to exclude HBSc trips.

Table 6.12 Trip Production Rates – WBO

	0-worker	1-worker	2-worker	3+ worker	All Workers
Low	0.41	0.81	0.89	0.23	0.41
Medium	0.73	0.81	0.89	0.62	0.73
High	0.78	1.20	1.32	0.88	0.78
All Incomes	0.69	1.02	1.18	0.66	0.69

Source: NFR 2012 Base Year Regional Travel Model Documentation.

Table 6.13 Trip Production Rates – OBO

	1-person	2-person	3-person	4-person	5-person	All Sizes
Low	1.24	1.24	1.24	3.25	5.64	1.53
Medium	1.24	1.55	2.37	3.28	5.64	2.19
High	1.24	1.55	2.69	3.28	5.64	2.39
All Incomes	1.24	1.51	2.37	3.27	5.64	2.15

Source: NFR 2012 Base Year Regional Travel Model Documentation.

In model validation, trip rate factors were applied by purpose. These factors, shown in **Table 6.14**, were adjusted so that the regional modeled VMT is consistent with the regional VMT as evidenced by counts. Commute (i.e., HBW) trips are assumed to be reported most accurately because they represent typical every day trips. Home-based non-work and non-home-based trips are assumed to have a higher rate of under-reporting. Because K-12 and university trips are balanced to enrollment-based attraction models instead of household-based trip rates, these trip purposes were not factored.

Table 6.14 Trip Production Rate Factors by Purpose

Trip Purpose	Factor
Commute trips (HBW)	1.35
Other trips (HBS, HBO, WBO, OBO)	1.55
School (HBSc, HBU)	1.0

6.5 Attraction Rates

Attraction rates identify ends of trips which occur at locations other than the trip-maker's home. For home-based trips, the attraction end of a trip occurs at a non-residential location, or occasionally at another person's home. For WBO trips, trip productions occur at the trip-maker's workplace and trip attractions occur at the non-work end of the trip. For OBO trips, trip production and attraction are synonymous with trip origin and destination. For non-home-based trip purposes, allocation models properly locate the production and attraction ends of each trip.

Both a classification model and a regression model were considered for use in development of revised trip attractions rates. After initial estimation of trip rates using both approaches, results from the regression model were selected for use in model application.

Due to the household survey capturing only 14,631 trips, it was not possible to run a regression model at the TAZ level. Instead, TAZs were aggregated into regression districts, shown in **Figure 6.2**. For each trip purpose, the number of trip attractions in each district was input to a regression model as the dependent variable, with employment by type input as the independent variable. For some purposes, the total number of households was also included as an independent variable. For HBSc trips, the trip attraction rate was calculated as the total number of observed HBSc trips divided by the total school enrollment. Trip rates resulting from the analysis are shown in **Table 6.15**.

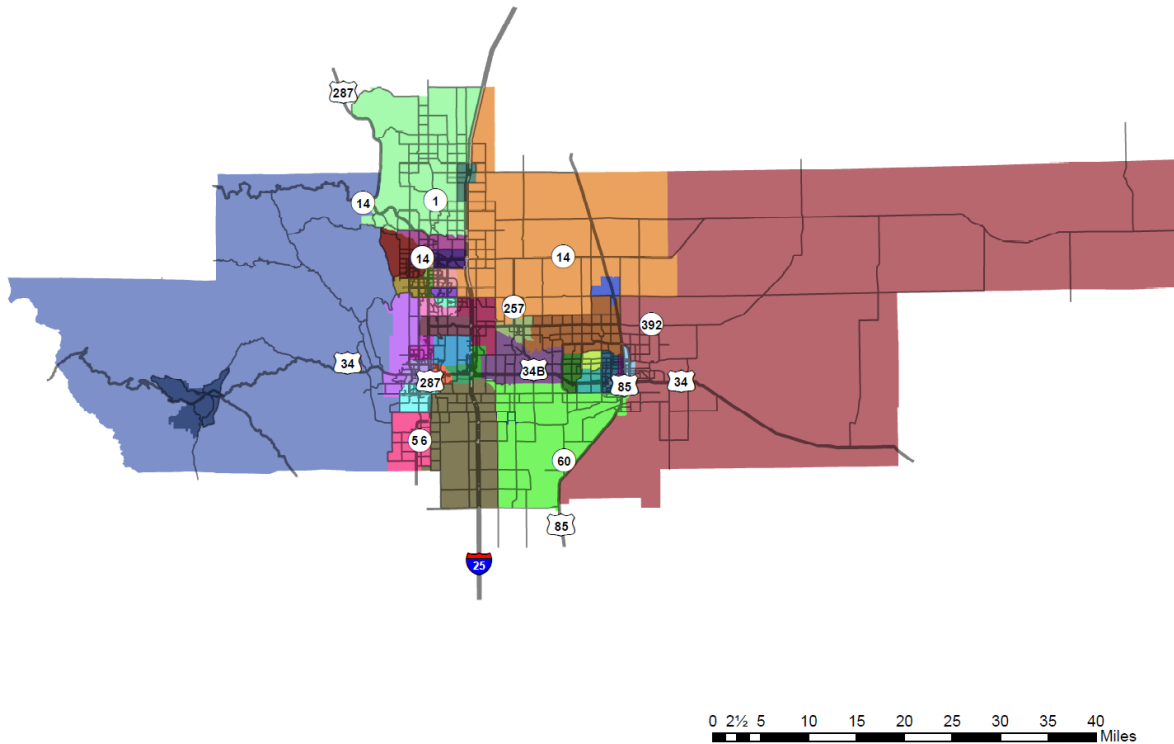
Table 6.15 Trip Attraction Rates

Trip Purpose	Retail Employment	Service Employment	Medical Employment	Basic / Industrial Employment	K-12 School Enrollment	Total Households
HBW	0.88	0.88	0.88	0.88	n/a	n/a
HBS	5.24	n/a	n/a	n/a	n/a	n/a
HBSc	n/a	n/a	n/a	n/a	0.95	n/a
HBO	2.93	0.93	n/a	n/a	n/a	2.60
WBO	0.77	0.35	0.35	n/a	n/a	0.15
OBO	5.72	0.075	0.075	n/a	n/a	0.91

Source: NFR 2012 Base Year Regional Travel Model Documentation, updated to include HBSc trips.

Note: Cells marked n/a were found to be insignificant or were manually excluded from the regression model.

Figure 6.2 Trip Attraction Regression Districts



Source: NFR 2012 Base Year Regional Travel Model Documentation.

During model validation, trip rate factors shown in **Table 6.14** were developed for application to production rates. These factors are also applied to trip attraction rates during model application.

6.6 Non-Home-Based Production Allocation Models

While the model initially generates WBO and OBO trips using household-based production rates, these trip productions occur at non-residential locations. The total number of WBO and OBO productions generated at households is used as a control total for trip balancing, but production allocation rates are used to move non-home-based productions to the appropriate work locations. For WBO trips, trip productions are defined as the work trip end and attractions are defined as the non-work trip end. To accommodate this, separate WBO production allocation rates are input to the model. WBO production allocation rates are based on a regression model, with resulting rates shown in **Table 6.16**. WBO production allocations are then factored by the same area type and subregion adjustment factors applied to WBO attractions.

A simpler approach was taken for OBO trips. OBO production allocation rates are identical to OBO attraction rates, repeated in **Table 6.16** for reference. This approach is possible because there is no distinct difference between OBO productions and attractions. OBO productions and attractions all occur at non-home, non-work locations. OBO production allocation adjustment factors are also identical to OBO attraction adjustment factors.

Table 6.16 WBO Production Allocation Rates

Employment Category	WBO PA	OBO PA
Retail Employment	0.44	5.72
Service Employment	0.62	0.075
Basic/Industrial Employment	0.44	n/a
Medical Employment	0.62	0.075
Total Households	n/a	0.91

Source: NFR 2012 Base Year Regional Travel Model Documentation.

6.7 Expanded Model Area Trip Generation

The NFR Model includes the capability to model expanded portions of Larimer and Weld counties for ozone analysis. Trip generation for the expanded area is performed using a methodology similar to that used for the primary modeling area, with modifications as described in the following section.

6.7.1 Estes Park Adjustments

In the Estes Park area, many trips are made by visitors rather than residents. This is especially true during the summer months when Ozone pollution is most problematic. Based on an analysis of seasonal traffic count data performed when the model was first expanded beyond the MPO boundary, it was determined that summer traffic volumes were reasonably similar to school season traffic volumes for the portion of the model outside of the Estes Park area. While some areas around schools and universities saw higher volumes in the school season, discussions with air quality modelers concluded that differences were not large enough to justify separately calibrating a summer season model outside of Estes Park. Conversely, summer traffic patterns and volumes were observed to be significantly different than non-summer conditions in the Estes Park area. Therefore, the Estes Park portion of the model was calibrated to summer conditions. A large portion of summer travel activity in Estes Park is related to visitor travel and Rocky Mountain National Park. This type of activity is accounted for by the lodging-based trip purpose described below and a national park special generator described in **Section 7.0**.

Zones in Estes Park include an additional socioeconomic variable: hotel/motel rooms. This variable is used to compute lodging-based-other trips, which are limited to the Estes Park area. Lodging-based-other trip production and attraction rates are shown in **Table 6.17**.

Table 6.17 LBO Production Allocation Rates

Socioeconomic Variable	Production Rate	Attraction Rate
Hotel/Motel Rooms	1.68	0
Basic/Industrial Employees	0	0
Retail Employees	0	0.35
Service Employees	0	0.0875
Medical Employees	0	0.0875
Total Households	0	0

Source: NFR 2012 Base Year Regional Travel Model Documentation.

6.8 Trip Balancing

Trip productions and attractions have been estimated separately by purpose using the trip rates and allocation models previously described. While an attempt is made to make the initial estimate of productions equal to the initial estimate of attractions, it is not feasible to make them exactly equal in all scenarios. The balancing process is used to ensure conservation of trips in the model by making the number of productions and attractions equal.

Balancing depends on the level of confidence associated with the initial estimate of productions and attractions. Since trip production rates are based on household survey data, most home-based trip purposes are balanced to trip productions. Two exceptions are the HBSc and HBU trip purposes. HBSc trips are balanced to attractions due to the higher confidence in school enrollment data. HBU trips are balanced to attractions because the special generator studies and cordon counts upon which the CSU and UNC estimates are based provided a more reliable estimate for HBU trip attractions to the university campus.

Non-home-based trips (WBO and OBO) are also balanced to productions. These trips are balanced to the initial estimate of productions from the basic trip rates in the cross-classified trip production model. Then, productions are re-allocated using production allocation models described in this section.

7.0 Special Generators

The NFR Model uses special generators to represent places with a high level of activity that is not well represented by the standard Trip Generation model. These include Colorado State University (CSU), the University of Northern Colorado (UNC), and Rocky Mountain National Park.

What's New

Special generator definitions and methodology remain largely unchanged from the previous 2012 base year model. Special generator values have been updated to reflect updated 2015 base year university enrollment data and Rocky Mountain National Park traffic count data.

7.1 Rocky Mountain National Park

Rocky Mountain National Park collects traffic count data at entrance stations throughout the year. Average summer (June, July, and August) weekday traffic counts, shown in **Table 7.1**, reflect the total number of vehicles entering the park at each of the three entrances included in the travel model. By assuming an equal number of vehicles enter and exit the park each day, the total assumed 2-way traffic is twice the total number of entering vehicles.

Traffic counts represent vehicle trips, but the travel model generates and distributes person trips. As shown in **Table 7.1**, traffic counts are expanded to represent total person trips. Because auto occupancy data at park entrances are not available, this analysis assumes an average vehicle occupancy of 2.2 persons per vehicle entering and exiting the park.

Special generator values are separated by purpose so they can be distributed to zones within the region. Due to a lack of data on trip purpose for park visitors, these assumptions are based on professional judgement and knowledge of the region. These assumptions include:

- 50% of park activity on a weekday is assumed to be matched directly to a lodging establishment. These are represented by lodging-based other (LBO) attractions in the park.
- 20% of activity entering/exiting the park is assumed to be matched to a non-home location, such as nearby restaurants and shops in Estes Park. These are represented by other-based other (OBO) trip-ends in the park, split evenly between productions and attractions.
- 25% of park activity is assumed to be matched to households, represented by home-based other (HBO) attractions in the park.
- 2% of activity is assumed to be park employees traveling to work, represented by home-based work (HBW) attractions.
- 3% of activity is assumed to be made by visitors staying in the park at campgrounds, represented by LBO productions in the park.

Applying the purpose assumptions to the total person trips by entrance results in the special generator values shown in **Table 7.2**. For the Fall River entrance, special generator values are split evenly between the two representative zones.

Table 7.1 Rocky Mountain National Park Special Generator Totals

Entrance Station	Entrance Count	Total Volume	Person Trips
Beaver Meadows (TAZ 1017)	3,297	6,595	14,509
Fall River (TAZ 1018 and 1019)	1,664	3,328	7,322
Wild Basin (TAZ 2100)	236	471	1,036

Source: Rocky Mountain National Park, CS analysis of gate count data.

Table 7.2 Rocky Mountain National Park Special Generator Values

Trip Purpose	Production / Attraction	Beaver Meadows (TAZ 1017)	Fall River (TAZ 1018)	Fall River (TAZ 1019)	Wild Basin (TAZ 2100)
HBW	Productions	0	0	0	0
	Attractions	290	73	73	21
HBS	Productions	0	0	0	0
	Attractions	0	0	0	0
HBSc	Productions	0	0	0	0
	Attractions	0	0	0	0
HBO	Productions	0	0	0	0
	Attractions	3,627	915	915	259
WBO	Productions	0	0	0	0
	Attractions	0	0	0	0
OBO	Productions	1,451	366	366	104
	Attractions	1,451	366	366	104
LBO	Productions	435	110	110	31
	Attractions	7,255	1,831	1,831	518

Source: CS Analysis of gate count data, trip purpose and direction assumptions.

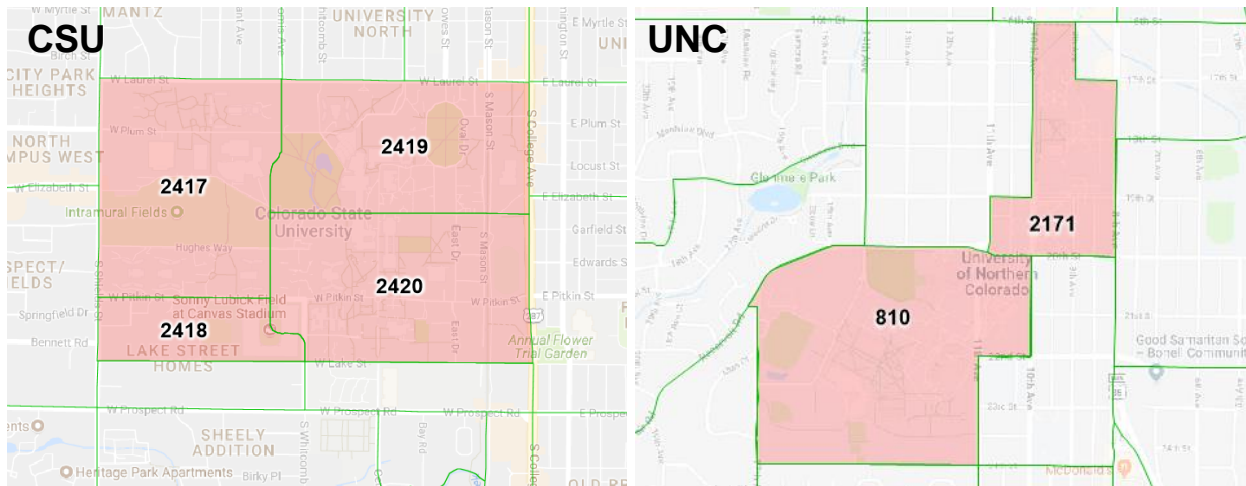
7.2 Universities

The North Front Range is home to two major universities: Colorado State University (CSU) and the University of Northern Colorado (UNC). At both universities, students tend to live on campus or in households concentrated near the university. This suggests a special university trip purpose and allocation model can improve representation of the universities in the travel model.

7.2.1 University Definition

CSU is separated into four TAZs. The west zone includes on-campus residence halls while the east zone includes offices and classrooms. UNC is represented in the model by two zones. **Figure 7.1** shows the definition of the university zones.

Figure 7.1 University Locations



7.2.2 Trip Types at Universities

Because universities do not fall into the normal trip patterns used by the model in the remainder of the region, some special considerations are given to trip types at universities. In particular, the Home-Based University (HBU) trip purpose is defined as a trip by a university student or visitor between an off-campus home and any location on the university campus. Trip ends at the university are associated with university faculty and staff, students living on campus, and students and visitors living off campus. Descriptions of how each trip purpose are addressed at university special generators are presented below.

- **HBW, HBS, and HBO Productions:** These production trip ends at the University can occur only for students living on campus.
- **HBW Attractions and WBO Productions:** These trip ends at the University can occur only for University faculty and staff.
- **WBO Attractions and all OBO Trips:** These trip ends at the University can only occur for students and visitors living off campus.

- **HBS and HBO Attractions:** These trip ends cannot occur at the university. All home-based trips to the university by students and visitors are considered HBU trips and all home-based trips to the university by faculty and staff are considered HBW trips.
- **HBU Productions:** Trips within the university campuses are not modeled, so HBU productions cannot occur on campus.
- **HBU Attractions:** HBU attractions can occur only for students and visitors living off campus.

7.2.3 Employment and Enrollment Data

University trip generation is based on 2015 employment and enrollment totals obtained from each university’s website. Employment data is summarized in **Table 7.3** in units of full time equivalent (FTE) and does not include third-party vendors or contractors. Enrollment data for each university is summarized in **Table 7.4**.

Table 7.3 Employment Data at CSU and UNC

Type	FTE Employment CSU	FTE Employment UNC
Faculty	1,612	476
Staff	3,767	891
Total Employment	5,379	1,367

Table 7.4 University Enrollment Summary

Student Type	CSU Students	% CSU Students	UNC Students	% UNC Students
On-Campus	7,060	26%	3,204	26%
Off-Campus	20,506	74%	9,012	74%
Total Enrollment	27,566	100%	12,216	100%

Source: CSU enrollment data represents resident instruction students in Fall 2015.

<http://irpe-reports.colostate.edu/pdf/ebk/ebkfa15.pdf>

UNC enrollment represents total enrollment in Fall 2015.

https://www.unco.edu/institutional-reporting-analysis-services/pdf/fact-books/UNC_Fall_2016_Fact_Book.pdf

7.2.4 Special Generator Values

Trips for the CSU and UNC special generators are based on special generator studies conducted for CSU in 1999 and UNC in 2004. Trip rates based on the survey are defined in units of trips per on-campus student, trips per off-campus student, or trips per employee. Where data are available, trip rates are based on the study corresponding to each university. However, the CSU special generator survey does not distinguish between different types of non-home-based trips, so trip rates are borrowed from the UNC survey for the WBO and OBO trip purposes. Trip rates and resulting special generator values are shown in **Table 7.5** and **Table 7.6**.

Table 7.5 CSU Special Generator Values

Trip Purpose	Production / Attraction	Trip Rate	Unit	CSU Special Generator Value
HBW	Productions	0.22	On Campus Students	1,353
	Attractions	1.6	Total Employment	6,037
HBS	Productions	0.2	On Campus Students	1,230
	Attractions	n/a	n/a	0
HBU	Productions	n/a	n/a	0
	Attractions	3.8	Off Campus Students	73,203
HBO	Productions	0.5	On Campus Students	3,075
	Attractions	n/a	n/a	0
WBO	Productions	0.37	Total Employment	1,396
	Attractions	0.19	Off Campus Students	3,660
OBO	Productions	0.25	Off Campus Students	4,816
	Attractions	0.25	Off Campus Students	4,816

Table 7.6 UNC Special Generator Values

Trip Purpose	Production / Attraction	Trip Rate	Unit	UNC Special Generator Value
HBW	Productions	0.28	On Campus Students	844
	Attractions	1.47	Total Employment	2,437
HBS	Productions	0.8	On Campus Students	2,413
	Attractions	n/a	n/a	0
HBU	Productions	n/a	n/a	0
	Attractions	3.5	Off Campus Students	33,933
HBO	Productions	1.3	On Campus Students	3,921
	Attractions	n/a	n/a	0
WBO	Productions	0.37	Total Employment	613
	Attractions	0.19	Off Campus Students	1,842
OBO	Productions	0.25	Off Campus Students	2,424
	Attractions	0.25	Off Campus Students	2,424

7.2.5 2045 University Trips

Since university trips are a function of number of students enrolled, not zonal population and employment, future-year forecasts require future enrollment projections. Between 2008 and 2018, CSU experienced a compound annual growth rate of 1.5% per year, slightly faster growth than the City of Fort Collins as a whole. Based on limited information regarding future university enrollment it was assumed the number of students

attending CSU will grow at the same rate as population in the Fort Collins subregion while the number of students attending UNC will remain constant through 2045. The resulting special generator values are shown in **Table 7.7**.

Table 7.7 2045 University Special Generator Values

Trip Purpose	Production / Attraction	CSU Special Generator Value	UNC Special Generator Value
HBW	Productions	2,085	844
	Attractions	9,297	2,437
HBS	Productions	1,893	2,413
	Attractions	0	0
HBU	Productions	0	0
	Attractions	112,734	33,933
HBO	Productions	4,735	3,921
	Attractions	0	0
WBO	Productions	2,148	613
	Attractions	5,636	1,842
OBO	Productions	7,416	2,424
	Attractions	7,416	2,424

8.0 Commercial Vehicles

The NFR Model includes a pair of truck trip purposes representing medium and heavy trucks. These truck trips are generated based on employment data input to the model and are distributed using a gravity model. Trip rates and trip lengths are based on the Front Range Commercial Vehicle Survey (FRCVS)¹⁰. This commercial vehicle survey was conducted in 2015 for the purpose of providing information that can be used to develop truck models in the Front Range of Colorado. This FRCVS was administered by the Denver Regional Council of Governments (DRCOG) on behalf of the four MPOs in eastern Colorado.

The NFR Model defines trucks in two categories, defined below.

- **Medium trucks:** Includes single-unit trucks, FHWA Vehicle Classifications 5-7.
- **Heavy Trucks:** Includes combo-unit trucks, FHWA vehicle classifications 8-13.

The truck model does not address light commercial vehicles, particularly commercial vehicle trips using passenger cars and SUVs, pickup trucks, and 4-wheel vans.

8.1 Truck Trip Rates

The FRCVS included an establishment survey of firms, by industry, where truck trip ends would occur. The firms were selected as part of a statistical sampling plan to ensure that the results would not be biased. As part of that survey, the firms were classified by location. This made it possible to separate out responses from only those firms that are located in the NFR modeling region. The establishments were classified by nine industry types. These industry types and their associated NFR Model employment categories are shown in **Table 8.1**.

Table 8.1 Front Range CVS Establishment Classification and NFR Model Employment Categories

FRCVS Category	NFR Model Category
0=Agriculture	Basic/Industrial
1=Mining	Basic/Industrial
2=Utilities/Construction	Basic/Industrial
3=Manufacturing	Basic/Industrial
4= Wholesale Trade	Basic /Industrial
5= Retail	Retail
6= Transportation	Basic/Industrial
7= Services	Service
8= Education	Service
9= Government	Service

¹⁰ ETC institute, Cambridge Systematics; Front Range Commercial Vehicle Travel Survey Final Report; Denver Regional Council of Governments; March 18, 2016

The FRCVS also identifies the number of employees at each establishment, and the number of truck trips by size (i.e., Single Unit Truck and Combination Unit Trucks), with trip ends at each establishment. This made it possible to establish truck trip rates per employee. The resulting trip rates, grouped into the NFR Model employment categories, are shown in **Table 8.2**. Since the NFR trip generation model also includes a separate medical trip purpose, truck trips for the service category are also applied to medical employment. Trip rates shown are the same for truck trip productions and attractions. For example, each basic employee generates 0.62 medium truck productions and 0.62 medium truck trip attractions, for a total of 1.24 medium truck trip-ends.

Table 8.2 Truck Trip Generation Rates by Employment Category

Employment Type	Medium Truck Trip Rates	Heavy Truck Trip Rates
Basic / Industrial	0.62	0.43
Retail	0.47	0.12
Service / Medical	0.29	0.06

Source: CS analysis of FRCVS Data.

The NFR Model also addresses truck trips at external stations. External truck trips are defined by vehicle classification counts collected or estimated at each of the model's external stations. External station truck volumes and procedures are defined in **Section 5.0**.

8.2 Truck Trip Distribution

The NFR Model distributes truck trips using a gravity model¹¹, which is consistent with guidance in the FHWA's Quick Response Freight Manual (QRFM)¹². The QRFM recommends that the friction factor for trucks should be a negative exponential function of time (in minutes) whose coefficient is the inverse of the average trip length (in minutes). As part of the FRCVS, truck drivers were recruited through a statistical sampling process to participate in a travel diary survey and record details about their travel within the Front Range. The analysis of truck trip survey data was limited to truck trips that began in and ended in the NFR for use in calculation of average truck trip lengths.

The trip survey data classifies trucks using more detailed categories than are appropriate for use in the NFR Model. Furthermore, the survey data includes information about light commercial vehicles that are not addressed directly by the NFR truck model. The resulting average trip lengths, measured in minutes, are shown in **Table 8.3**. These average trip lengths were used to develop an initial set of friction factors for use in the gravity model. Because this data was fairly sparse, it was supplemented with GPS-based commercial vehicle trip data obtained by CDOT to support a study of trucks in the northern portion of the NFRMPO. The calibrated friction factors are shown in **Table 8.4**. Calibration to trip length frequency distributions based on this dataset is demonstrated in **Section 12.2.4**.

¹¹ The gravity model is described in more detail in **Section 9.5** of this report.

¹² Cambridge Systematics, Quick Response Freight Manual, Federal Highway Administration, 2007, <https://ops.fhwa.dot.gov/freight/publications/qrfm2/index.htm>

Table 8.3 Average Truck Trip Lengths (ATL)

Detailed Truck Type	ATL (min)	ATL (min)	Combined Truck Type
Passenger Car or SUV	30.13		
Pickup Truck	15.82	23.11	Light Trucks (not explicitly modeled)
Van (Cargo or minivan) (4 wheels)	19.89		
Single Unit 2-axle	16.52		
Single Unit 3-axle	18.86	18.30	Medium (Single Unit) Trucks
Single Unit 4-axle	34.55		
Single-Unit Cargo	33.69		
Semi (all Tractor- Trailer combinations)	32.81	32.81	Heavy (Combination Unit) Trucks
Grand Total	22.35		

Source: CS analysis of FRCVS Data.

Table 8.4 Truck Friction Factors

Parameter	Medium Truck	Heavy Truck
Alpha	815	815
Beta	0.04	0.04
Gamma	0.00	0.00

9.0 Trip Distribution

Trip distribution is the second phase of the traditional four step travel model. Trip distribution is the process through which trip productions and attractions from the trip generation model are apportioned between all zone pairs in the modeling domain. The resulting trip table matrix contains both intrazonal trips (i.e., trips that do not leave the zone) on the diagonal and interzonal trips in all other zone interchange cells for each trip purpose.

What's New

The 2015 Base Year NFR Model replaces the gravity model with a destination choice model for most trip purposes. The destination choice model better accounts for all possible modes of travel, including both auto and transit modes. The destination choice model also accounts for tolls, HOV lanes, and managed lanes in the trip distribution step of the travel model.

Home-based university (HBU) trips and the new home-based school (HBSc) trip purposes continue to utilize a gravity model formulation. The HBU trip purpose uses a singly constrained gravity model, resulting in a production allocation model that allocates HBU trip productions in areas close to universities. The HBSc gravity model uses a doubly constrained model based on the previous model's home-based other (HBO) model but calibrated specifically to observed HBSc trips.

9.1 Peak and Off-peak Period Definitions

The NFR Model distributes trips occurring during the AM and PM peak hours using peak congested speeds, and distributes trips occurring during off-peak times using off-peak congested speeds. Trip distribution is performed in Production-Attraction (PA) format rather than Origin-Destination (OD) format because the majority of trips in the AM peak period travel from production to attraction (e.g., to work) and the majority of trips in the PM peak period travel from attraction to production (e.g., from work). The model uses directional AM peak period speeds and the resulting travel times, travel distances, and logsum values to compute impedance for both AM and PM peak period trips in PA format.

To implement trip distribution by time of day, factors representing the portion of trips occurring in the combined AM and PM peak period and separately in the off-peak time period are necessary. Trips are further separated into more detailed peak periods during the time of day step prior to traffic assignment. Trip distribution time of day factors based on the 2010 Front Range Travel Counts household survey data are shown in **Table 9.1**.

Table 9.1 Trip Distribution Time of Day Factors

	HBW	HBS	HBU	HBSc	HBO	WBO	OBO
Peak	45%	32%	44%	57%	56%	39%	42%
Off-Peak	55%	68%	56%	43%	44%	61%	58%

Source: CS analysis of household travel survey data and time of day traffic count data.

9.2 Roadway Shortest Path

The roadway shortest path between each zone pair is an important input to the logsums that feed Destination Choice, as well as to the gravity model used for HBSc and HBU trips. The shortest path is determined through pathbuilding, which identifies the shortest route between two network centroids that minimizes an impedance variable. Shortest paths cannot pass through other centroid connectors. Various data, such as path distance, can be *skimmed* along the shortest impedance route. The set of all zone to zone shortest paths is called a *shortest path matrix* and is sometimes referred to as a *skim matrix* with the understanding that the skimmed variable may differ from the impedance variable used to determine the shortest path.

9.3 Impedance Variable

The NFR Model finds the roadway shortest paths between each zone pair based on the generalized cost function shown in the equation below. This function considers congested travel time along with any tolls that may be incurred along a path. The value of time parameter, expressed in 2010 dollars, varies by time period with values shown in **Table 9.2**. Travel time, distance, and toll costs are individually skimmed during the pathbuilding process. It is important to note there are not currently any toll facilities in the NFR region. Therefore, the toll and HOT aspects of the travel model are only applicable in forecast year scenarios that include toll and/or managed lane facilities.

$$GC = Time \cdot VOT + Toll$$

Where:

- GC* = Generalized cost
- Time* = Congested travel time
- VOT* = Value of time (dollars per minute)
- Toll* = Toll in dollars

Table 9.2 Value of Time Parameters

Time Period	Value of Time
Peak	0.24 \$/minute (\$14.40/hour)
Off-Peak	0.18 \$/minute (\$10.80/hour)

Note: Values in 2010 dollars.

Peak congested travel time is defined as the AM peak hour directional travel time, while off-peak travel time is defined as the mid-day congested travel time. Travel times are calculated using a speed feedback process, described in the *Traffic Assignment* chapter.

The toll values incorporated into the generalized cost function are based on tolls identified on the input roadway network and are not adjusted during the speed feedback process. To accommodate managed lanes that are free to vehicles containing at least 2 or at least 3 occupants but charge tolls to other vehicles, separate shortest path matrices are generated for single occupant vehicles (SOV), shared ride 2 (SR2) vehicles, shared ride 3 or more (SR3+) vehicles. Through the logsum calculations described further in **Section 10.2**, the destination choice model accounts for the impact of tolls and managed lanes on trip distribution. The gravity model used for HBSc and HBU trips considers only the SOV paths.

9.3.1 Terminal Penalties

Terminal penalties are applied to the shortest paths to simulate several travel-related variables such as the time to locate a parking space, walk to a final destination, or pay for a parking space. Terminal penalties, shown in **Table 9.3**, are added to both the production and attraction end of each zone pair based on the area type of each zone.

Table 9.3 Terminal Penalties by Area Type

Area Type	Area Type Description	Terminal Time (minutes)
1	CBD	1.5
2	Commercial	1.5
3	Urban	1
4	Suburban	1
5	Rural	0.75

9.3.2 Intrazonal Impedance

Impedance for trips within a zone (intrazonal impedance) is not generated in the zone to zone pathbuilding process because the roadway network is not detailed enough for a sub-TAZ level analysis. Instead, a nearest neighbor procedure is used to approximate intrazonal impedance. The nearest neighbor procedure is applied by taking the travel time or impedance to the nearest TAZ and multiplying that time by a factor. The NFR Model calculates intrazonal impedance and travel time using a factor of 0.75.

9.4 Destination Choice Model

The NFR Model uses a destination choice model to create the trip distribution for the trip purposes listed below. Trip purposes not listed here are distributed using a gravity model, described in **Section 9.5**.

- Home-Based Work (HBW).
- Home-Based Shopping (HBS).
- Home-Based Other (HBO).
- Work-Based (WBO).
- Other-Based (OBO).

The destination choice models are multinomial logit models. Logit models are discrete choice models, which attempt to explain the behavior of individuals making a choice between a finite number of separate alternatives, in this case destination zones. In the logit model, the probability of choosing a particular zone i is given by the following formula:

$$P(i) = \frac{\exp(U_i)}{\sum_j \exp(U_j)}$$

where:

$P(i)$ = probability of choosing zone i

U_i = utility of zone i

exp = exponential function

The utility function U_i represents the relative attractiveness of zone i compared to other zones and is expressed as a linear function:

$$U_i = B_{1i}X_{1i} + B_{2i}X_{2i} + \dots + B_{ni}X_{ni} + \log(A_i)$$

where the X_{ki} variables represent qualitative attributes of alternative i , the decision maker, or the environment in which the choice is made and B_{ki} represents the coefficient reflecting the effect of variable X_{ki} on the utility of zone i . In addition to the qualitative attributes, which describe how good the attractions of zone i are, there is also a quantitative term A_i , which represents the number of individual attractions (jobs, shopping opportunities, etc.) there are within a zone. This term enters the utility in a (natural) logarithm form, which reverses the effect of the exponential term in the probability function, and ensures that if the quantity of attractions in a zone changes by some fixed percentage, the probability of choosing that zone as a destination also changes by that same percentage.

9.4.1 Destination Choice Variables

The destination choice models include both qualitative variables (which describe how good the attractions in a particular zone are relative to other zones) and quantitative variables (which describe how many attractions are found in a particular zone). The qualitative variables included in the various purpose-specific destination choice models include:

Purpose and time period (peak/off-peak) specific mode choice logsum values

For each purpose, peak and off-peak mode choice logsums are computed for every origin-destination pair. In addition, for the Home-Based Work trip purpose, the logsum values are further segmented by income group, with unique values calculated for low, middle, and high household income segments. This logsum value is computed by taking the natural log of the sum of exponential utility values from the mode choice models for each purpose, time period, and (for HBW) income level. This value gives a representation of the overall “level of service” provided between origin and destination zones. It can be interpreted as a (negative) generalized cost of travel across all modes, such that zones with higher logsum values have a better level of service (faster, cheaper, more convenient).

Network Distance

For each purpose, network distance enters the utility function in a piecewise linear form. By using a piecewise linear function, the model is better able to accommodate clear non-linearities in travel behaviors. The breakpoints for the piecewise functions are set at 1, 3, 8, and 12 miles, and have been identified by selecting a group of breakpoints that generally provide a good fit across all trip purposes, to minimize the overall complexity of generating and applying the piecewise function. (Not every trip purpose includes a coefficient change at every breakpoint, but all trip purpose models use breakpoints from this list.)

Intrazonal Indicator

The network distance and mode choice logsum values are generally calculated for all zone-to-zone interchanges, including intrazonal interchanges. However, because of the lower network resolution and high coefficient of variation on trip length for intrazonal trips (i.e., the variance in point-to-point trip length is very large compared to the average trip length), these intra-zonal values are generally susceptible to bias in the estimates for these qualitative measures. To compensate for this potential bias, as well as to capture propensity for or against exceptionally short trips, each destination choice model also includes an indicator variable for intra-zonal destinations. This variable takes on a value of 1 when the proposed destination zone is the same as the origin zone, and zero otherwise.

Destination-Specific Adjustment Factor: Rocky Mountain National Park

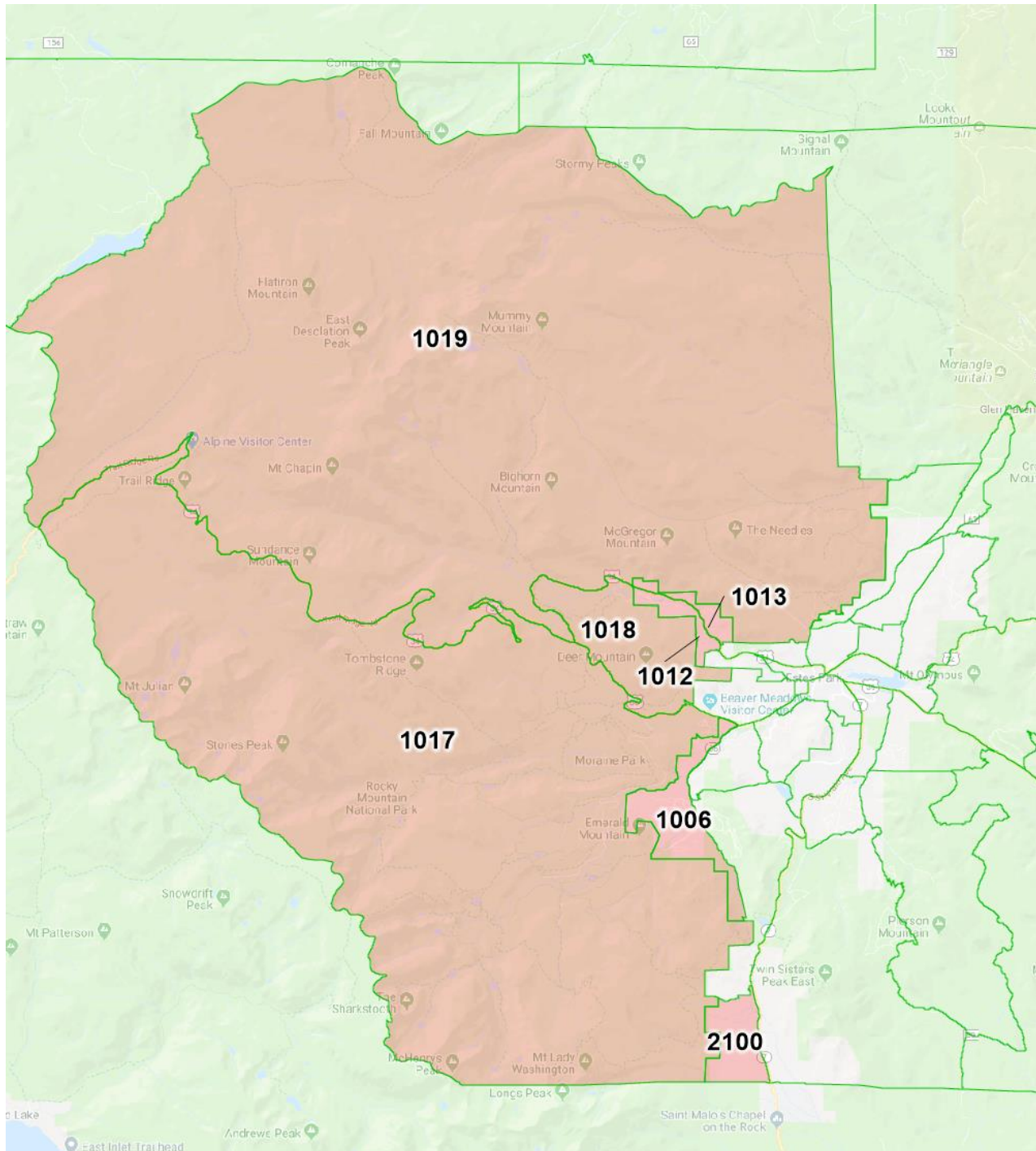
Although *Rocky Mountain National Park* is specifically identified as a special generator and is modeled as having quantitative attractions far in excess of that which would be expected based on land use factors alone, it also is qualitatively different from other places. It tends to attract home-based other and other-based other trips from other zones across the NFR modeling area, at a much greater rate than would be expected for “normal” zones, given the relative inconvenience of traveling to the park. To capture this effect, the zones within and immediately adjacent to the park, shown in **Figure 9.1** (TAZs 1006, 1012, 1013, 1017, 1018, 1019, and 2100), have a binary indicator variable attached, which takes a value of 1 for these zones and 0 otherwise.

Accessibility to Other Attractions

For the home-based work model, the explanatory data includes measure of the number of work-based other attractions located within 3 miles of the destination zone, as measured by highway network distance. This computed value for each destination zone enters the utility function in a piecewise linear form, with break points at 20,000 and 45,000 households within the 3-mile buffer. Zones that have very high accessibility to WBO attractions are modeled as more attractive, as seems intuitive. However, zones that have very low accessibility to WBO attractions (i.e., zones that are more remote) also have greater qualitative attractiveness. While these zones tend to have fewer quantity of attractions, they are able to entice trips from greater distances than average zones. While this variable was found to be significant during model estimation, it was not included in the travel model due to concerns identified during calibration and sensitivity testing.

Each destination choice also includes a quantitative factor, which gives the number of attractions in a particular zone. For each trip purpose model other than Home-Based Work, the number of attractions for each zone is derived from the number of productions computed in the trip generation model. For the Home-Based Work model, the number of attractions is computed conditional on household income category, i.e. the low-income attractions value is used for low income households, and similarly for middle- and high-income households. In each model, the attractions variable enters the utility in logarithmic form, as discussed above, to ensure that the relative probability of zones is consistent with the total number of attractions in that zone.

Figure 9.1 Rocky Mountain National Park Zones



9.4.2 Destination Choice Estimation Results

Destination choice estimation was conducted using data from the Front Range Travel Counts household travel survey. The processed trip data, as developed to support the trip generation model, was combined with logsum and zone to zone distance data produced from a preliminary updated 2012 model run. Estimation results are shown in **Table 9.4** through **Table 9.13**, while **Figure 9.2** demonstrates the piecewise linear distance functions for each trip purpose. In addition, geographic constants were added to the destination choice model, as further detailed in **Section 12.2**.

Table 9.4 Home Based Work Destination Choice Model Parameters

Category	Parameter	Value	Std Err	t Stat	Null Value
Size	log(HBW Attractions)	1	fixed value		
Accessibility	HBW Mode Choice Logsum	0.7155	0.0997	7.17	0.0
Distance	Network Distance, up to 1 mi	-0.7147	0.0998	-7.16	0.0
	Network Distance, 1 to 8 mi	-0.1605	0.0237	-6.78	0.0
	Network Distance, 8 to 12 mi	-0.08737	0.0244	-3.58	0.0
	Network Distance, over 12 mi	-0.05292	0.0108	-4.92	0.0
Other	Intrazonal Indicator [0/1]	0.6446	0.157	4.09	0.0
	WBO Attractions within 3 mi, over 45K*	0.02451	0.00523	4.68	0.0
	WBO Attractions within 3 mi, up to 20K*	-0.04857	0.00343	-14.16	0.0

* WBO Attraction parameters were removed from the model after they were determined to be problematic during sensitivity testing.

Table 9.5 Home Based Work Destination Choice Model Estimation Statistics

Statistic	Aggregate	Per Case
Number of Cases	2273	
Log Likelihood at Convergence	-12600.97	-5.54
Log Likelihood at Null Parameters	-14316.36	-6.30
Rho Squared w.r.t. Null Parameters	0.120	

Table 9.6 Home Based Shopping Destination Choice Model Parameters

Category	Parameter	Value	Std Err	t Stat	Null Value
Size	log(HBS Attractions)	1	fixed value		
Accessibility	HBS Mode Choice Logsum	0.6105	0.609	1.00	0.0
Distance	Network Distance, up to 1 mi	-1.495	0.318	-4.69	0.0
	Network Distance, 1 to 3 mi	-0.5347	0.116	-4.60	0.0
	Network Distance, 3 to 8 mi	-0.4051	0.0696	-5.82	0.0
	Network Distance, 8 to 12 mi	-0.2829	0.0665	-4.25	0.0
	Network Distance, over 12 mi	-0.1103	0.0538	-2.05	0.0
Other	Intrazonal Indicator [0/1]	-0.5635	0.197	-2.86	0.0

Table 9.7 Home Based Shopping Destination Choice Model Estimation Statistics

Statistic	Aggregate	Per Case
Number of Cases	1814	
Log Likelihood at Convergence	-8037.26	-4.43
Log Likelihood at Null Parameters	-10617.61	-5.85
Rho Squared w.r.t. Null Parameters	0.243	

Table 9.8 Home Based Other Purposes Destination Choice Model Parameters

Category	Parameter	Value	Std Err	t Stat	Null Value
Size	log(HBO Attractions)	1	fixed value		
Accessibility	HBO Mode Choice Logsum	1	fixed value		
Distance	Network Distance, up to 3 mi	-0.2927	0.0265	-11.03	0.0
	Network Distance, 3 to 12 mi	-0.2306	0.00864	-26.67	0.0
	Network Distance, over 12 mi	-0.0634	0.00911	-6.96	0.0
Other	Intrazonal Indicator [0/1]	0.9964	0.0699	14.26	0.0
	RockyMtnNatIPark	5.627	0.338	16.65	0.0
	Network Distance, up to 3 mi, High Income*	0.137	0.0378	3.63	0.0

* The separate Network Distance coefficient for high income was not implemented, as this information is not available to the destination choice model.

Table 9.9 Home Based Other Purposes Destination Choice Model Estimation Statistics

Statistic	Aggregate	Per Case
Number of Cases	4174	
Log Likelihood at Convergence	-21086.73	-5.05
Log Likelihood at Null Parameters	-22859.50	-5.48
Rho Squared w.r.t. Null Parameters	0.078	

Table 9.10 Work Based Other Destination Choice Model Parameters

Category	Parameter	Value	Std Err	t Stat	Null Value
Size	log(WBO Attractions)	1	fixed value		
Accessibility	WBO Logsum	0.2158	0.187	1.15	0.0
Distance	Network Distance, up to 1 mi	-0.2149	0.187	-1.15	0.0
	Network Distance, 1 to 3 mi	-0.5178	0.0868	-5.97	0.0
	Network Distance, 3 to 8 mi	-0.2427	0.0366	-6.62	0.0
	Network Distance, 8 to 12 mi	-0.223	0.0504	-4.42	0.0
	Network Distance, over 12 mi	-0.06848	0.0205	-3.35	0.0
Other	Intrazonal Indicator [0/1]	0.5836	0.184	3.17	0.0

Table 9.11 Work Based Other Destination Choice Model Estimation Statistics

Statistic	Aggregate	Per Case
Number of Cases	1124	
Log Likelihood at Convergence	-5948.73	-5.29
Log Likelihood at Null Parameters	-7010.15	-6.24
Rho Squared w.r.t. Null Parameters	0.151	

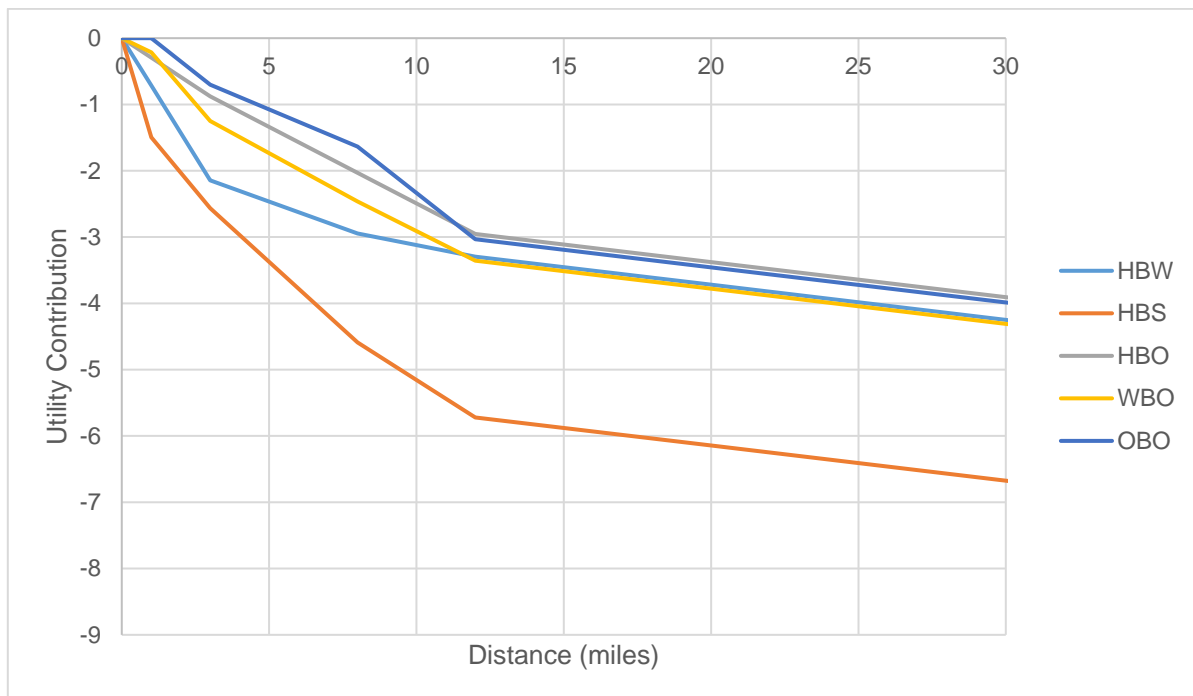
Table 9.12 Other Based Other Destination Choice Model Parameters

Category	Parameter	Value	Std Err	t Stat	Null Value
Size	log(OBO Attractions)	1	fixed value		
Accessibility	OBO Mode Choice Logsum	1	fixed value		
Distance	Network Distance, up to 1 mi	0	fixed value		
	Network Distance, 1 to 3 mi	-0.3503	0.0332	-10.54	0.0
	Network Distance, 3 to 8 mi	-0.187	0.0209	-8.96	0.0
	Network Distance, 8 to 12 mi	-0.3496	0.0306	-11.44	0.0
	Network Distance, over 12 mi	0	fixed value		
Other	Intrazonal Indicator [0/1]	0.9679	0.0823	11.77	0.0
	RockyMtnNatIPark	2.835	1.32	2.16	0.0

Table 9.13 Other Based Other Destination Choice Model Estimation Statistics

Statistic	Aggregate	Per Case
Number of Cases	2666	
Log Likelihood at Convergence	-13343.80	-5.01
Log Likelihood at Null Parameters	-14371.50	-5.39
Rho Squared w.r.t. Null Parameters	0.072	

Figure 9.2 Piecewise Linear Curves (Estimated)



9.5 Gravity Model

The NFR Model uses a gravity model to distribute Home-based School (HBSc) and Home-based University (HBU) trips, as well as Lodging-based Other (LBO) and truck trips (as described in **Section 8.2**). The gravity model applies friction factors to represent the effects of impedance between zones. As the impedance between zones increases, the number of trips between those zones decreases as represented by a decreasing friction factor. The gravity model also assumes that the number of trips between two zones is directly proportional to the number of productions and attractions contained in those zones. The gravity model is defined in the equation below.

$$T_{ij} = P_i \cdot \frac{A_j \cdot F_{ij} \cdot K_{ij}}{\sum_{i=1}^n (A_j \cdot F_{ij} \cdot K_{ij})}$$

Where:

- T_{ij} = trips from zone i to zone j
- P_i = productions in zone i
- A_j = attractions in zone j
- K_{ij} = K-factor adjustment from i to zone j
- i = production zone
- j = attraction zone
- n = total number of zones
- F_{ij} = friction factor (a function of impedance between zones i and j)

For HBSc trips, the gravity model is double constrained. This means that the total number of productions and attractions resulting from trip generation is maintained at the TAZ level. For HBU trips, the gravity model is constrained at the attraction end. As a result, HBU productions associated with each university are allocated based on distance to the university. Zones closer to CSU or UNC will produce more HBU trips than zones farther away from a university.

K-factors are sometimes used in travel demand models to account for nuances in travel behavior and the transportation system cannot be accurately modeled with simplified aggregate modeling techniques. They are typically applied at a district or jurisdictional level to adjust regional distribution patterns. They may be applied by trip purpose or for all trips. The NFR Model includes K-factors to improve external station trip distribution calibration, as further discussed in **Section 12.2**.

9.5.1 Friction Factors

Friction factors represent the impedance to travel between each zone pair. The NFR Model applies friction factors in the form of gamma functions, defined by the equation below, for the HBSc and HBU trip purposes. Gamma function parameters are defined in **Table 9.14**.

$$F_{ij} = \alpha t^{\beta} e^{\gamma t}$$

Where:

F_{ij} = friction factor between zones i and j

t = travel time

α, β, γ = calibration parameters

Table 9.14 Gravity Model Friction Factors

	HBSc	HBU	LBO
Alpha	1000	40	1000
Beta	-1	-0.85	0.85
Gamma	-0.23	-0.001	0.185

10.0 Mode Choice

The NFR Model produces and distributes all person trips including non-motorized, auto, and transit trips. The mode choice model separates the resulting person trip tables into the drive alone, shared ride by occupancy (2 and 3+ occupancy), transit (walk access and drive access), and non-motorized (bicycle and walk) modes. Roadway and transit networks provide important input to the mode choice model and include information about bicycle facilities. The mode choice model considers trip lengths produced by the destination choice model, resulting in sensitivity to higher density and mixed-use areas. Such areas produce shorter trips which are more likely to be made using non-motorized modes.

10.1 Observed Mode Shares

10.1.1 Non-Transit Mode Shares

The mode choice model has been calibrated to reproduce observed mode shares. Observed mode share values for auto trips and non-motorized trips are based on data from the 2010 Front Range Travel Counts household travel survey data shown in **Table 10.1**.

The household survey datasets do not provide sufficient information to develop non-motorized and vehicle mode share targets for the HBU trip purpose. Therefore, university trip shares are instead based on data from special generator surveys conducted at Colorado State University (CSU) in Fort Collins and the University of Northern Colorado (UNC) in Greeley. These surveys included a complete cordon count paired with student/visitor and faculty/staff surveys. The datasets also contain information about university trip mode share. University mode shares from the special generator surveys have been combined into a weighted average, shown in **Table 10.1**.

Table 10.1 Observed Non-Transit Mode Shares

Purpose	DA	SR2	SR3+	Walk	Bike
HBW Low Income	86.4%	5.7%	2.3%	5.1%	0.5%
HBW Medium Income	83.3%	6.7%	2.7%	2.4%	4.9%
HBW High Income	80.2%	6.2%	2.5%	1.7%	9.5%
HBS	43.3%	32.6%	17.7%	4.7%	1.8%
HBU	46.0%	12.2%	6.5%	23.3%	12.1%
HBO	33.7%	27.7%	24.8%	10.8%	3.0%
HBS _c	15.6%	31.9%	33.8%	13.1%	5.5%
WBO	77.6%	7.8%	4.1%	8.3%	2.1%
OBO	36.8%	27.8%	24.9%	9.5%	1.0%

Note: Observed non-transit mode shares are shown as a percentage of person-trips not using transit.

10.1.2 Observed Transit Trips

For transit trips, total transit boardings were obtained from Transfort, Greeley-Evans Transit (GET), City of Loveland Transit (COLT), and CDOT as shown in **Table 10.2**. The boardings cannot be directly used as

mode choice calibration targets because they include transfers and need to be converted to complete origin-to-destination trips, or linked transit trips. The NFRMPO conducted a transit on-board survey in 2008, which identifies the distribution of transit trips by purpose and the average number of boardings per transit trip. This allowed estimation of the total number of linked transit trips by purpose for each transit operator and for the region as a whole, with the exception of Transfort. A more recent Transfort system-wide on-board survey was conducted in October 2017, which has been used to obtain transit targets (distribution of transit trips by purpose and average number of boarding ser transit trip) for Transfort, which has undergone substantial service changes since 2008. **Table 10.3** shows a summary of weighted and expanded on-board survey data, along with information about trip purposes and average transfer rates, scaled up or down to match observed boardings by route system. This information was used to generate updated 2015 mode choice transit calibration targets, discussed later in this Chapter.

Table 10.2 2015 Fixed Route Boardings

Operator	Average Weekday Boardings
Transfort	12,304
Greeley Evans Transit (GET)	2,704
City of Loveland Transit (COLT)	473
Interregional	766
Total	16,247

Source: Data provided by NFR area transit agencies.

Notes: The inter-regional routes FLEX and Bustang are operated by Transfort and CDOT, respectively. GET boardings reflect 2016 service.

Table 10.3 Transit On-board Survey Summary Data

Trip Purpose	Linked Trips	Transfers	Total Boardings	Total Boardings per Linked Trip	% Transfers per Boarding
Transfort					
Home-based Work	2,504	154	2,657	1.06	6%
Home-based Shopping	931	91	1,023	1.10	9%
Home-based University	6,616	94	6,710	1.01	1%
Home-based Other	3,338	232	3,570	1.07	7%
Home-based School	314	38	352	1.12	12%
Work-based Other	1,168	107	1,275	1.09	8%
Other-based Other	3,204	234	3,437	1.07	7%
System Total	18,076	949	19,024	1.05	5%
Greeley – Evans Transit (GET)					
Home-based Work	168	69	242	1.44	28%
Home-based Shopping	127	85	177	1.39	48%
Home-based University	57	26	82	1.43	32%
Home-based Other*	380	176	555	1.46	32%
Work-based Other	131	38	192	1.47	20%

Trip Purpose	Linked Trips	Transfers	Total Boardings	Total Boardings per Linked Trip	% Transfers per Boarding
Other-based Other	223	94	327	1.46	29%
System Total	1,086	488	1,574	1.45	31%
City of Loveland Transit (COLT)					
Home-based Work	80	36	111	1.39	32%
Home-based Shopping	38	23	57	1.51	39%
Home-based University	14	10	19	1.36	52%
Home-based Other*	119	42	175	1.47	24%
Work-based Other	38	26	56	1.48	46%
Other-based Other	37	14	58	1.56	25%
System Total	326	150	476	1.46	32%

Source: Transfort ridership from 2017 on-board transit survey.
GET and COLT ridership from 2008 NFRMPO on-board transit survey.

Note: * COLT and GET on-board survey summaries include HBSc trips in the HBO purpose.

The NFR Model represents two transit access modes: walk access and drive access. Walk access includes all non-motorized transit access, while drive access includes transit trips that make use of a formal park-n-ride. Coinciding with the opening of MAX BRT service in 2015, several formal park-n-ride locations opened along the Mason Street corridor. These park-n-ride lots have been added to the model network and transit skimming process. In addition, the Bustang inter-regional bus service stops at park-n-ride lots located along I-25. Future parking lots were included based on Transfort's Transit Master Plan (2019), the Transit Development Program (TDP), and expected stops for the Great Western Railway.

The 2017 Transfort on-board survey asked about walk and drive access. **Table 10.4** presents the observed share of walk and drive access transit trips. Because further data is not available to quantify the share of walk and drive access trips, the mode share targets assume minimal drive access on COLT and GET routes, and 80 percent drive access on Bustang.

Table 10.4 Observed Walk and Drive Access Shares

Access Mode	Share of Trips
Walk and bike	88%
Drive	12%

Source: 2017 Transfort On-board Survey

Based on the analysis above, regional transit trip targets can be separated into the five available transit modes. Transit service is separated into local, express (FLEX and Bustang), and premium (MAX). Drive access targets are included for express and premium service. Transit calibration targets are shown in **Table 10.5**, expressed as number of linked trips. Transit targets are computed in number of linked trips rather than as a percent share of overall travel to ensure that small changes in trip totals that may occur during model calibration do not change the transit targets that have been developed based on observed data. These targets are combined with the auto and non-motorized mode share targets discussed previously to form a complete set of mode choice calibration targets.

Table 10.5 Resulting Transit Trip Targets

Purpose	Walk to Local	Walk to Express	Walk to Premium	Drive to Express	Drive to Premium	Total Transit Linked Trips
HBW Low Inc	278	161	273	40	114	866
HBW Med Inc	433	251	426	63	178	1,351
HBW High Inc	95	54	92	14	38	293
HBS	480	0	279	0	40	799
HBU	3,639	0	427	0	472	4,538
HBO	1,697	29	702	7	423	2,859
HBSc	160	0	0	0	0	160
WBO	424	58	415	15	116	1,029
OBO	1,139	29	962	7	292	2,430
Total	8,345	583	3,577	146	1,674	14,325

10.2 Mode Choice Model Structure

The NFR Model applies a logit-based mode choice model for all internal trip purposes except for truck trips and LBO trips. The general equation describing a multinomial mode choice is shown in the equation below.

$$P_i = \frac{e^{U_i}}{\sum_m e^{U_m}}$$

Where:

- P_i = the probability of using mode i
- u_i = the utility of mode i
- u_m = the utility of mode m

The logit model is based on the concept of utilities (or disutilities) that describe the characteristics of travel by each mode. The utility function can be made up of impedance variables such as travel time, wait time, and cost as well as locational and socioeconomic variables. Each variable is multiplied by an estimated coefficient that describes the relative weight (positive or negative) of each variable. A mode constant that captures mode preferences not measured by the other utility variables is also added to the utility. Due to the relative nature of the mode constants, the mode constant for one mode must be set to zero. The utility equation applied to each mode is shown below.

$$u_i = c_1X_{1i} + c_2x_{2i} + c_3x_{3i} + \dots + c_nx_{ni}$$

Where:

- u_i = Utility for mode i
- $c_1, c_2, c_3, \dots, c_n$ = Estimated coefficients for variables 1 through n
- $x_{1i}, x_{2i}, x_{3i}, \dots, x_{ni}$ = Values for variables 1 through n

The NFR Model uses a mode choice structure that nests multiple multinomial choices. At the bottom level of the nested logit structure, utility values are computed using the method described for multinomial application. Utilities at the upper level are computed as a combination of utilities for the nested modes (i.e., modes below the upper level choice). An example of a lower level mode is walk, while the corresponding upper level mode is non-motorized. Utilities for intermediate modes are based on the natural log of the sum of exponentiated sub-mode utilities. This term, referred to as the “logsum” variable, is computed as shown below.

$$LS_i = \ln \left(\sum_{j=1}^n e^{u_j} \right)$$

Where:

- LS_i = The logsum of intermediate mode i
- u_j = Utility terms for nested mode j
- n = The number of sub-modes under mode i

Once the logsum variables have been computed for all intermediate modes, mode probabilities are calculated in a manner similar to that described for multinomial logit models. However, for nested modes, utilities are replaced by the product of the logsum and a nesting coefficient as shown in the equation below. The nesting coefficient has a value between zero and one, where a nesting value of zero indicates sub-modes are identical and do not need to be included as separate modes and a nesting value of one indicates sub-modes are distinctly different and could be represented as separate non-nested modes.

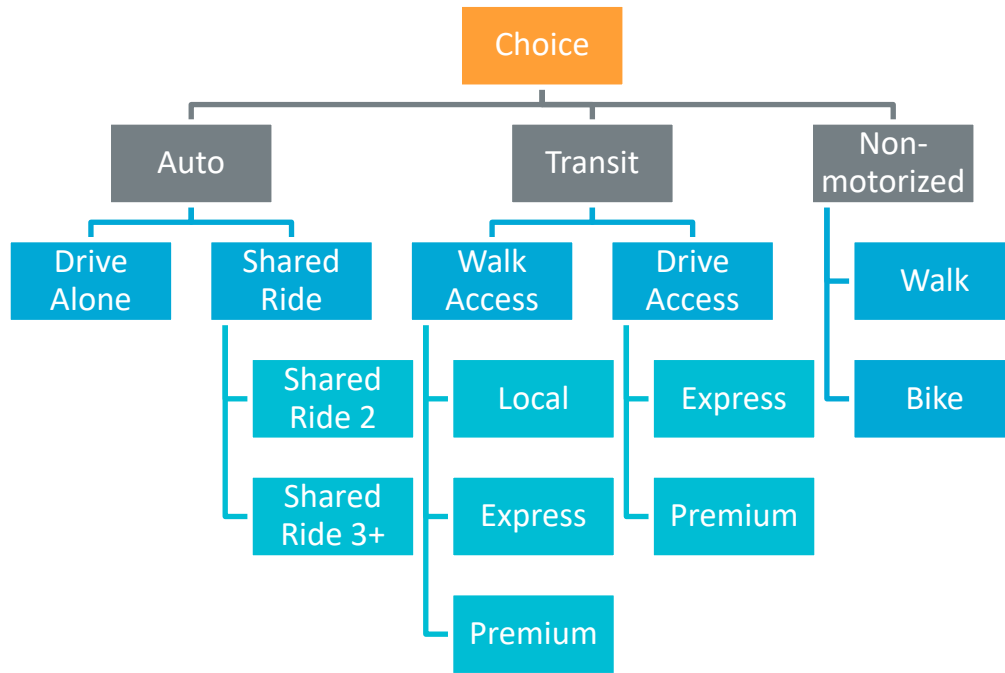
$$P_i = \frac{e^{\theta_i \cdot LS_i}}{\sum_{m=1}^n e^{\theta_m \cdot LS_m}}$$

Where:

- P_i = The probability of selecting intermediate mode i
- θ_i = The nesting coefficient for intermediate mode i
- θ_m = The nesting coefficient for mode m
- n = The number of modes at the same level as mode i

The structure for the NFR mode choice models, shown in **Figure 10.1**, assumes modes, sub-modes, and access modes are distinctly different types of alternatives that present distinct choices to travelers. Within each nest, the model operates on the modes included in the nest as a multinomial logit model. Likewise, the model operates on nests included at a specific nesting level as a multinomial logit model. However, the competition between modes included in different nests or nesting levels is not in proportion to initial estimates of the mode shares. As a result, an important departure from multinomial logit models is “lower level” choices are more elastic than they would be in a multinomial logit model.

Figure 10.1 Nested Logit Mode Choice Structure



The nested logit model employs several multinomial logit models. The first is choice among primary modes: auto, transit, and non-motorized. The second model provides a choice between drive alone and shared ride followed by a choice between shared ride 2 and shared ride 3+. The next model provides a choice between walk and drive access to transit, followed by a choice between walk or drive access and then local, express, and premium. The drive access mode only considers express and premium transit, as on-board data shows that drive access to local transit is minimal in the region. Lastly, the model provides a choice between walk and bike.

In application, utilities are calculated at the bottom levels first and passed up through the nesting structure. When this is complete, the probabilities are estimated from the top of the structure down. Composite utilities are passed upward using “logsum” variables. For example, for composite walk access mode, the “logsum” would be based on walk to local bus, walk to express bus, and walk to premium. Logsums for walk access and drive access to transit are calculated as shown in the equations below.

$$LS_{wacc} = -\ln(e^{u_{wl}} + e^{u_{we}} + e^{u_{wp}})$$

$$LS_{dacc} = -\ln(e^{u_{de}} + e^{u_{dp}})$$

The logsum terms for the walk access and drive access modes would then appear in the multinomial choice model for transit access as follows:

$$P_{wacc} = \frac{e^{B_1 \cdot LS_{wacc}}}{e^{B_1 \cdot LS_{wacc}} + e^{B_1 \cdot LS_{dacc}}}$$

Where:

- P_{wacc} = the probability that a traveler will use walk access to transit, given she has already decided to use transit
 B_1 = the nesting coefficient for the lower (first) level nest

While there have been attempts to estimate mode choice model coefficients and constants using a combination of household and on-board survey data, transit service in the region is not currently varied enough to allow estimation. Therefore, mode choice coefficients are consistent with guidance provided by the Federal Transit Administration (FTA). This guidance, summarized in **Table 10.6**, specifies allowable ranges for certain model coefficients. The NFR Model uses coefficient values that fall mid-way between the minimum and maximum recommended coefficients.

Table 10.6 New Starts Coefficient Guidelines

Coefficient	Minimum Value	Maximum Value
In-Vehicle Travel Time (IVTT)	-0.030	-0.020
Out of Vehicle Travel Time (OVTT)	-0.090	-0.040

Note: Guidance states that the coefficient for out of vehicle travel time should be between 2 and 3 times the in-vehicle travel time coefficient.

Market Segmentation

The updated NFR Model utilizes market segmentation to more accurately model transit ridership. Market segmentation by walk access and egress distance is used to provide a finer level of detail in the walk to transit modes. Market segmentation by income is used to more accurately identify potential transit riders, as the on-board survey indicated members of low-income households are more likely to use transit. Segmentation of markets into three walk access categories, three walk egress categories, and three income groups results in 27 different transit markets for the home-based work trip purpose. Additionally, the nine walk access/egress markets demonstrated in **Table 10.7** are included for other trip purposes. The mode choice models are applied once for each of these markets.

Segmentation by walk access is vital to the correct implementation of a mode choice model. This importance can be illustrated by the application of a mode choice model to a 1 square-mile zone with access to transit along one edge. Without market segmentation, all residents in the zone would be assumed to have access to transit with a ½ mile walk access resulting in minimal transit ridership in this zone. With market segmentation, some residents would be assumed to have very short walk access lengths, some medium access lengths, and the remainder long (over ½ mile) access lengths. This scenario results in more realistic representation of actual conditions. A similar example could be applied to walk egress market segmentation.

The walk access/egress segmentation model is further enhanced by use of Census block level data to determine the portion of zonal data within each walk access segment. This level of detail can be achieved because the MPO's land use allocation model produces data at the Census block level. The model includes a GIS process which separates TAZ data into three access/egress market segments. This has the effect of more appropriately representing concentrated densities often associated with multi-family dwelling units

(apartments or condos) or transit-oriented development. For example, a large zone consisting of mainly low-density housing with a transit-oriented development on one end would be accurately represented by the walk access/egress market segmentation model due to use of block level data.

Table 10.7 Walk Access and Egress Market Segments

Access/Egress	Short Egress	Medium Egress	Long Egress
Short Access	1	2	3
Medium Access	4	5	6
Long Access	7	8	9

Note: Short, medium, and long access and egresses are defined as less than ¼ mile, ¼ to ¾ mile, and more than ¾ mile, respectively.

FTA guidelines suggest using an implied value of time between ¼ and 1/3 of income. Implied value of time is a measure of monetary value placed on time spent traveling. Value of time in cents per minute can be computed by dividing the bottom-level utility for in-vehicle travel time (in minutes) by the bottom-level utility for cost (in cents). The NFR Model uses cost coefficients resulting in an implied value of time of ¼ of the average income for the low-income market segment and 1/3 of the average income for medium and high-income market segments. The three income groups included in the income market segmentation model are defined in **Table 10.8**.

Table 10.8 Income Market Segmentation

Income Group	Annual Income Range	Assumed Average Income	Implied Value of Time (\$/hour)	Resulting Coefficient
Low	Less than \$20,000	\$17,233	2.4	-0.621
Medium	\$20,000 – \$74,999	\$49,914	7.0	-0.214
High	\$75,000 or greater	\$88,302	12.4	-0.121

Note: The long-term values of time utilized in mode choice are set separately from short-term values of time used for roadway pathbuilding and traffic assignment. Values of time are carried forward from the previous model and do not reflect revised income categories applied during model validation.

Production and Attraction Density Variables

To increase sensitivity of the travel model to transit-oriented development, production and attraction density variables are included in the utility equations. Density is computed in each zone based on a combination of household and employment data. A weight is applied to employment data based on the ratio of total households to employees in the base year socioeconomic dataset. The production density variable was specified to provide ¼ of the effect of the CBD attraction dummy variable in a zone with an activity density of 20 units per acre. Density for each zone is computed as shown below. Test runs performed during model validation confirmed these density variables have a beneficial effect on transit mode choice validation.

$$Density_i = \frac{HH_i + EMP_i \cdot \frac{\sum_{Zones} HH_i}{\sum_{Zones} EMP_i}}{Area_i}$$

Where:

HH_i = total households in zone i
 EMP_i = total employment in zone i
 $Area_i$ = area of zone i in acres

Model Specification

The utility equations for the mode choice model follow. The coefficient designations (e.g., C_{ivtt} for Coefficient of in-vehicle travel time) rather than the actual model coefficients are shown to aid in the understanding of the model specification. The actual model coefficients are shown in **Table 10.9**. Model constants (K_m) calibrated to reproduce observed mode shares in the North Front Range are shown in **Table 10.10**.

Drive Alone Utility:

$$U_{DA} = C_{IVTT} \cdot IVTT_{drive} + C_{OVTT} \cdot TTIME + C_{Cost(income)} \cdot \left(CPM \cdot Dist + \frac{Park8}{2} \right)$$

Shared Ride 2 Utility:

$$U_{SR2} = C_{IVTT} \cdot (IVTT_{drive} + Form) + C_{OVTT} \cdot TTIME + C_{Cost(income)} \cdot \left(CPM \cdot Dist + \frac{Park8}{2} \right) + C_{CBD(SR)} \cdot CBD + K_{SR}$$

Shared Ride 3+ Utility:

$$U_{SR2} = C_{IVTT} \cdot (IVTT_{drive} + Form) + C_{OVTT} \cdot TTIME + C_{Cost(income)} \cdot \left(CPM \cdot Dist + \frac{Park8}{2} \right) + C_{CBD(SR)} \cdot CBD + K_{SR} + K_{SR3}$$

Note: the cost terms are divided by 2 for SR2 and by 3.1 for SR3+.

Walk to Transit Utilities (PWL, PWE, PWP):

$$\begin{aligned}
 U_{PWL} = & C_{IVTT} \cdot IVTT_{transit} \\
 & + C_{OVTT} \cdot WalkAccessTime \\
 & + C_{OVTT} \cdot WalkEgressTime \\
 & + C_{OVTT} \cdot \min(WaitTime, 7.5) \\
 & + C_{LWAIT} \cdot \max(WaitTime - 7.5, 0) \\
 & + C_{OVTT} \cdot XferTime \\
 & + C_{Cost(income)} \cdot Fare \\
 & + C_{CBD(mode)} \cdot CBD \\
 & + C_{Pdensity(mode)} \cdot \sqrt{Pdensity} \\
 & + C_{Adensity(mode)} \cdot \sqrt{Adensity} \\
 & + K_{TRN} + K_{mode}
 \end{aligned}$$

Drive to Transit Utilities (PDE, PDP):

$$\begin{aligned}
 U_{PDE} = & C_{IVTT} \cdot (IVTT_{transit}) \\
 & + C_{OVTT} \cdot DriveAccessTime \\
 & + C_{OVTT} \cdot WalkEgressTime \\
 & + C_{OVTT} \cdot \min(WaitTime, 7.5) \\
 & + C_{LWAIT} \cdot \max(WaitTime - 7.5, 0) \\
 & + C_{OVTT} \cdot XferTime \\
 & + C_{Cost(income)} \cdot (Fare + CPM \cdot Dist) \\
 & + C_{CBD(mode)} \cdot CBD \\
 & + C_{Pdensity(mode)} \cdot \sqrt{Pdensity} \\
 & + C_{Adensity(mode)} \cdot \sqrt{Adensity} \\
 & + K_{TRN} + K_{mode} + K_{DACC}
 \end{aligned}$$

Walk Utility:

$$\begin{aligned}
 U_{Walk} = & C_{WALK} \cdot TT_{walk} \\
 & + K_{mode}
 \end{aligned}$$

Bike Utility:

$$\begin{aligned}
 U_{Bike} = & C_{BIKE} \cdot IMP_{bike} \\
 & + K_{mode}
 \end{aligned}$$

Where:

$IVTT_{transit}$	= Transit in-vehicle travel time
$IVTT_{drive}$	= Drive in-vehicle travel time
$TTIME$	= Terminal time in minutes
CPM	= Auto operating cost per mile in cents
$Dist$	= Distance traveled in miles
$Park8$	= Daily (8-hour) parking cost in cents
$Form$	= Carpool formation time
CBD_{mode}	= CBD Attraction dummy variable for the specified mode (1 if attraction TAZ has is in the CBD, 0 otherwise)

<i>Pdensity</i>	= Production zone activity density in activity per acre
<i>Adensity</i>	= Attraction zone activity density in activity per acre
<i>AAO</i>	= Average auto occupancy
<i>AccessTime</i>	= Walk or drive access time
<i>EgressTime</i>	= Walk egress time
<i>WaitTime</i>	= Initial wait tie for transit in minutes
<i>XferTime</i>	= Transfer wait time in minutes (1/2 of the headway of the route being boarded)
<i>Fare</i>	= Transit fare in cents (average rate paid by all riders)
<i>TT_{walk}</i>	= Walk time
<i>IMP_{bike}</i>	= Bike impedance, weighted by bicycle facility type
<i>C_x</i>	= Coefficient for variable “x”
<i>K_{TRN}</i>	= Transit Constant
<i>K_{DACC}</i>	= Drive Access Constant
<i>K_{mode}</i>	= Constant for specified mode (i.e., express or premium)

Table 10.9 Mode Choice Model Coefficients

Coefficient	Value
In-Vehicle Travel Time (IVTT)	-0.025
Out of Vehicle Travel Time (OVTT)	-0.050
Long wait time (LWAIT)	-0.125
Cost (low income, HBU)	-0.621
Cost (med income)	-0.214
Cost (high income)	-0.121
CBD Dummy (Shared Ride)	0
CBD Dummy (Walk Access)	0.010
CBD Dummy (Drive Access)	0.010
Production Density (Shared Ride)	0.022
Production Density (Walk Access)	0.184
Production Density (Drive Access)	0
Attraction Density (Shared Ride)	0.066
Attraction Density (Walk Access)	0.552
Attraction Density (Drive Access)	0.552
Walk Time (TT)	-0.05
Bike Time (TT)	-0.15
Access Mode, Share-Ride Nesting Coefficient	0.7
Sub-mode nesting coefficient	0.5

Note: Mode choice coefficients are scaled to represent values at the top level of the nested logit structure to facilitate comparison to other mode choice models.

Table 10.10 Mode Choice Model Constants

Mode	HBW Low Income	HBW Medium Income	HBW High Income	HBU	HBS	HBO	HBSc	WBO	OBO
Drive Alone	0	0	0	0	0	0	0	0	0
Shared Ride	-10.94	-2.36	-2.22	-3.86	-0.43	-0.34	-0.34	-1.99	-0.37
Shared Ride 3	-2.77	-0.31	-0.50	3.10	0.05	0.58	0.30	0.05	0.34
Transit	-6.58	-7.39	-8.22	-5.25	-7.69	-7.55	-5.36	-8.52	-8.01
Drive Access	3.26	2.08	1.34	0.92	1.34	1.98	1.98	2.86	3.18
Express	-3.60	1.48	1.45	1.78	-1.33	-1.85	-1.85	0.15	-2.21
Premium	0.51	0.68	0.65	-1.40	0.14	0.74	0.74	0.29	-0.09
Walk	-2.06	-0.69	0.36	0.05	-1.46	-0.15	-0.92	-1.68	-1.88
Bike	-0.08	-0.84	-0.48	0.93	-0.47	1.11	0.27	-0.44	-0.07

Auto Occupancy

Once person trips have been separated into the different available modes, it is necessary to convert person trips in vehicles to vehicle trips. This is accomplished through use of an auto occupancy factor. Each drive alone person trip is equivalent to one vehicle trip, and every two SR2 person trips are equivalent to a vehicle trip. Average auto occupancy for SR3+ trips is assumed to be 3.1.

10.3 External Transit

The NFR Model accounts for external transit as described in Section 5.2.3.

11.0 Trip Assignment

Trip assignment is the final phase of the four-step travel model. Trip assignment includes a process where person trips from mode choice are converted into directional vehicle trips by time of day, followed by identification of specific paths taken by vehicle and transit trips. The resulting traffic volumes and transit boarding data are available for peak hours, peak periods, and for a 24-hour period. Due to limited data, trips made with non-motorized modes are not assigned to the network.

Because the travel model represents a typical school day, traffic volumes are representative of a typical weekday when school is in session. When running the expanded model, traffic volumes in the Estes Park area are reflective of a typical summer weekday. The remainder of the modeling area, including the expanded Weld County area continues to reflect a typical school-season weekday.

When the model is run with speed feedback enabled, travel times resulting from traffic assignment are fed back to trip distribution. The model is then run iteratively until speeds input to trip distribution are reasonably consistent with speeds resulting from traffic assignment.

What's New

With this model update, time of day assumptions have been revised to better reflect analysis of traffic count data gathered for this project. Specific changes include:

- Revision of the PM peak period definition to fall on the hour instead of on the half-hour.
- Revision of peak hours within the AM and PM peak periods based on count data rather than survey data.
- Replacement of the one-hour mid-day peak hour with a longer mid-day peak period.
- Updates to the share of traffic in each time period, consistent with available count data. This results in the AM peak period being considerably less congested overall than the PM peak period.

The traffic and transit assignment procedures in this version of the model remain relatively unchanged from the 2012 base year model. Some roadway capacities have been updated, and volume delay function parameters have been revised. Consistent with changes to mode choice, shared-ride 2 and shared-ride 3+ vehicles are now assigned separately.

11.1 Time of Day

11.1.1 Time Period Definitions

Based on the analysis of the household travel survey along with traffic count data for 2013-2017, the NFR Model includes a two-hour AM peak period, a six-hour mid-day period, and a four-hour PM peak period as defined in **Table 11.1**. Peak hours and shoulder periods are defined based on analysis of trip mid-points occurring in each half-hour period throughout the day as reported in the household travel survey, combined with analysis of available traffic count data.

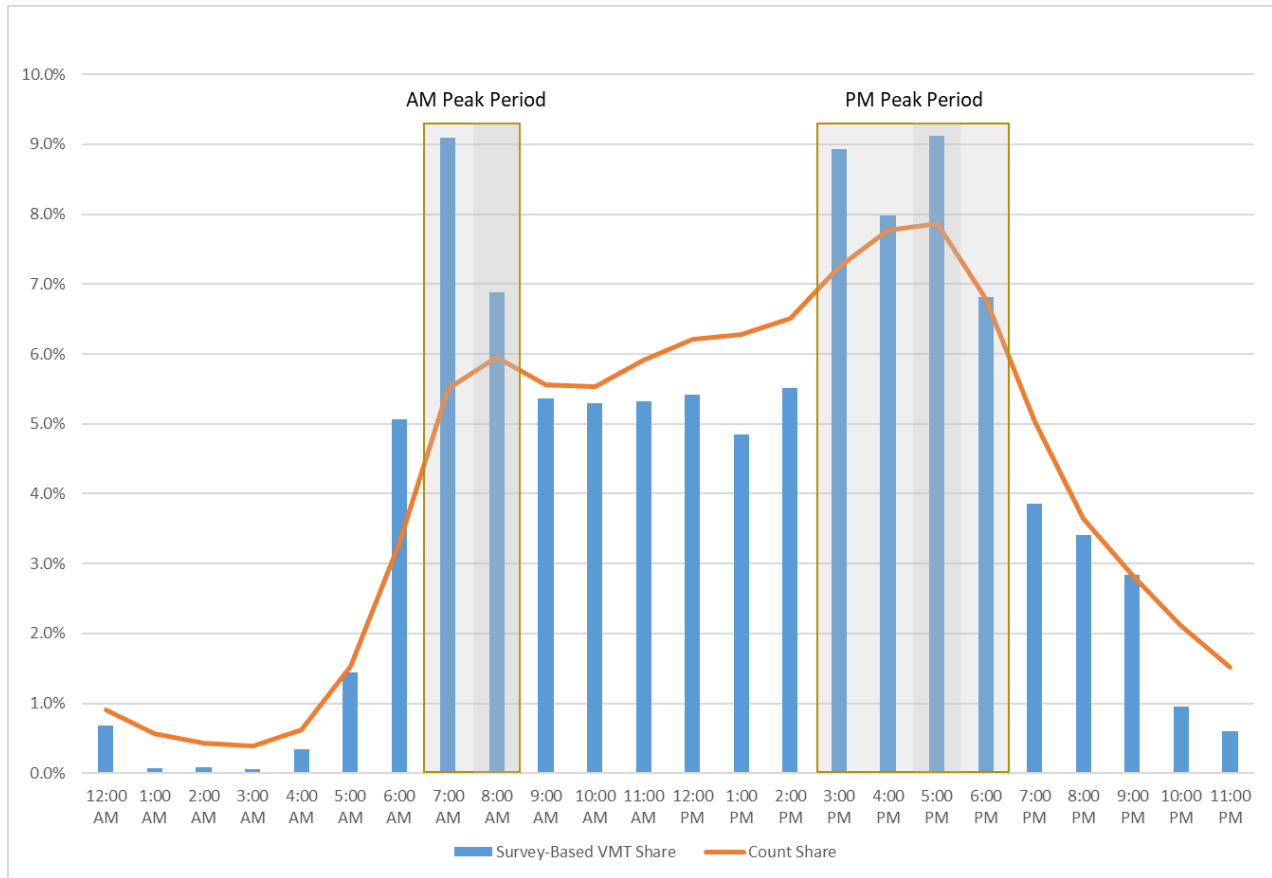
Table 11.1 Travel Model Time Periods and Sub-Periods

Period Name	Time Period	Description
AM	7:00 AM – 9:00 AM	AM Peak Period
AM1	7:00 AM – 8:00 AM	AM Peak Hour
AM2	8:00 AM – 9:00 AM	AM Peak Hour
PM	3:00 PM – 7:00 PM	PM Peak Period
PM1	3:00 PM – 4:00 PM	PM Shoulder
PM2	4:00 PM – 5:00 PM	PM Shoulder
PM3	5:00 PM – 6:00 PM	PM Peak Hour
PM4	6:00 PM – 7:00 PM	PM Shoulder
MD	9:00 AM – 3:00 PM	Mid-Day Period
OP	7:00 PM – 7:00 AM	Off-Peak Period

Source: NFR Travel Model.

To define time of day for each trip in the household survey, reported vehicle trips were multiplied by zone to zone distance to produce an observed distribution of VMT for each hour. Separately, traffic count data was summarized for all locations where time of day traffic data were available, weighted by facility type to account for different levels of count coverage. As demonstrated in **Figure 11.1**, there are distinct differences between the VMT distribution from the household survey and the distribution of traffic count volumes by time of day. The survey suggests that activity levels in the AM peak hour are similar to or higher than in the PM peak hour. Conversely, traffic count data show considerably lower volumes in the AM peak period. In addition, traffic count data show a higher amount of activity happening during the mid-day period than would be expected based on household survey data.

Figure 11.1 Observed Time of Day Distributions



Source: CS and FHU analysis of traffic count data and household travel survey data.

Causes of the differences between household survey data and traffic count data may include under-reporting of certain trips or trips at certain times of day, changes in time of day patterns between the time the survey was conducted and the 2015 base year, or systematic errors in the traffic count dataset. The somewhat arbitrary nature of locations where count data were available may also have contributed to these differences. Because the traffic count dataset was collected passively (i.e., did not rely on participants to self-report) and at numerous independent locations, it is assumed that the time of day distribution represented by traffic count data is more reliable than the distribution developed based on survey data. Therefore, time of day parameters developed based on the survey were modified during model validation so that modeled VMT distributions by time period are consistent with traffic count data.

The travel model assigns all off-peak trips in a single off-peak period and assigns mid-day trips in a single mid-day period. However, some model users may desire to separate off-peak and mid-day model results into different times of day. This is particularly important in modeling ozone precursors, as varying temperatures throughout the day impact ozone generation. **Table 11.2** provides further detail about off-peak and mid-day VMT by time of day for use in such applications.

Table 11.2 Off-Peak and Mid-Day VMT Distribution by Time of Day (count-based)

Time Period	Description	Off-Peak VMT Percentage
12:00 AM – 7:00 AM	Early Morning Off-Peak	33.8%
7:00 PM – 12:00 AM	Evening / Late Off-Peak	66.2%
9:00 AM – 10:00 AM	Mid-day 1	15.4%
10:00 AM – 11:00 AM	Mid-day 2	15.4%
11:00 AM – 12:00 PM	Mid-day 3	16.4%
12:00 PM – 1:00 PM	Mid-day 4	17.3%
1:00 PM – 2:00 PM	Mid-day 5	17.4%
2:00 PM – 3:00 PM	Mid-day 6	18.1%

Source: CS and FHU analysis of traffic count data.

11.1.2 Directional Time of Day Factors

The NFR Model uses directional time of day factors to convert trips from production to attraction (PA) format to origin to destination (OD) format and into the time periods described previously. This process is based on data from the household travel survey indicating that trips are made directionally by time of day. For example, HBW trips generally occur from the production to the attraction (i.e., from home to work) in the AM peak and from the attraction to the production (i.e., from work to home) in the PM peak. It is also recognized some trips are made in the reverse of this pattern and many trips are made outside of peak periods, so the factors represent this activity as well as the predominant movements.

In the travel model, time of day factors are applied directly to purpose-specific vehicle trip tables created by the mode choice model. As described in the **Section 9.1**, daily trip tables are separated into peak period (combined AM and PM peak periods) and off-peak (combined mid-day and off-peak) period trips during trip distribution. The traffic assignment time of day module further separates peak period trips into AM and PM peak period trips and off-peak trips into mid-day trips and other off-peak trips. During this conversion, trip tables are also converted from PA format to OD format. Peak period trips are then separated into sub-periods later in the process.

Time of day factors shown in **Table 11.3** identify the portion of trips by purpose and direction assigned to each time period. These detailed factors were initially created using the household travel survey, as traffic count data does not contain the trip purpose and direction information necessary to develop this table. Initial time of day factors were then adjusted in an iterative process so that VMT resulting from traffic assignment was consistent with the time of day distribution developed based on traffic count data. The factors in **Table 11.3** are split and applied in a two stage process: first in a pre-distribution time of day module and second in a pre-assignment time of day module. The pre-distribution time of day parameters are defined in **Section 9.1** and are repeated in **Table 11.4** for reference. The pre-assignment time of day parameters are shown in **Table 11.5**.

Table 11.3 24-Hour Time of Day Factors

	HBW P to A	HBW A to P	HBS P to A	HBS A to P	HBU P to A	HBU A to P	HBO P to A	HBO A to P	HBSc P to A	HBSc A to P	WBO P to A	WBO A to P	OBO P to A	OBO A to P
AM	0.133	0.010	0.015	0.006	0.123	0.005	0.077	0.034	0.268	0.001	0.018	0.070	0.025	0.025
PM	0.044	0.266	0.116	0.183	0.055	0.256	0.155	0.171	0.026	0.278	0.262	0.041	0.183	0.183
MD	0.194	0.126	0.215	0.278	0.298	0.169	0.221	0.169	0.078	0.157	0.370	0.174	0.247	0.247
OP	0.139	0.087	0.042	0.145	0.051	0.043	0.052	0.121	0.097	0.094	0.038	0.027	0.045	0.045

Source: CS analysis of household survey data, adjusted in model validation to match count-based distribution by time period.

Table 11.4 Pre-Distribution Time of Day Factors

	HBW	HBS	HBU	HBO	HBSc	WBO	OBO
PK	45%	32%	44%	44%	57%	39%	42%
OP	55%	68%	56%	56%	43%	61%	58%

Source: CS analysis of household survey data, adjusted in model validation to match count-based distribution by time period.

Table 11.5 Pre-Assignment Directional Time of Day Factors

	HBW P to A	HBW A to P	HBS P to A	HBS A to P	HBU P to A	HBU A to P	HBO P to A	HBO A to P	HBSc P to A	HBSc A to P	WBO P to A	WBO A to P	OBO P to A	OBO A to P
AM	0.294	0.022	0.046	0.019	0.279	0.012	0.176	0.078	0.467	0.002	0.045	0.179	0.060	0.060
PM	0.097	0.587	0.363	0.572	0.125	0.583	0.354	0.392	0.046	0.485	0.670	0.106	0.440	0.440
MD	0.355	0.231	0.316	0.409	0.531	0.301	0.393	0.299	0.184	0.368	0.608	0.286	0.423	0.423
OP	0.255	0.159	0.062	0.213	0.091	0.077	0.093	0.215	0.228	0.221	0.062	0.044	0.077	0.077

Source: CS analysis of household survey data, adjusted in model validation to match count-based distribution by time period.

For the peak period, the trip distribution time of day factor for each purpose is computed as the sum of daily factors for the AM and PM periods. Similarly, off-peak period trip distribution time of day factors are the sums of daily factors for the MD and OP periods. In model application, pre-distribution time of day factors are applied by multiplying productions and attractions resulting from trip generation by the corresponding trip distribution time of day factor.

Because they are applied to trip tables that have been separated into peak and off-peak periods, pre-assignment time of day factors are computed by dividing 24-hour factors by the pre-distribution factors for each period and trip purpose. The factors for each purpose and time period sum to 100 percent. They are applied to the peak and off-peak person trip tables using the equation below. This converts trip tables from production/attraction format to origin/destination format, while also retaining directional peaking characteristics.

$$T_{OD,per} = \left(\frac{1}{2} \cdot T_{PA,pkop} \cdot F_{PA} \right) + \left(\frac{1}{2} \cdot T'_{PA,pkop} \cdot F_{AP} \right)$$

Where:

- $T_{OD,per}$ = OD trip-table by time period
- $T_{PA,pkop}$ = PA trip-table for the peak or off-peak period
- $T'_{PA,pkop}$ = Transposed PA trip-table for the peak or off-peak period
- F_{PA} = Pre-assignment time of day factor for the P to A direction
- F_{AP} = Pre-assignment time of day factor for the A to P direction

The time of day process results in four trip tables in origin/destination format. Prior to traffic assignment, the AM and PM trip tables are further broken down into peak hour and shoulder periods. This is accomplished using the peak period to peak hour loading factors shown in **Table 11.6**. No further disaggregation is performed for the mid-day or off-peak periods. Instead, hourly capacities are multiplied by the number of hours in the mid-day and off-peak time periods to produce mid-day and off-peak capacities.

Table 11.6 Hourly Loading Factors for Traffic Assignment

Period	Loading Factor
AM1	0.481
AM2	0.519
PM1	0.244
PM2	0.262
PM3	0.265
PM4	0.229

Source: CS and FHU Analysis of traffic count data.

11.2 Traffic Assignment

The Traffic Assignment module loads the travel demand represented by the time of day vehicle trip tables onto the roadway network. Several different algorithms have been used in past and present models. Most current travel demand models make use of user equilibrium assignment, which minimizes travel time for all vehicle trips assigned to the network. This is an iterative assignment algorithm that calculates congested travel time as a function of link volume and shifts travelers to the shortest path. As a result, user equilibrium traffic assignment represents traffic diversion from congested links.

After each iteration, the user equilibrium traffic assignment algorithm computes a relative gap corresponding to the difference between the previous and current iteration volumes. The algorithm stops when a pre-selected relative gap is achieved, indicating the network has reached equilibrium and users have found their optimal paths. The relative gap parameter is set to 0.00001 for the NFR Model, which ensures a sufficiently high level of convergence. When a larger relative gap is used, oscillations between equilibrium iterations can sometimes result in unstable assignment results. If closure criteria are not sufficient, two very similar model runs (e.g., with only one small adjustment to the roadway network) can produce non-intuitive results. There are, however, cases when the network is extremely congested and the relative gap of 0.00001 cannot be reached within a reasonable amount of time and hence an upper limit is imposed on the number of iterations. This limit is set to 500 for the NFR Model, but model runs completed during testing have not reached this upper limit.

The current version of the NFR Model uses the bi-conjugate Frank-Wolfe equilibrium assignment method. This method takes advantage of multi-threaded processors and converges relatively quickly when compared to other available equilibrium assignment methods.

11.2.1 Volume-Delay Functions

A volume-delay function represents the effect of increasing traffic volume on link travel time. While several volume delay functions are available for consideration, the most commonly used function is the modified Bureau of Public Roads (BPR) function, shown in the equation below.

$$T_C = T_F \left(1 + \alpha \left(\frac{V}{C} \right)^\beta \right)$$

Where:

T_C	= Congested impedance
T_F	= Freeflow travel time
V	= Traffic volume
C	= Ultimate roadway capacity (upper limit LOS E capacity)
α	= Coefficient alpha
β	= Exponent beta

Ultimate roadway capacities for links in the NFR Model roadway network are defined in **Section 2.2.7**. For the AM and PM hours defined in **Section 11.1**, hourly capacities are used directly in the volume delay function. For the Mid-Day and Off-peak periods, hourly capacities are multiplied by period length to determine total period capacity. The coefficient alpha and the exponent beta are defined in **Table 11.7**.

Table 11.7 Alpha and Beta Values (Alpha / Beta)

	1 - CBD	2 - Commercial Corridor	3 - Urban	4 - Suburban	5 - Rural
1 - Interstate	0.90 / 6	0.90 / 6	0.60 / 5	0.50 / 5	0.40 / 5
2 - Expressway	0.90 / 3	0.90 / 3	0.90 / 3	0.90 / 3	0.90 / 3
3 - Principal Arterial	0.90 / 3	0.90 / 3	0.90 / 3	0.90 / 3	0.90 / 3
4 - Minor Arterial	0.90 / 3	0.90 / 3	0.90 / 3	0.90 / 3	0.90 / 3
5 - Collector	0.60 / 2	0.60 / 2	0.60 / 2	0.60 / 2	0.60 / 2
6 - Ramps	0.55 / 5	0.55 / 5	0.55 / 5	0.55 / 5	0.55 / 5
7 - Frontage Road	0.45 / 2	0.45 / 2	0.45 / 2	0.45 / 2	0.45 / 2
8 - Centroid Connector	0.15 / 7	0.15 / 7	0.15 / 7	0.15 / 7	0.15 / 7

Source: NFR Travel Model.

11.2.2 Generalized Cost Function

The NFR Model uses a generalized cost function to account for a combination of distance and time in the traffic assignment process. In addition, the generalized cost function accounts for tolls charged on some links in forecast year networks. The generalized cost function converts travel time, travel distance, and toll costs

into a common unit. The model then replaces the travel time variables T_F and T_C in the modified BPR equation with generalized cost values specified below.

$$GC = t(1 - W_{dist}) + d \cdot W_{dist} + \frac{toll}{vot}$$

Where:

GC	= Generalized Cost
t	= travel time in minutes
d	= travel distance in miles
W_{dist}	= Distance weight (validated value set to 0.5)
$toll$	= Link toll in dollars
vot	= Value of time in dollars per minute

The calibrated distance weight indicates both time and distance are considered in identification of the best route connecting two zones. This minimizes the tendency of the model to show vehicles traveling a longer distance to save time (e.g., traveling out of the way to a freeway). Model validation statistics were reviewed with varying distance weights, and with the distance weight removed, to determine the most appropriate setting.

11.2.3 Multi-Class Assignment

The NFR Model considers five different types of vehicles in the traffic assignment step: single occupant vehicles, shared ride 2 vehicles, shared ride 3+ vehicles, medium trucks, and heavy trucks. Heavy trucks are pre-loaded on the roadway network using an unconstrained all-or-nothing assignment, while other vehicle classes are assigned using the equilibrium assignment process described above. The NFR model does not assign transit vehicles to the highway network.

In the unconstrained heavy truck assignment, all heavy trucks are assigned to the roadway network based on free-flow speed. Heavy trucks are prohibited from using any links with a truck prohibition flag, and/or from using HOV lanes. To prevent heavy trucks from using tolled express lanes, the truck prohibition flag must be set. In addition, travel time is increased on collectors by a factor of 5 to minimize use of collector streets by heavy trucks. If desired, heavy truck time factors can be added to specific links to improve truck validation in subarea and corridor studies. The unconstrained assignment has been shown to produce more reasonable results for trucks in the NFR Region, as this approach prevents the model from showing diversion of trucks from I-25 and other congested facilities onto arterial and collector streets.

In the constrained traffic assignment, the four remaining vehicle classes are assigned simultaneously, but with slightly different settings. Some classes are prohibited from using certain links, and different value of time and toll value are permitted. A description of settings applied for each class is included below, with value of time values shown in **Table 11.8**. After traffic assignment is complete, traffic volumes are available for each individual vehicle class.

- Single Occupant Vehicle: SOVs are excluded from using HOV lanes and can be set to incur toll charges on express lanes or standalone toll facilities.
- Shared Ride 2 Vehicles: These vehicles are excluded from HOV links coded with a minimum occupancy requirement of 3 and can be set to incur toll charges on express lanes or standalone toll facilities.

- Shared Ride 3+ Vehicles: These vehicles can use any roadway link in the network but can still be set to incur tolls on express lanes or standalone toll facilities. At the time the model was developed, network coding was performed such that SR3+ vehicles could use all proposed express lanes free of charge.
- Medium Trucks: These trucks are excluded from HOV lanes and any link with a truck prohibition (TRUCK_PROHIB = 1). Value of time for medium trucks is slightly higher than the value of time applied for passenger vehicles.

Table 11.8 Value of Time by Vehicle Class

Vehicle Class	Peak Period Value of Time	Off-Peak Period Value of time
Passenger Vehicle (HOV and SOV)	\$14.4 / hour (\$0.24 / min)	\$10.80 (\$0.18 / min)
Medium Truck	\$22.20 (\$0.37 / min)	\$22.20 (\$0.37 / min)
Heavy Truck	\$48.00 (\$0.80 / min)	\$48.00 (\$0.80 / min)

Source: NFR 2012 Base Year Regional Travel Model.

Heavy truck volumes are preloaded on the roadway prior to constrained traffic assignment so that the model can account for congestion caused by heavy trucks. Heavy trucks are pre-loaded using a passenger car equivalent (PCE) value of 3.0, while medium trucks and passenger vehicles receive a PCE value of 1.0.

11.3 Speed Feedback

The destination choice model used in the trip distribution process makes use of roadway and transit travel times, along with travel distance, between each zone pair. Later in the model process, the traffic assignment procedure calculates congested travel speeds based on traffic flows and application of a volume-delay equation. The speeds input to trip distribution and the speeds output by traffic assignment are generally not consistent after the initial model run. To rectify this inconsistency, results from traffic assignment are used to re-compute zone to zone travel times and distances for input to trip distribution. The model is rerun, and a comparison is then made between the initial and updated zone to zone travel times. If the travel times are not reasonably similar, the updated travel times are then used to rerun trip distribution and the subsequent model steps. This process is repeated iteratively until a convergence criterion is met.

Inclusion of a speed feedback process in the travel model process can have interesting and desirable effects on the way the travel model represents the effects of network improvements in congested situations. Without speed feedback, overall regional travel demand remains constant regardless of the roadway network assumptions because trip distribution patterns are not affected by changing congestion levels. Vehicle travel routes are always affected by congestion in the traffic assignment model by virtue of the volume-delay functions.

When speed feedback is added to the process, heavy congestion results in slower speeds, leading to shorter trip patterns throughout the region. As roadway improvements are added to the model, addition of capacity to the network will initially result in faster travel speeds because of less localized congestion. The speed feedback process recognizes the additional capacity and higher speeds and allows for longer trip lengths across the region, which has the effect of incrementally increasing overall travel demand due to roadway network characteristics. This is consistent with the “build it and they will come” philosophy suggesting that new roadway capacity can induce travel where roadway access did not previously exist and/or where conditions change from congested to uncongested conditions. The speed feedback process can produce

model results that change trip lengths and travel mode (e.g., shifts between drive alone to transit or shared ride), but does not affect the total number of person trips generated.

11.3.1 Methodology

There are various approaches to incorporating speed feedback. Three well-documented methods are the naïve method, constant-weight method, and method of successive averages (MSA). The naïve method is not recommended for use as lack of information sharing between subsequent iterations leads to an inefficient process that will often fail to converge. Furthermore, the naïve method feeds speed data directly from traffic assignment to trip distribution; while the constant weight and MSA methods feed volumes to trip distribution which are then used to compute updated speeds (speed feedback is sometimes referred to as volume balancing). The NFR Model implements speed feedback using the MSA method.

The MSA uses a simple average of all flows resulting from previous assignment runs. Flows can be computed as shown in the equation below.

$$MSAFlow_n = \left(MSAFlow_{n-1} - \frac{MSAFlow_{n-1}}{n} \right) + \frac{Flow_n}{n}$$

This can be further simplified as follows:

$$MSAFlow_n = MSAFlow_{n-1} + \frac{1}{n} (Flow_n - MSAFlow_{n-1})$$

Where:

- MSAFlow = Flow calculated using the MSA
- n = current iteration
- Flow = Flow resulting from traffic assignment

The method of successive averages is commonly used in regional travel models and is the approach recommended by the TransCAD documentation. The method of successive averages also is supported by built-in functions in the TransCAD software.

The method of successive averages effectively assigns a weight to traffic volumes from each traffic assignment iteration equal to the reciprocal of the iteration number. In other words, the volume results from each previous iteration are weighted equally when computing travel times for trip distribution. After the new MSA-weighted flows are calculated, speeds on each link in the roadway network are re-estimated, and the remainder of the model is run to complete the iteration.

11.3.2 Initial Speeds and Borrowed Feedback Results

Use of the MSA feedback procedure produces results sensitive to the initial speeds/travel times input to the first iteration of the trip distribution model. For this reason, a consistent set of initial speeds should be used when running multiple scenarios. This is particularly important when model results and summary statistics from different scenarios will be directly compared.

In some cases, it is desirable to run the model to test multiple alternatives without running speed feedback for each scenario. For these cases, it is possible to run the model once with speed feedback enabled to establish a baseline forecast scenario (e.g., future growth on existing and committed network) and then save

the final model results with speed feedback for use in alternatives testing. When this approach is taken, it is important that feedback is disabled when using the copied feedback results. In addition, the baseline scenario should be run a second time using copied speeds as input data and with speed feedback disabled to ensure consistency between all scenarios.

11.3.3 Convergence Criteria

It is important a meaningful convergence criterion is specified when running a model with speed feedback. A meaningful speed feedback convergence measure ensures, either directly or indirectly, that travel time skims input to trip distribution are reasonably similar to travel time skims created from traffic assignment output. It provides better consistency between similar model runs so the differences can be attributable to transportation system performance and not due to computational issues.

The convergence criterion used must be specified carefully to prevent unnecessary iterations of the speed feedback process, as the convergence measure will provide diminishing benefits after a certain point. The point at which the best possible convergence has been met will often vary with the level of congestion in a network. Therefore, it is necessary to monitor speed feedback convergence when first running a dataset that is significantly different than previously considered scenarios.

Traffic assignment convergence settings also affect speed feedback convergence. If traffic assignment does not adequately converge, the speed feedback convergence measure may improve slowly or inconsistently. Alternately, if traffic assignment is set to converge more thoroughly, the speed feedback convergence measure may improve more consistently and more quickly. However, closure settings that are too stringent can result in unreasonably long model run times.

The NFR Model measures convergence using shortest path percent Root Mean Square Error (% RMSE). This measure compares zone to zone travel time matrices from subsequent iterations to the current iteration using the equation below, thereby providing an indication of the similarity between two travel time matrices. This approach directly satisfies the requirement that inputs to trip distribution and outputs from traffic assignment are reasonably similar. The default speed feedback convergence criterion is set at 0.01 percent RMSE and the iteration limit is set to 10, but model users are encouraged to review speed feedback convergence on a case by case basis.

$$\%RMSE = \frac{\sqrt{\sum_{jk} (t_{jk(i)} - t_{jk(i-1)})^2}}{\frac{\sum_{jk} t_{jk(i)}}{n}}$$

Where:

- $\%RMSE$ = Percent Root Mean Square Error
- $t_{jk(i)}$ = Travel time between zones j and k for the current iteration i
- $t_{jk(i-1)}$ = Travel time between zones j and k for the previous iteration (i-1)
- n = Number of zone to zone pairs

11.3.4 Application of Speed Feedback for Alternatives Analysis

Speed feedback ensures travel time consistency within the entire modeling structure. It was conceived as a model enhancement in the early 1990's largely in response to environmental lawsuits, although it is good

practice and now considered a necessity. Generally, speed feedback is most sensitive to network changes that provide a significant travel time improvement. These types of alternatives warrant running the feedback process because they can affect regional travel patterns. Less significant improvements can also affect travel times and regional travel patterns to various degrees and should be considered for feedback.

For any and all interim milestone and horizon years, speed feedback should be executed to closure. For subsequent alternatives analysis, speed feedback should be considered for any of the conditions listed below.

- A significant new roadway alternative (i.e., new or greatly improved access) over the base case would likely warrant speed feedback. This would be true for new or significantly better access to areas that are undeveloped, developing, or already developed. For undeveloped areas, it is likely the effect is more significant in later years. Examples include new freeway interchanges, new freeway lanes, new freeways and arterials, and in limited cases new collector roads.
- Less significant roadway improvements might warrant running speed feedback. These might include roadway widening or corridor improvements that imply functional class, speed, or capacity changes. Improvements limited to a short section of roadway or an intersection generally would not warrant running speed feedback.
- A significant change to socioeconomic assumptions as compared to the base case. Speed feedback is more likely to be necessary when changes cover a large area and involve significant demographic shifts but could conceivably be warranted after changes to a small number of zones with very high activity. Socioeconomic changes should also include an update to area type assumptions.
- Significant changes to external trip or special generator assumptions.
- Any model run in which a significant change in congestion on any corridor is anticipated could affect regional travel times and travel patterns. This criterion is largely covered by those above.
- Changes to model parameters, factors, coefficients, etc. – *Note: These changes should only be made in conjunction with model calibration and validation, but any tests of changes to parameters should include running the feedback process.*

11.4 Transit Assignment

Transit person trips resulting from the mode choice model are assigned to the transit route system. Each trip is assigned from zone centroid to zone centroid using walk or drive access links, transit routes, and walk egress links. The transit assignment step does not include capacity constraint, so increasing transit volumes do not result in diversion of transit trips to other transit service.

Transit assignment results include the total number of boardings at each transit stop, as well as transit volumes on all stop to stop transit route segments. However, transit results are generally best evaluated at the systemwide or route group level. Individual route, stop, and segment values have not been validated to observed conditions. Prior to using the model to support detailed transit corridor studies, a focused transit model calibration and validation effort is recommended.

12.0 Calibration and Validation

The NFR Model has been calibrated to match household travel survey data and on-board transit survey data and validated to traffic count and transit boarding data. This section documents the stepwise model calibration and validation process.

12.1 Trip Generation Calibration

Trip rate factors have been calibrated so that overall travel model volumes match regional and sub-regional VMT totals. Calibrated trip rate factors are shown in **Table 12.1** and are applied to both production and attraction rates. Home-based work factors are lower than those for other trips, as daily commute trips tend to be more accurately reported in household travel surveys. The home-based school and home-based university trips are not factored, as these trip purposes are based on enrollment data rather than household data. LBO trips are not factored because they were developed directly to match traffic count data as visitor survey data were not available to support estimation of LBO trip rates.

Table 12.1 Trip Production Rate Factors, by Trip Purpose

Trip Purpose	Trip Rate Factor
Home-Based Work (HBW)	1.35
Home-Based Shop (HBS)	1.55
Home-Based Other (HBO)	1.55
Home-Based School (HBSc)	1.00
Home-Based University (HBU)	1.00
Work-Based Other (WBO)	1.55
Other-Based Other (OBO)	1.55
Medium Truck	0.40
Heavy Truck	0.90
Lodging-Based Other	1.00

Source: NFR Model Input Files.

12.2 Trip Distribution Calibration

12.2.1 Destination Choice Calibration and Validation

The destination choice model was validated by comparing observed and modeled average trip lengths and trip length frequency distributions. Trip length frequency distributions produced by the estimated destination choice model indicated slightly longer average trip lengths than those observed in the household travel survey. While it is possible to make slight adjustments to the destination choice model coefficients to produce shorter average trips, this approach would have required higher trip rate factors in the trip generation step. In order to achieve a balance between the magnitude of trip rate factors and the trip distribution calibration error, the originally estimated destination choice constants were retained.

Analysis of traffic count data demonstrated that modeled traffic volumes between communities were generally higher than traffic counts. This was particularly noticeable on facilities connecting Greeley to areas west of I-25. To account for this, the geographic constants shown in **Table 12.2** were added to the destination choice model. These calibrated constants have the effect of encouraging trips that stay within the Greeley, Fort Collins, and Loveland subareas. In addition, they further discourage travel between areas west of I-25 and areas east of I-25. While the model continues to produce a significant amount of travel between cities and across I-25, the constants reduce the amount of travel produced to be consistent with observed levels.

Table 12.2 Geographic Constants

Trip Interchange	Constant
Within Greeley, Fort Collins, or Loveland	+ 0.4
Between Greeley and East Weld	+ 0.4
Within East Weld	+ 0.4
Between Greeley and Fort Collins or Loveland	- 0.5
Between East Weld and Fort Collins or Loveland	- 0.5
Between Loveland and Fort Collins	+ 0.1
Within the Estes Park area	+ 0.5

Note: For the purposes of geographic constants, East Weld is defined as portions of Weld County east of I-25 that are within the NFR region but not within the Central I-25 sub-region. Greeley, Fort Collins, and Loveland constants are defined based on the corresponding sub-region, not the city limits or GMA.

A comparison of average trip lengths by trip purpose is shown in **Table 12.3**, with trip length frequency distributions for each trip purpose shown in **Figure 12.1** through **Figure 12.6**.

Table 12.3 Average Trip Lengths, by Trip Purpose

Purpose	Average Trip Length		
	Modeled	Target	Percent Difference
HBW	6.96	6.63	5%
HBS	4.51	3.79	19%
HBU	6.88	6.08	13%
HBO	5.24	4.20	25%
HBS _c	3.79	3.37	12%
WBO	4.75	4.76	0%
OBO	3.56	3.61	-1%

Source: NFR Model Output Files and 2010 FRTC Survey Data

Figure 12.1 Home-based Work Trip Length Frequency Distribution

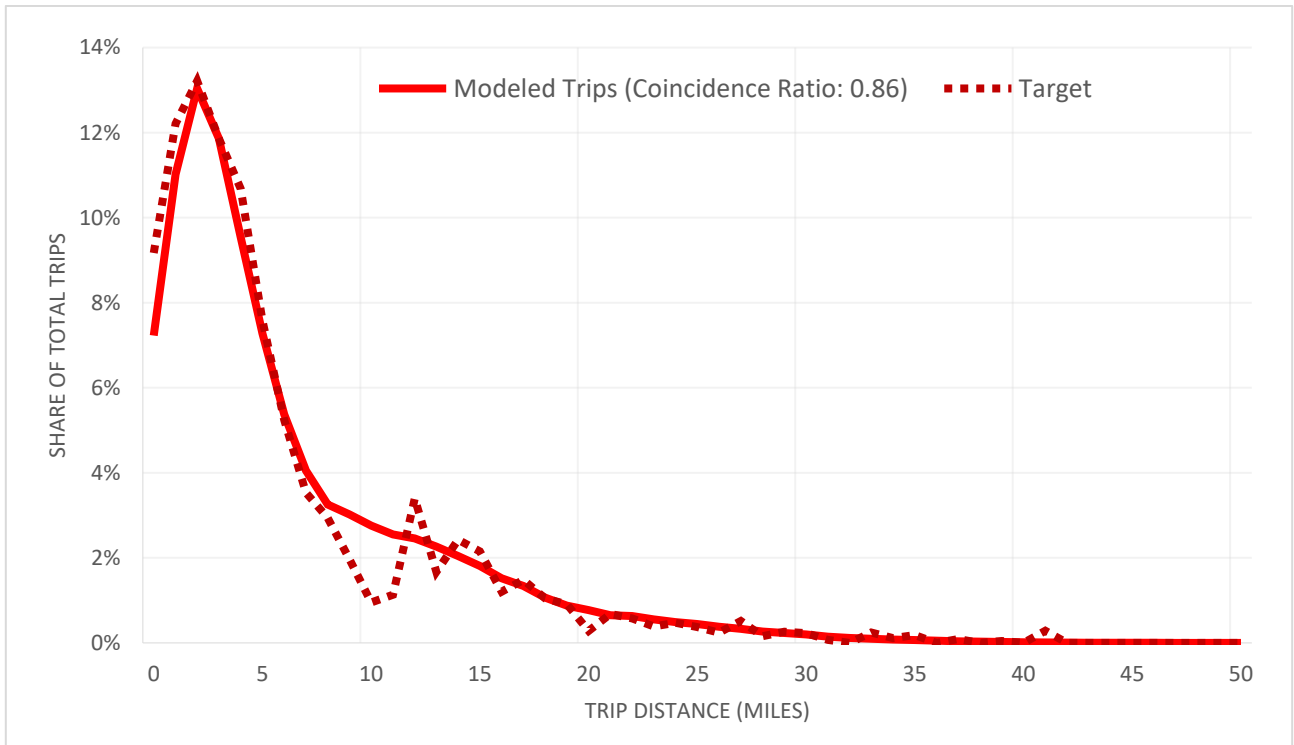


Figure 12.2 Home-based Shop Trip Length Frequency Distribution

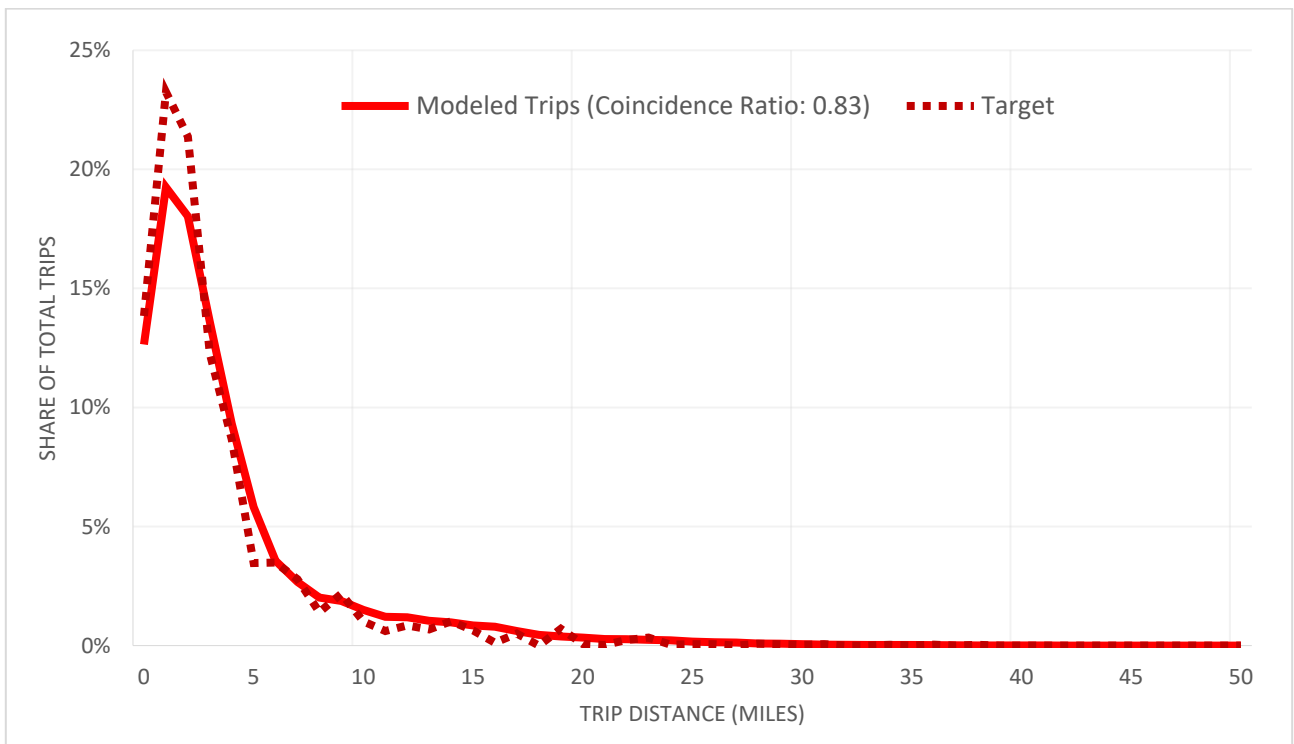


Figure 12.3 Home-based School Trip Length Frequency Distribution

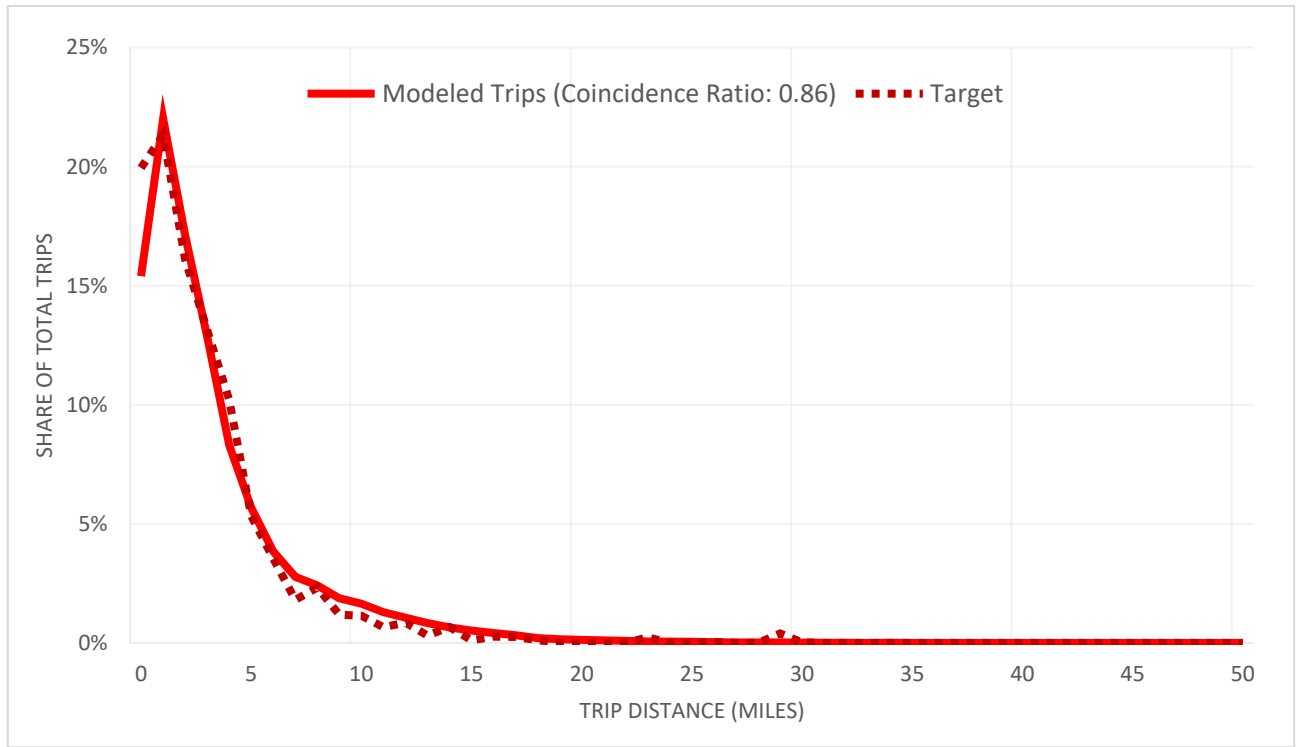


Figure 12.4 Home-based Other Trip Length Frequency Distribution

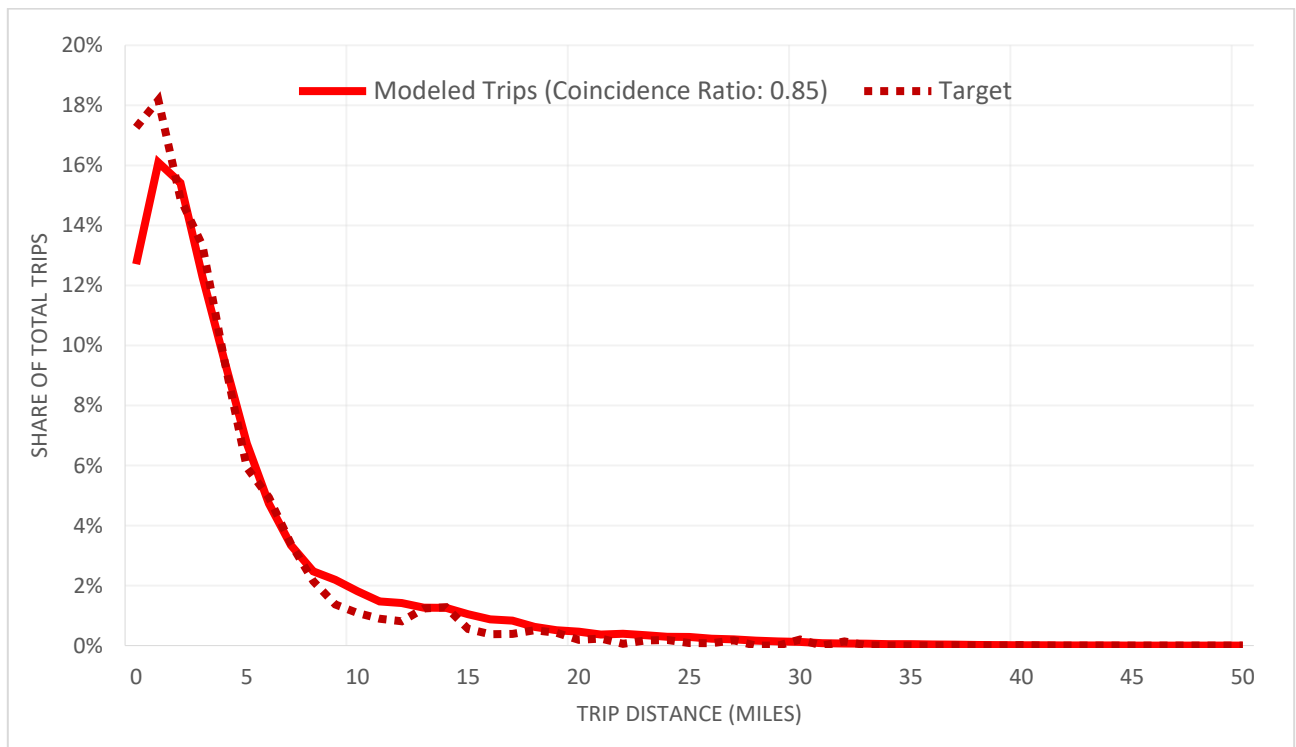


Figure 12.5 Work-based Other Trip Length Frequency Distribution

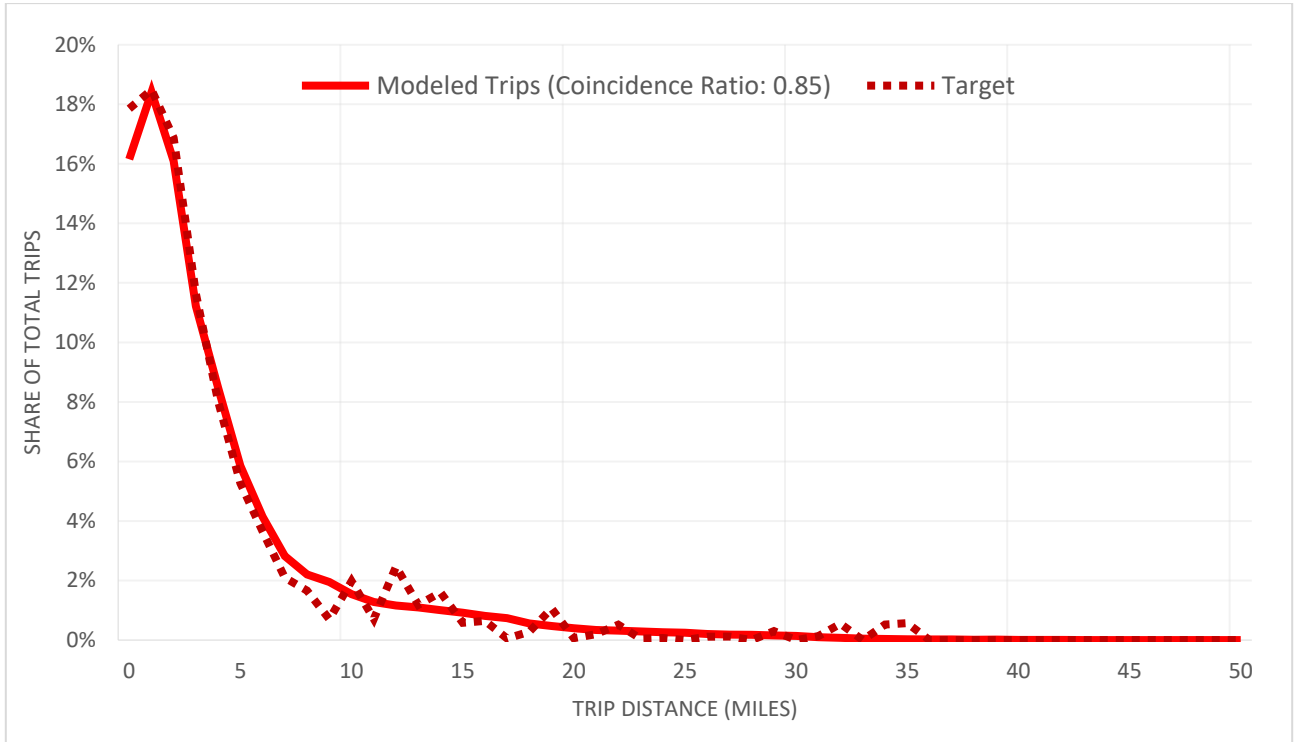
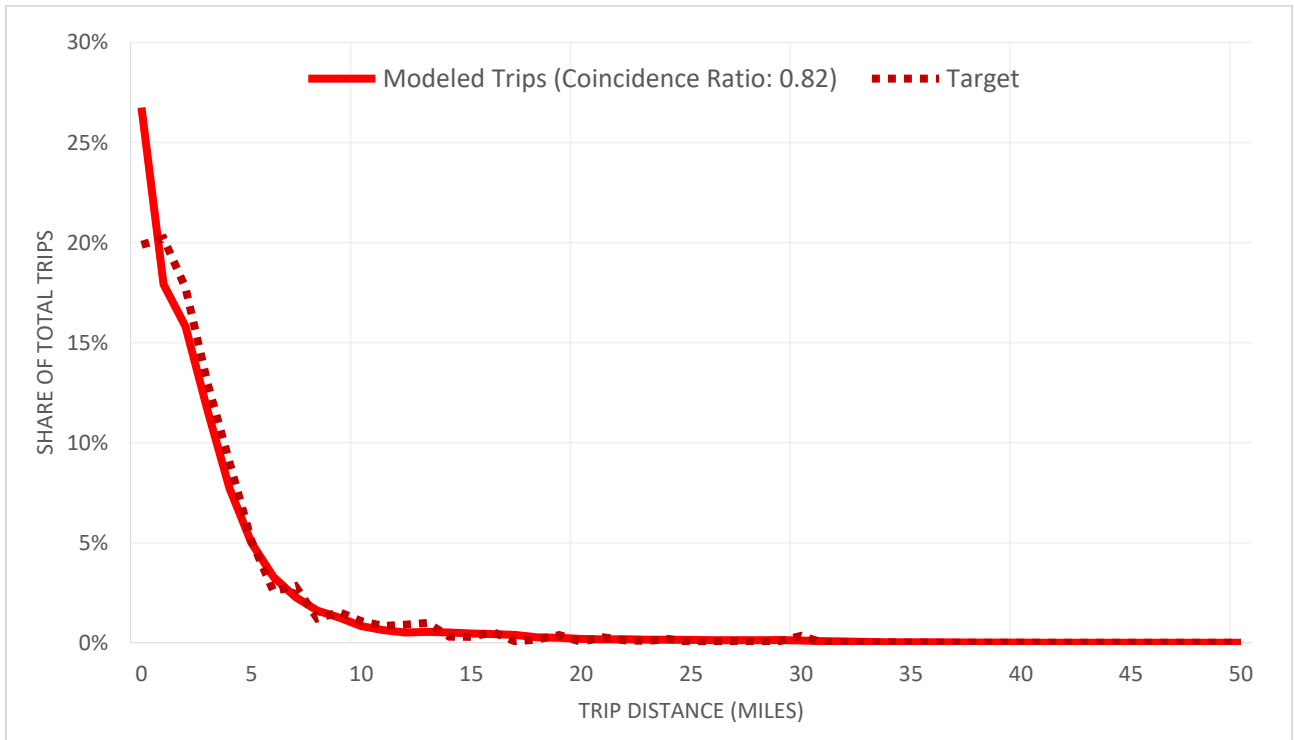


Figure 12.6 Other-based Other Trip Length Frequency Distribution



12.2.2 External Station Trip Distribution

During model validation, it was found that the destination choice model was not accurately reproducing trip distribution patterns to and from external stations. Therefore, a gravity model was implemented for external trip distribution. The external gravity model was calibrated using traffic count data on facilities near external stations, along with location-based-services data obtained by CDOT for use in a study of I-25. The resulting friction factors are defined by the parameters listed in **Table 12.4**. In addition, K-factors were added to the gravity model at two specific locations.

- At the South US-85 external station, a K-factor of 0.1 is applied to strongly discourage traffic between this external station and areas west of I-25. Analysis of available paths indicate that most traffic entering on US-85 would not travel to the west of I-25, as better paths from the east DRCOG region to I-25 are available south of the NFR Model boundary.
- At Estes Park external stations (US-34, SH-7, and US-36), a K-factor of 0.5 is applied to all zones outside of the Estes Park area.

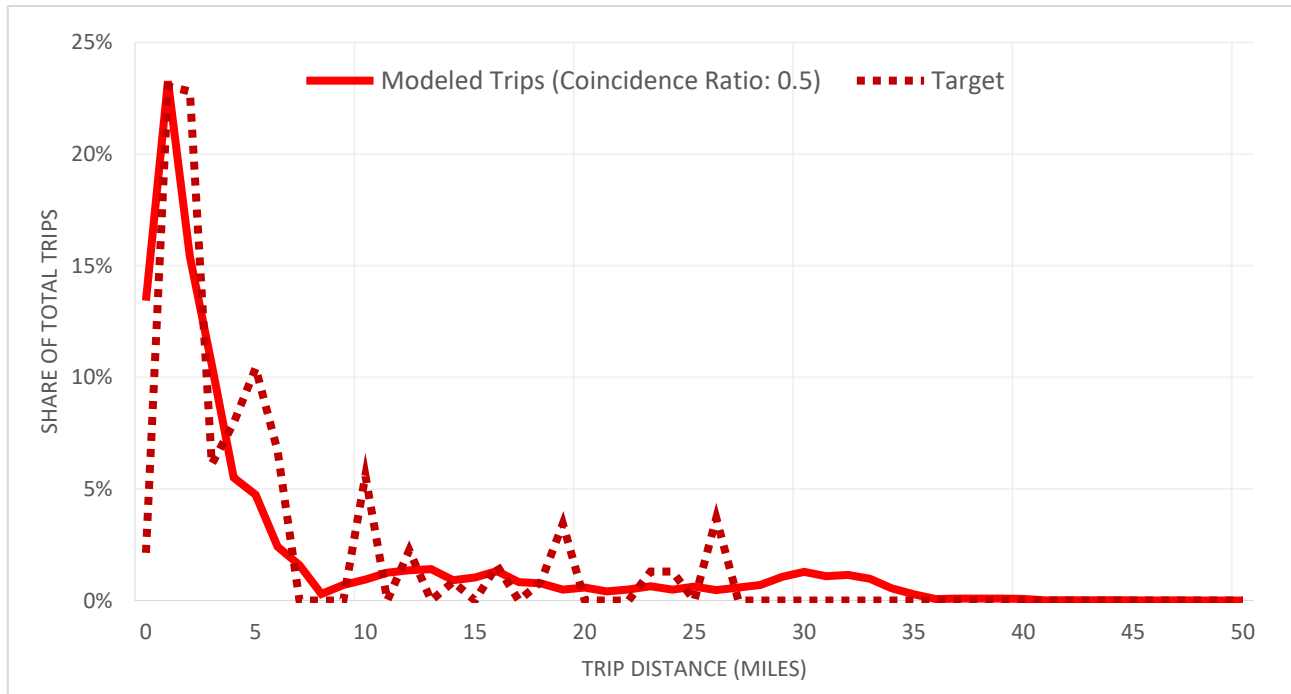
Table 12.4 Friction Factors for External Station Trip Distribution

Parameter	North Front Range Region	Estes Park
Alpha (α)	650	750
Beta (β)	0.45	0.5
Gamma (γ)	0.12	0.25

Source: NFR Model Input Files

12.2.3 University Trip Distribution

Trip distribution was calibrated based on anonymous CSU student address data aggregated to TAZs. The trip length frequency distributions shown in **Figure 12.7** compares the travel model HBU trip distribution results to that based on student address data.

Figure 12.7 Home-based University Trip Length Frequency Distribution

12.2.4 Truck Trip Distribution

After initial development of the truck model based on commercial vehicle survey data, a new data source became available through a separate CDOT study. This dataset is comprised of GPS-based origin-destination trip tables for medium and heavy trucks. This data provided the information necessary to further adjust the truck trip length distribution model, resulting in updated friction factors. The resulting trip length frequency distributions are shown in **Figure 12.8** and **Figure 12.9**.

Figure 12.8 Medium Truck Trip Length Frequency Distribution

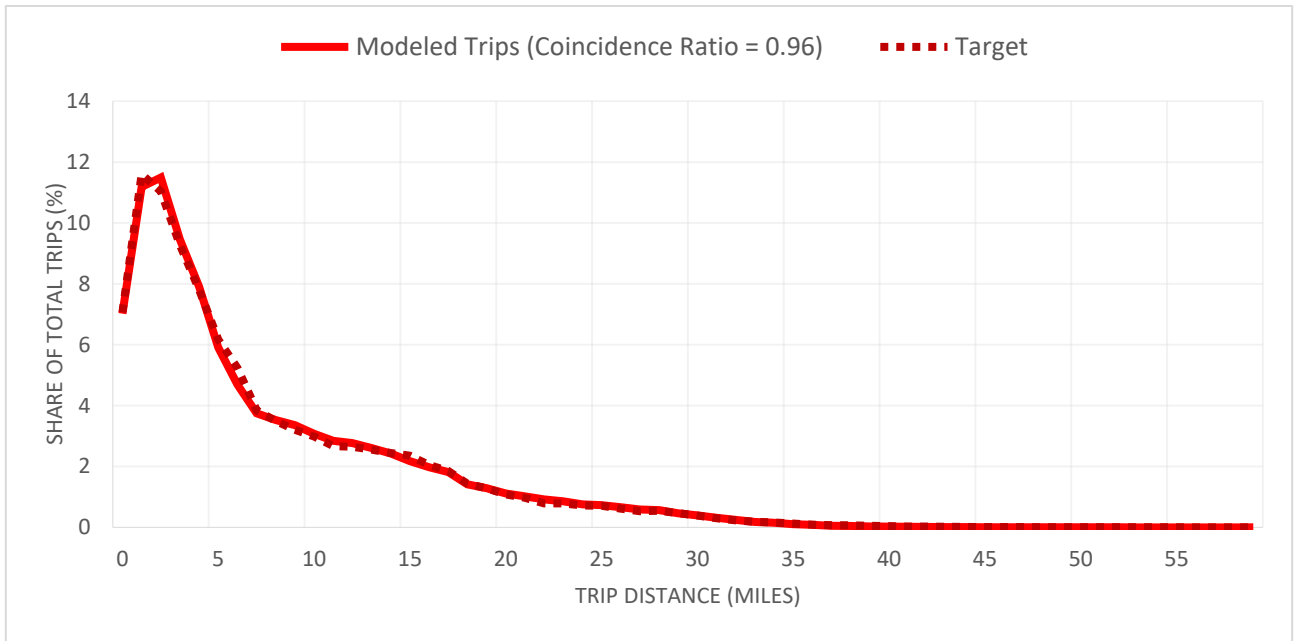
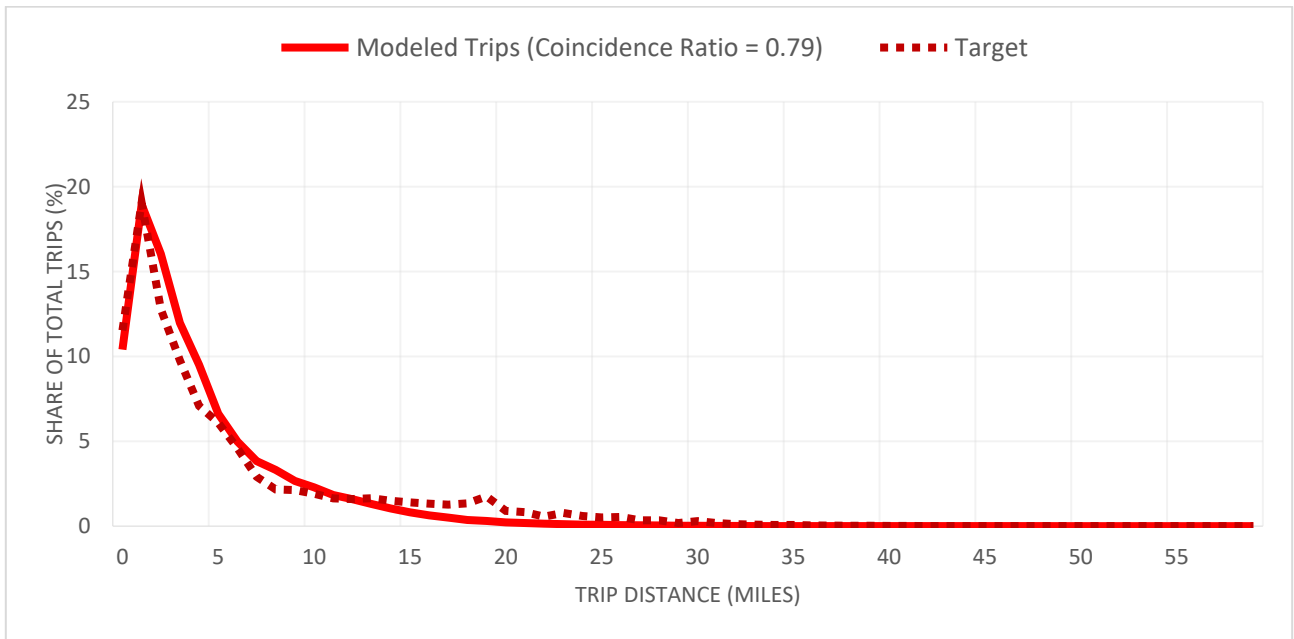


Figure 12.9 Heavy Truck Trip Length Frequency Distribution



12.3 Mode Choice Calibration

The mode choice model has been calibrated to the targets documented in **Section 10.1**. A summary of mode choice calibration results is shown in **Table 12.5**.

Table 12.5 Mode Choice Calibration Results

Purpose	Difference in Mode Shares (Modeled – Target)					
	Drive Alone	SR2	SR3	Walk	Bike	Transit
HBW	-0.2%	-0.3%	0.2%	-0.1%	0.3%	1.7%
HBS	-0.1%	0.0%	0.0%	0.0%	0.1%	-0.1%
HBU	-0.3%	0.0%	0.0%	-0.4%	0.6%	-0.6%
HBO	0.0%	0.0%	0.0%	-0.1%	0.1%	0.4%
HBS _c	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
WBO	0.0%	0.0%	0.0%	0.0%	0.1%	1.8%
OBO	0.0%	0.0%	0.0%	0.0%	0.1%	0.4%
All Purposes	-0.1%	0.0%	0.0%	-0.1%	0.1%	0.4%

Source: NFR Model Output Files, 2010 FRTC Survey Data, and 2017 Transfort Onboard Survey Data

12.4 Traffic Assignment Calibration

Roadway volumes resulting from traffic assignment were compared to traffic count data. This process, called traffic assignment validation, ensured the model is reasonably representing observed traffic patterns. Traffic count data were obtained from various sources and placed on the roadway network. Travel model results were compared to traffic count data using a variety of techniques, including regional comparisons and inspection of individual link values.

The discussion and tables below reflect the unexpanded MPO modeling area. A similar exercise was performed for the expanded modeling area, ensuring calibration of the expanded Larimer and Weld portions of the model.

12.4.1 Overall Activity Level

Overall vehicle trip activity was validated by comparing count data to model results on all links where count data is available using two statistics: model volume to count volume ratio and model VMT as compared to count VMT. These statistics were reviewed at facility type, area type, and regional levels, as shown in **Table 12.6**. In addition, regional daily VMT, VHT, and average travel speed are shown in **Table 12.7**.

Table 12.6 Regional Activity Validation

Link Type	Number of Counts	Model Volume / Count Volume	Model VMT / Count VMT	Target
Freeway	30	102%	103%	+/- 10%
Expressway	46	97%	100%	+/- 10%
Principal Arterial	327	104%	103%	+/- 10%
Minor Arterial	520	98%	97%	+/- 15%
Collector	888	78%	84%	+/- 25%
CBD	92	110%	111%	n/a
Commercial Corridor	66	104%	103%	n/a
Urban	495	96%	95%	n/a
Suburban	514	96%	95%	n/a
Rural	648	103%	104%	n/a
Total	1,815	99%	99%	+/- 5%

Notes: Activity level targets are based on industry standard practice guidelines, not a rule or regulation. Values shown were obtained from a complete model run. Values may change slightly with edits to input details.

Table 12.7 Traffic Assignment Regional Totals

Link Type	VMT	VHT	Average Speed
Freeway	3,743,385	51,577	72.6
Expressway	2,055,192	41,926	49.0
Principal Arterial	3,606,649	109,560	32.9
Minor Arterial	2,629,139	71,522	36.8
Collector	954,456	32,621	29.3
Ramp	111,829	3,084	36.3
Frontage Road	81,961	1,913	42.8
Centroid Connector	1,442,054	47,780	30.2
CBD	272,370	12,251	22.2
Commercial Corridor	330,803	13,270	24.9
Urban	3,397,808	114,630	29.6
Suburban	4,732,023	111,870	42.3
Rural	5,891,662	107,963	54.6

Note: Values shown were obtained from a complete model run. Values may change slightly with edits to input details.

12.4.2 Measures of Error

While the model should accurately represent the overall level of activity, it is also important to verify the model has an acceptably low level of error. It is expected the model will not perfectly reproduce count

volumes on every link, but the level of error should be monitored. The plot shown in **Figure 12.10** demonstrates the ability of the NFR Model to match individual traffic count data points and notes the resulting R-squared value. **Table 12.8** lists % RMSE values and target values for each facility type. General guidelines suggest that % RMSE should be near 40 percent region-wide, with values below 30 percent for high volume facility types such as freeways. The % RMSE measure tends to over-represent errors on low volume facilities, so values on collectors are not particularly meaningful. **Table 12.8** shows % RMSE values by facility type and area type. **Table 12.9** show the % RMSE values by volume group.

Figure 12.10 Model Volume/Count Comparison

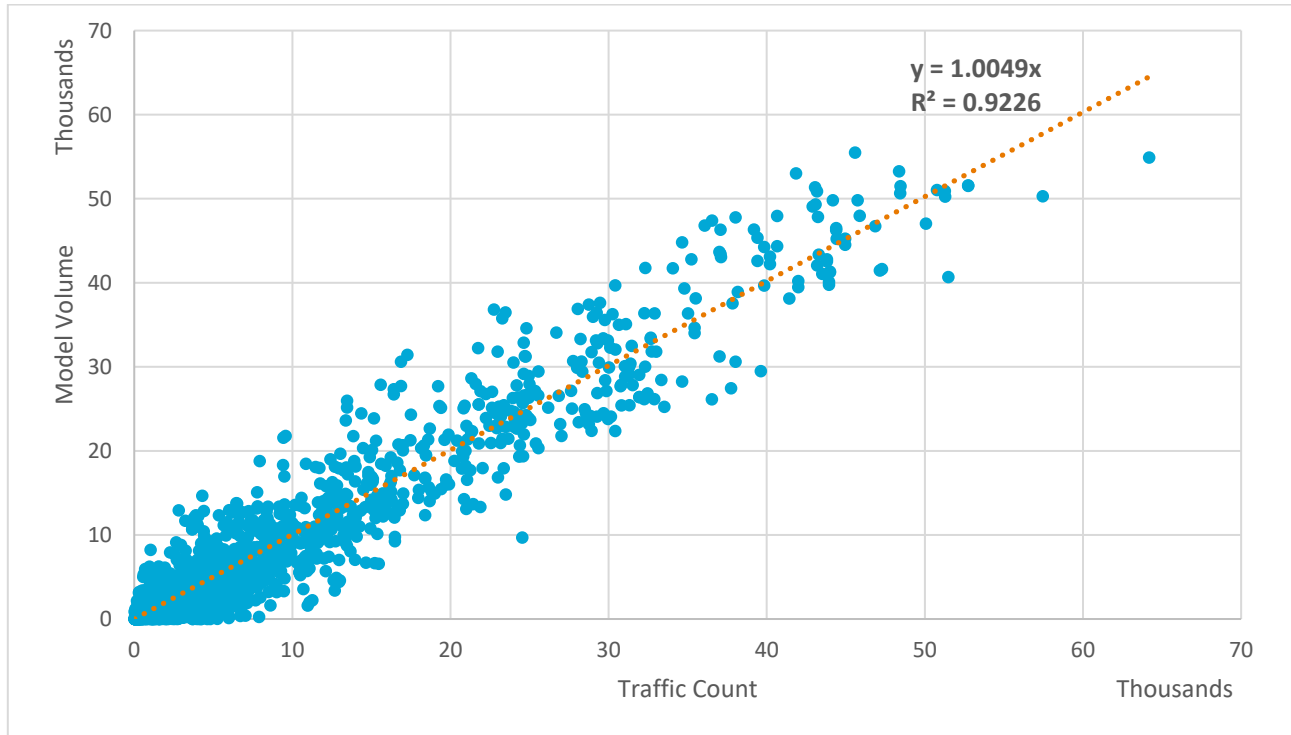


Table 12.8 RMSE Statistics, by Facility Type and Area Type

Link Type	Number of Counts	RMSE	% RMSE	Target
Freeway	30	2,779	8.2%	< 20%
Expressway	46	4,059	15%	< 30%
Principal Arterial	327	5,045	24%	< 30%
Minor Arterial	520	3,172	43%	< 40%
Collector	888	1,788	96%	n/a
CBD	92	4,739	45%	n/a
Commercial Corridor	66	5,350	24%	n/a
Urban	495	3,806	32%	n/a
Suburban	514	2,820	35%	n/a
Rural	648	1,855	57%	n/a
Total	1,815	3,094	38%	< 40%

Table 12.9 RMSE Statistics, by Volume Group

Volume Group	Number of Counts	RMSE	% RMSE
0 - 9,999	1,344	2,209	75%
10,000 - 19,999	233	4,454	32%
20,000 - 29,999	128	4,860	20%
30,000 and up	110	5,361	14%

12.4.3 Screenline Analysis

The NFR Model includes 11 screenlines, shown in **Figure 12.11**. Screenlines capture distinct regional or inter-regional travel patterns and can be useful in understanding the model's trip generation and trip distribution characteristics. Screenlines have been drawn to cover links that either have observed traffic volumes or are known to carry very low traffic volumes. As demonstrated in **Table 12.10** and **Figure 12.12**, error on each screenline falls within the maximum desirable error as defined in NCHRP Report 255.

Table 12.10 NFR Model Screenline Analysis

Screenline	Model Volume	Observed Volume	% Error	Maximum Desirable Error
1 - North Boundary	50,666	42,365	20%	22%
2 - North of Fort Collins	64,292	56,259	14%	19%
3 - East of Fort Collins	143,187	137,509	4%	14%
4 - South of Fort Collins	163,831	162,090	1%	14%
5 - East of Loveland	102,473	93,063	10%	14%
6 - South of Loveland	109,122	108,153	1%	14%
7 - East of I-25	162,743	161,447	1%	14%
8 - North of Greeley	43,390	49,474	-12%	21%
9 - West Greeley	107,166	111,616	-4%	14%
10 - South of Greeley	125,698	126,412	-1%	14%
11 - South Boundary	149,709	149,481	0%	14%

Figure 12.11 NFR Model Screenlines

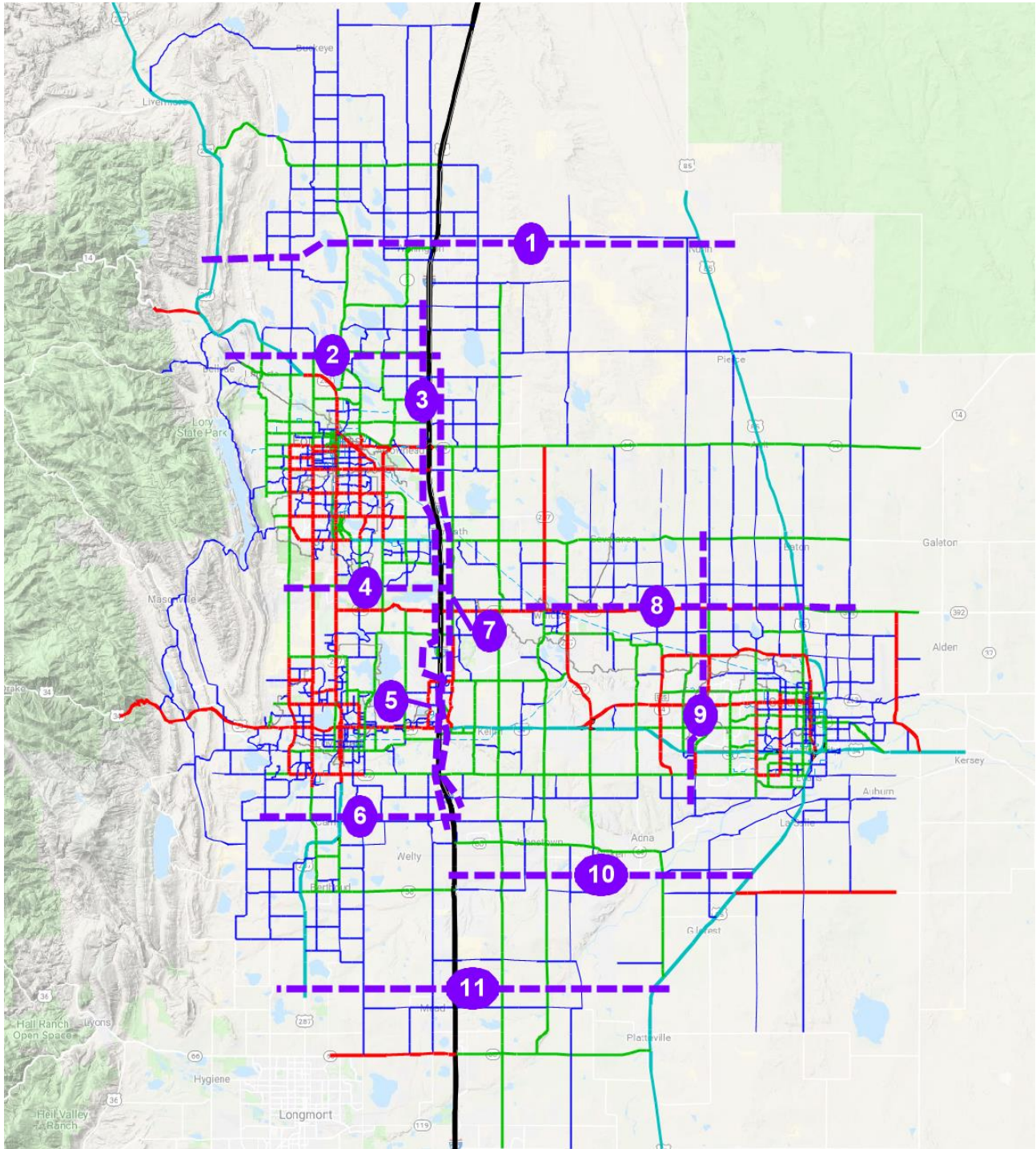
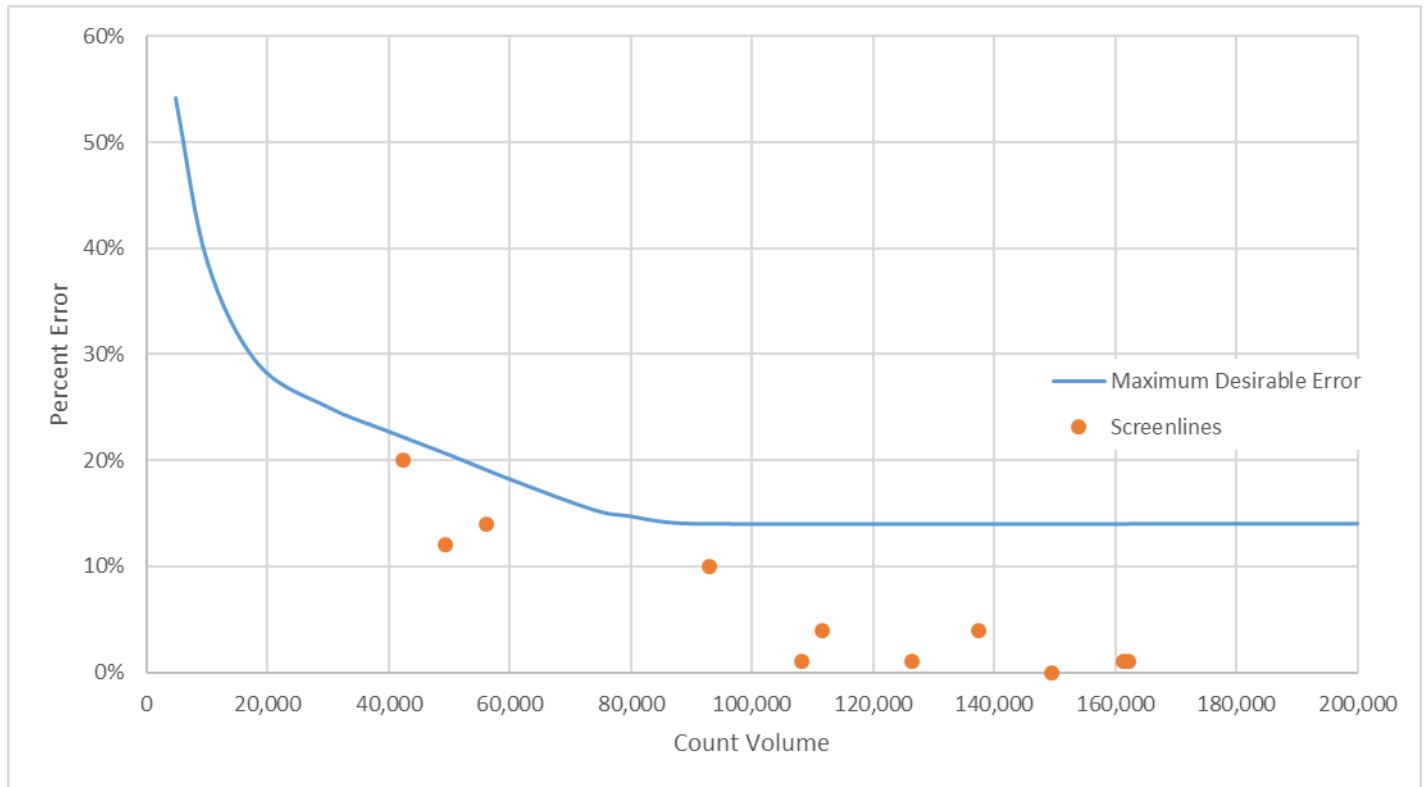


Figure 12.12 NFR Model Screenline Analysis



12.5 Transit Assignment Calibration

Transit assignment has been validated to observed route boardings by operator. As shown in **Table 12.11**, the overall number of boardings is within 6 percent of observed values. For Transfort the total number of system boardings is within 10 percent of observed boardings. The Greeley and Loveland systems have higher error on a percentage basis, but total boardings for each system is within 500 boardings of the observed total.

The transit assignment validation results show the NFR Model is sufficiently calibrated to support testing of transit alternatives and scenarios on a regional basis. The model is useful for comparative analysis of different transit improvements and accounts transit as part of the overall transportation system in the region. The model serves as a starting point for detailed transit planning activities, such as corridor studies or New Starts/Small Starts analysis. If the model is used for detailed transit planning, localized calibration and validation efforts should be conducted.

Table 12.11 Transit Assignment Results

Operator	Observed	Modeled	Error	% Error
COLT	475	530	55	12%
GET	2,220	1,804	-416	-19%
Transfort	13,349	14,566	1,217	9%
CDOT	206	251	45	22%

Operator	Observed	Modeled	Error	% Error
Total	16,250	17,151	901	6%

Source: NFR Model Output Files and 2015 transit boardings data obtained from transit agencies. GET boardings reflect 2016 conditions. Bustang boardings were averaged over 2015-2016, the most recent available at the time.

12.6 Year 2012 Back-cast

A back-cast to a year previous to the validation year (2015) provides a temporal validation, better ensuring the model's ability to be appropriately sensitive to changes in model inputs. The year 2012 back-cast scenario included changes in the networks, socioeconomic data, and external station assumptions.

Table 12.12 provides the differences in the input and outputs of the 2012 and 2015 modeled scenarios, showing increases in socioeconomic data between 6-11% and corresponding increases in transit boardings and vehicle assignment (6-8%). **Table 12.13** provides regional validation statistics for both scenarios. Because the back-cast was completed prior to finalization of the travel model, values shown below for 2015 are preliminary and therefore inconsistent with values shown elsewhere in this document.

Table 12.12 Back-cast Model Run Summaries

	Metric	2012	2015	% Growth
Inputs	Total Households	182,231	193,812	6.4%
	Total Employment	252,996	280,241	10.8%
	Network Centerline Miles	1,760	1,763	0.2%
	Network Lane Miles	4,020	4,038	0.4%
Outputs	VMT	13,547,048	14,624,665	8.0%
	VHT	333,890	359,984	7.8%
	Transit Boardings	16,088	17,172	6.7%

Table 12.13 Back-cast Assignment Validation

Metric	2012	2015	Target
Vol / Count Ratio	105.8%	98.8%	+/- 5%
% RMSE	36.6%	38.3%	< 40%
RMSE	3,570	3,094	