CAMBRIDGE SYSTEMATICS

# North Front Range Regional Travel Demand Model

*2019 Base Year*

technical report

*prepared for*

**North Front Range MPO**

*prepared by*

**Cambridge Systematics, Inc.**

April 17, 2024

**www.camsys.com**

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1801 Broadway, Suite 1100
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# 1.0 Introduction

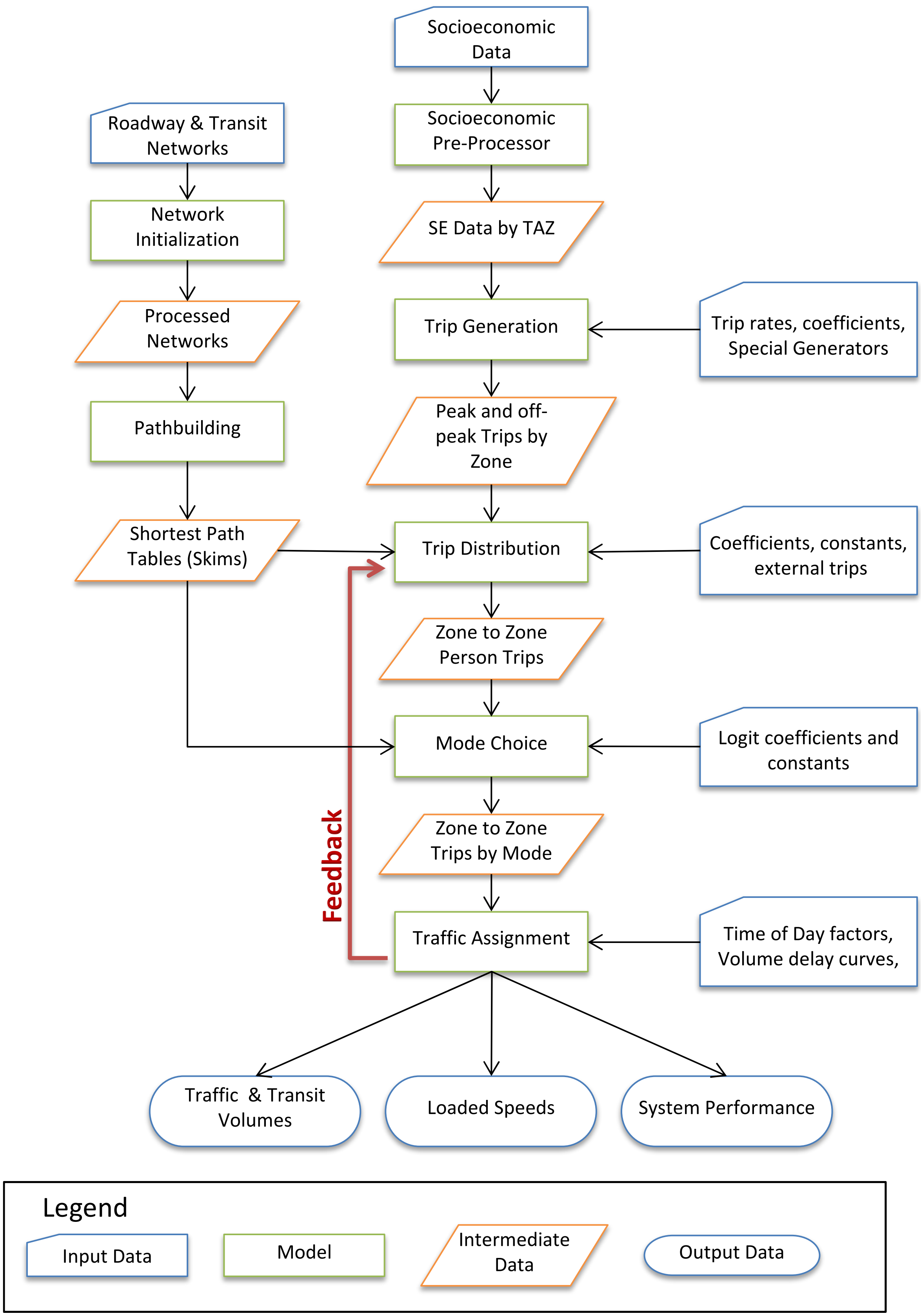
The North Front Range Metropolitan Planning Organization (NFRMPO) and member jurisdictions use the NFR Regional Travel Demand Model (NFR Model) as a tool to forecast traffic and travel in communities throughout the region. The primary purposes of the travel model are to support the Regional Transportation 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 2019 and contains future year data reflecting forecast 2050 conditions. Interim year data representing several intermediate timeframes is also maintained in the travel model dataset.

The previous version of the model featured a 2015 base year and 2045 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 a new disaggregate trip generation model that utilizes socioeconomic data from the Land Use Allocation Model (LUAM), the ability to test changes in the share of people working from home, improved handling of bicycle facilities on the transportation network, and extension of the model to include an additional portion of Weld County. Observed datasets were supplemented with location based services data collected in 2019 and expanded to ACS and Census data representing 2019 conditions.

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 2019 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 2019 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.
- 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 2019 base year network as well as a list of planned and proposed roadway projects. The network also retains information about the 2015 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 2019 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 2019 roadway networks include:

- Network contents have been updated to reflect 2019 base year conditions.
- Posted speed limits have been updated on 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 updated on the network.

- Toll, HOV, and managed lane assumptions have been updated.
- Storage of roadway project information has been moved to a separate table and revised to include information about each roadway project.
- 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 2019 and 2050. 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.

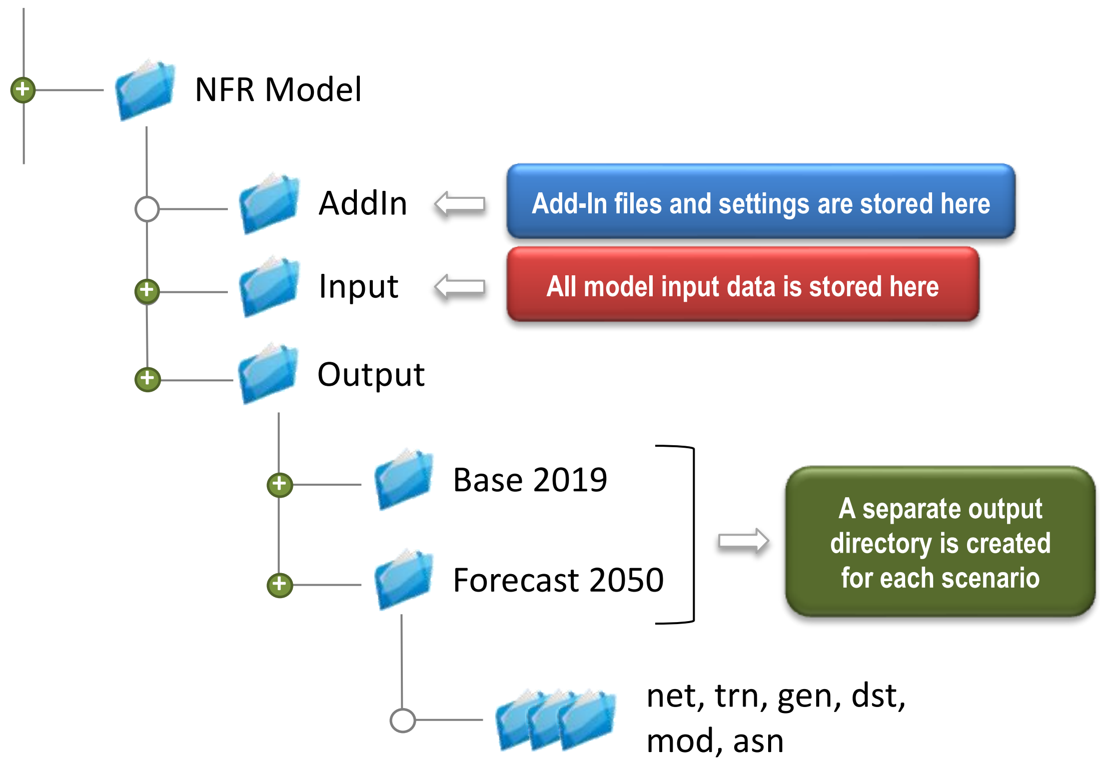
### *2.1.1 Input and Output Networks*

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. The model creates and modifies a copy of the input roadway network each time it 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.
- 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., 2019, 2045) or the string BC12 (Backcast 2012) or Unc (Unconstrained) |
| FT_yyyy | Scenario-specific facility type (see Table 2.3 for definition) | |
| BIKEFT_yyyy | Bicycle facility type. | |

| Field Name | Description | Comments |
|---|---|---|
| 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. | Managed or express lanes are coded using the TOLL_CODE_yyyy field and accompanying toll table, not with HOV_yyyy. |
| | A value of "3" indicates that the link is an HOV lane that permits vehicles with 3 or more occupants. | |
| AB/BA_FBAM_yyyy<br>AB/BA_FBOP_yyyy | Scenario-specific fields used to hold speed feedback results. These fields are managed by the travel model interface. | |
| NFR_SCRL | Indicates whether the link is on a screenline, and if so, which screenline | |
| 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 | Value — Subregion | Subregion identifiers were used for model validation and reasonableness checks, but to not reflect city limit or growth management area (GMA) details. |
| | 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 | |

| Field Name | Description | Comments |
|---|---|---|
| COUNTY | Optional county name | |
| NFRMPO | Identifies links within the MPO boundary | |
| Expand | Identifies links that are in the expanded ozone non-attainment region. (See note 1) | |
| | 1 = Links in the unexpanded area (includes the MPO area and areas to the north and south of the MPO) | |
| | 2 = External station connectors for the unexpanded area | |
| | 3 = All links in the expanded area | |
| 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 | Validation year, month, notes, ID, and override fields are not required by the model but have been retained on the network for reference. |
| VAL_Year | Year validation count was taken | |
| VAL_Month | Month validation count was taken | |
| VAL_Notes | Notes taken during validation process | |
| VAL_MTruck | Classified counts: medium truck | |
| 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_2019).
- 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. When using the network editor accessible from the model dialog box, some aspects of the Dir attribute is handled automatically.

### *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**.

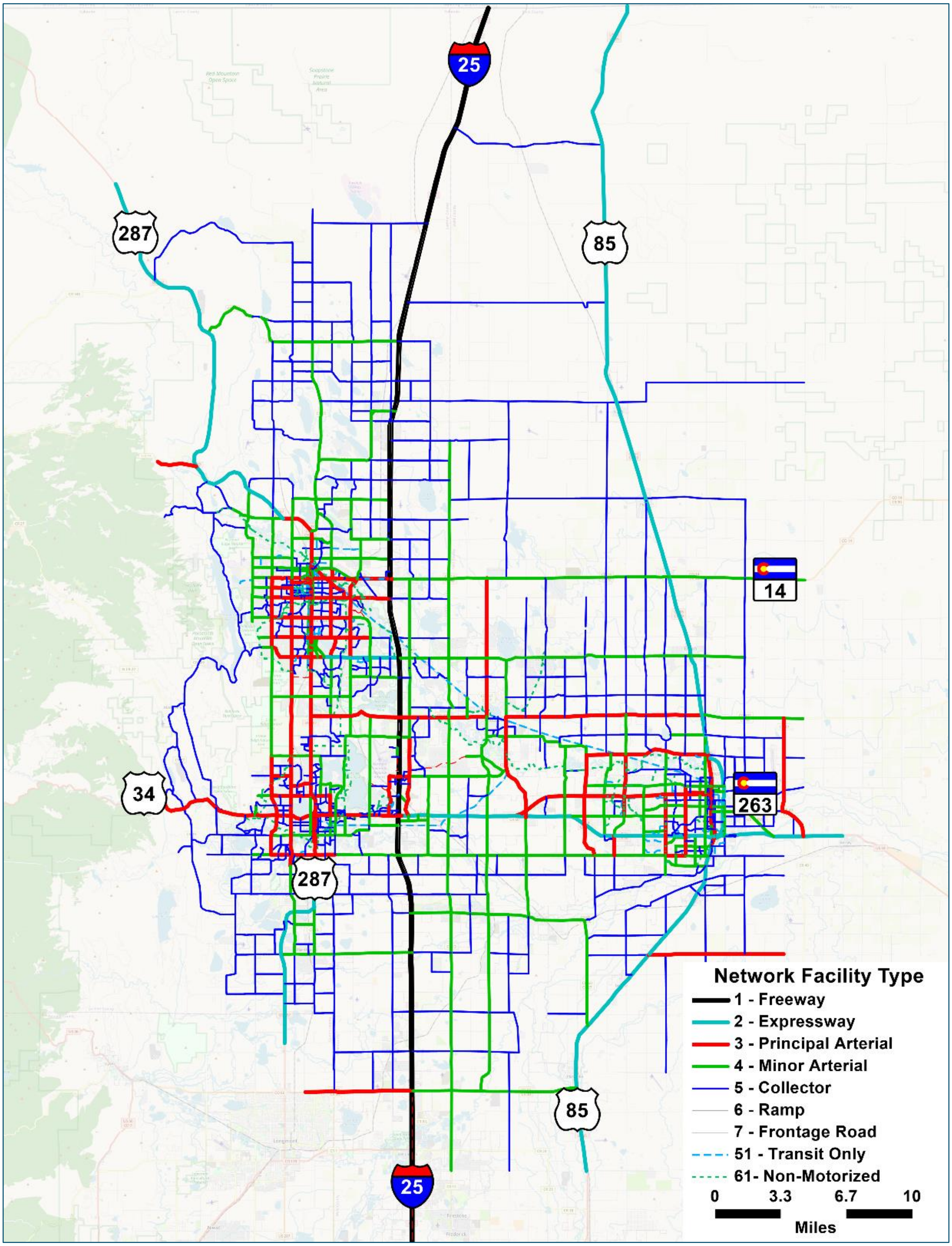
**Table 2.4** demonstrates the relationship between interstate, expressway, arterial, collector, and local facility types, and a description of each facility type follows.

## 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 |

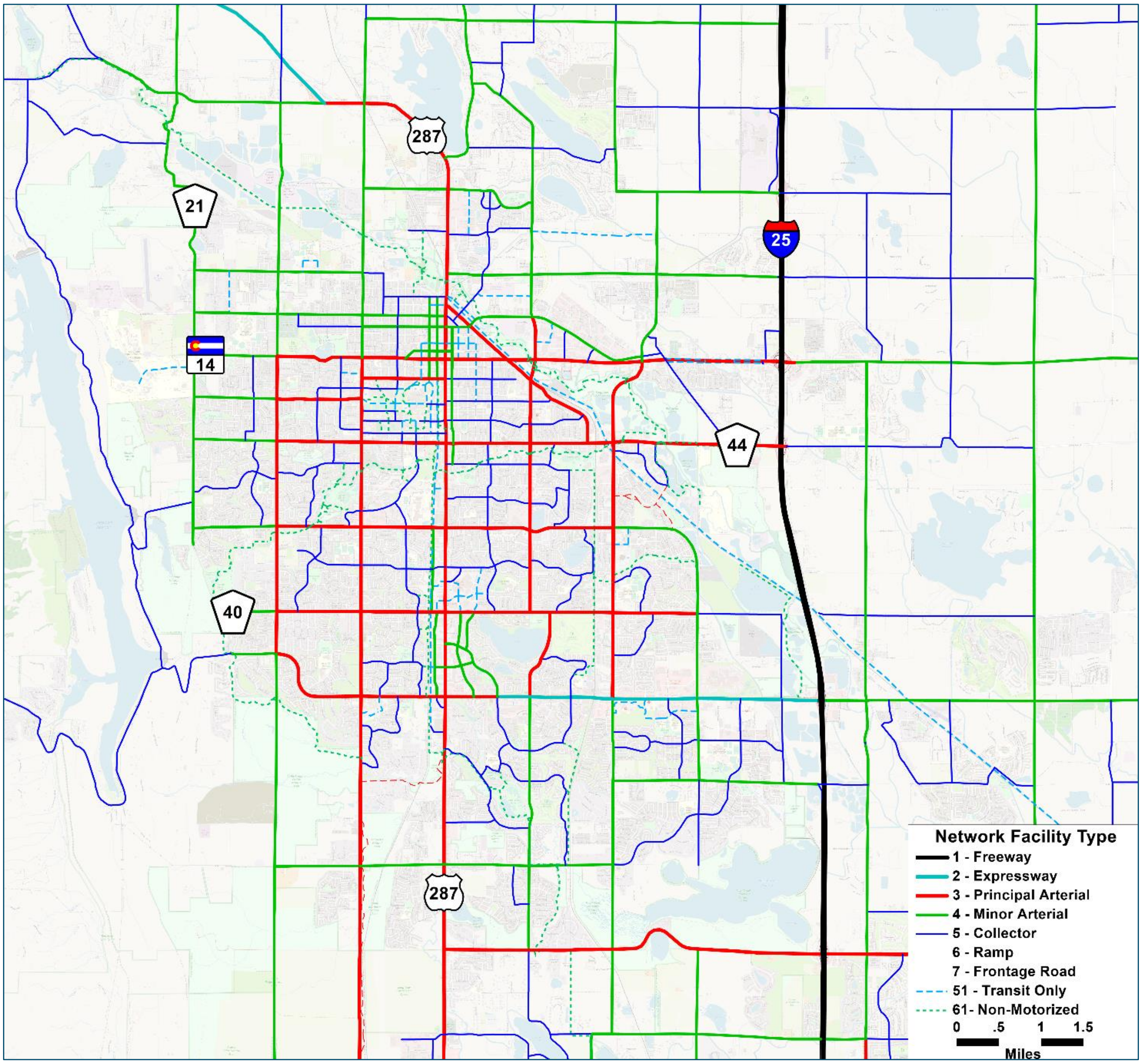
## Figure 2.2 2019 Facility Type Designations

*MPO Region*

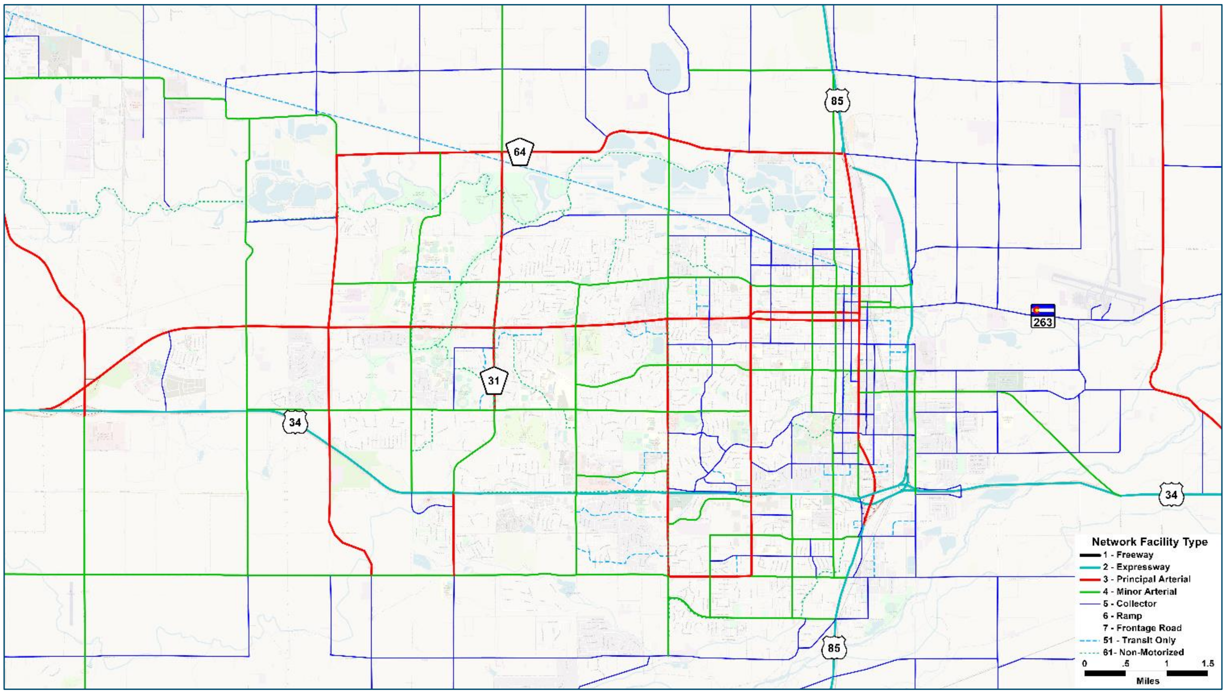


## Figure 2.3 2019 Facility Type Designations

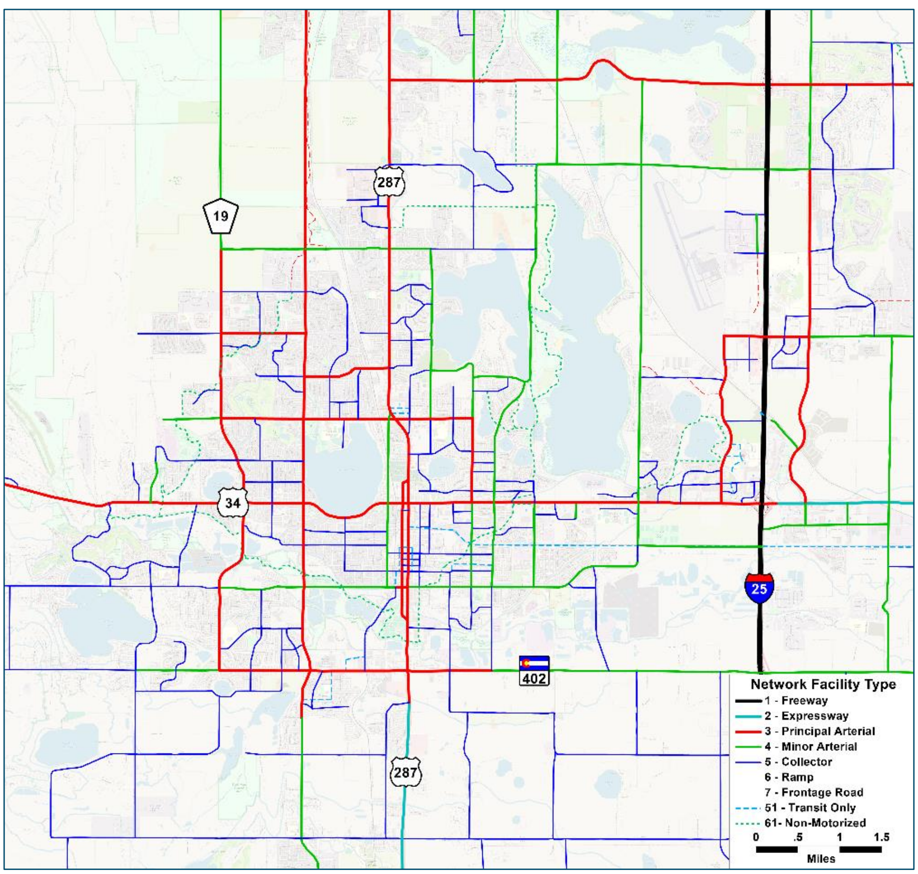
*Fort Collins*



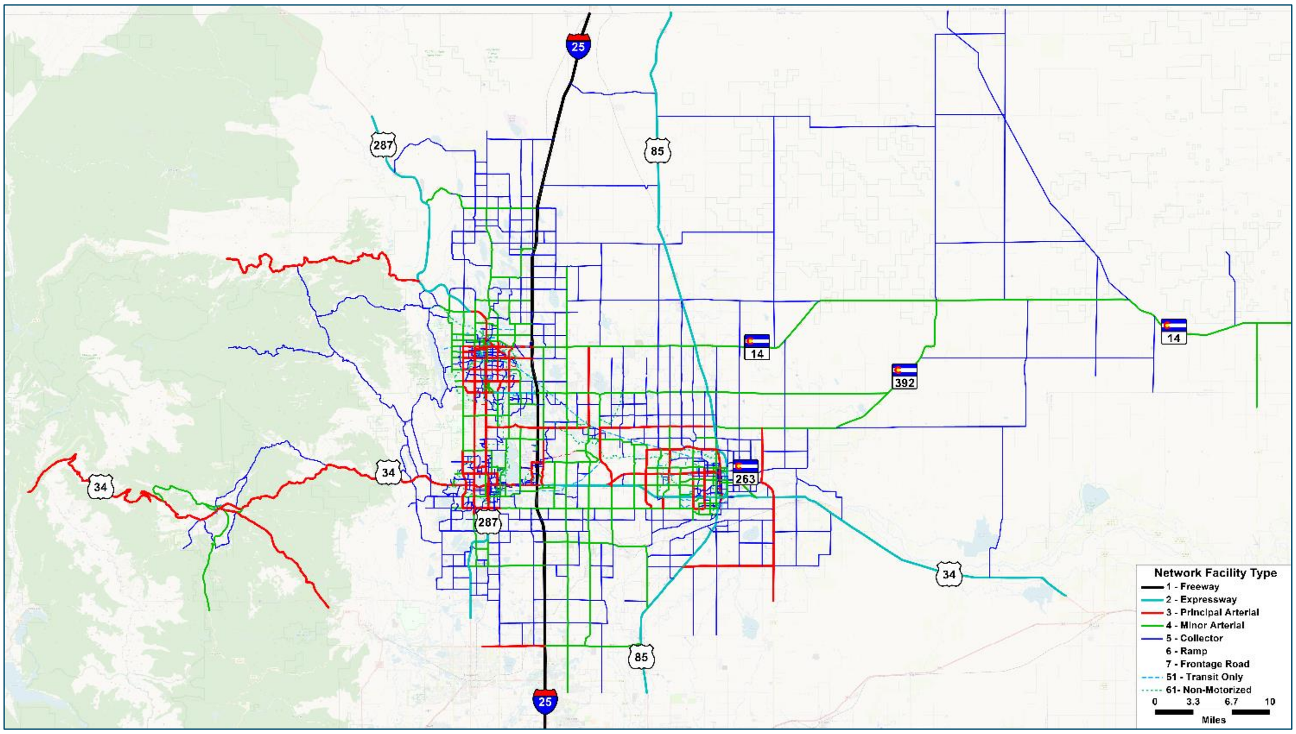
## Figure 2.4 2019 Facility Type Designations
*Greeley*




## Figure 2.5 2019 Facility Type Designations
*Loveland*



## Figure 2.6 2019 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 U.S. 34 and U.S. 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 U.S. 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 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.

### 2.2.5 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 2019. 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 2.5**. 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 2.6**. 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 2.7** and **Table 2.8**.

## Table 2.5 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 2.6 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 | 0.85 | 0.84 | 0.9 | 0.96 | 1 |
| 3 | Principal Arterial | 0.85 | 0.84 | 0.88 | 0.9 | 0.96 |
| 4 | Minor Arterial | 0.84 | 0.88 | 0.93 | 0.96 | 0.96 |
| 5 | Collector | 0.75 | 0.7 | 0.85 | 0.85 | 0.98 |
| 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 2.7 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 2.8 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 | 0.6 | 0.57 | 0.57 | 0.82 | 0.85 |
| 3 | Principal Arterial | 0.6 | 0.56 | 0.56 | 0.56 | 0.58 |
| 4 | Minor Arterial | 0.57 | 0.58 | 0.58 | 0.58 | 0.58 |
| 5 | Collector | 0.5 | 0.47 | 0.5 | 0.55 | 0.8 |
| 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.

### 2.2.6 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 2015 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 Manual (HCM) provides guidance on the definition of roadway capacity.[1] 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 applied.[2]

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

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

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 HCM according to selected freeflow speed values are shown in **Table 2.9**, along with adjusted capacities computed using Equation (2).[3] 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 2.9 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]

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

*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 2.10**, along with resulting capacity values.

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

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

[4] HCM 2000, p. 30-5

$f_a$ = 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 2.10 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 2.10** 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 2.11**. 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 2.11 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 | 2,100 |
| 2 | Expressway | 740 | 830 | 920 | 1200 |
| 3 | Principal Arterial | 740 | 830 | 920 | 960 |
| 4 | Minor Arterial | 650 | 705 | 760 | 790 |
| 5 | Collector | 590 | 635 | 680 | 710 |
| 6 | Ramp | 650 | 700 | 750 | 800 |
| 7 | Frontage Road | 590 | 635 | 680 | 710 |
| 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.

### 2.2.7 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 2.12**. 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 2.12 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 |

### 2.2.8 Bicycle Facility Type

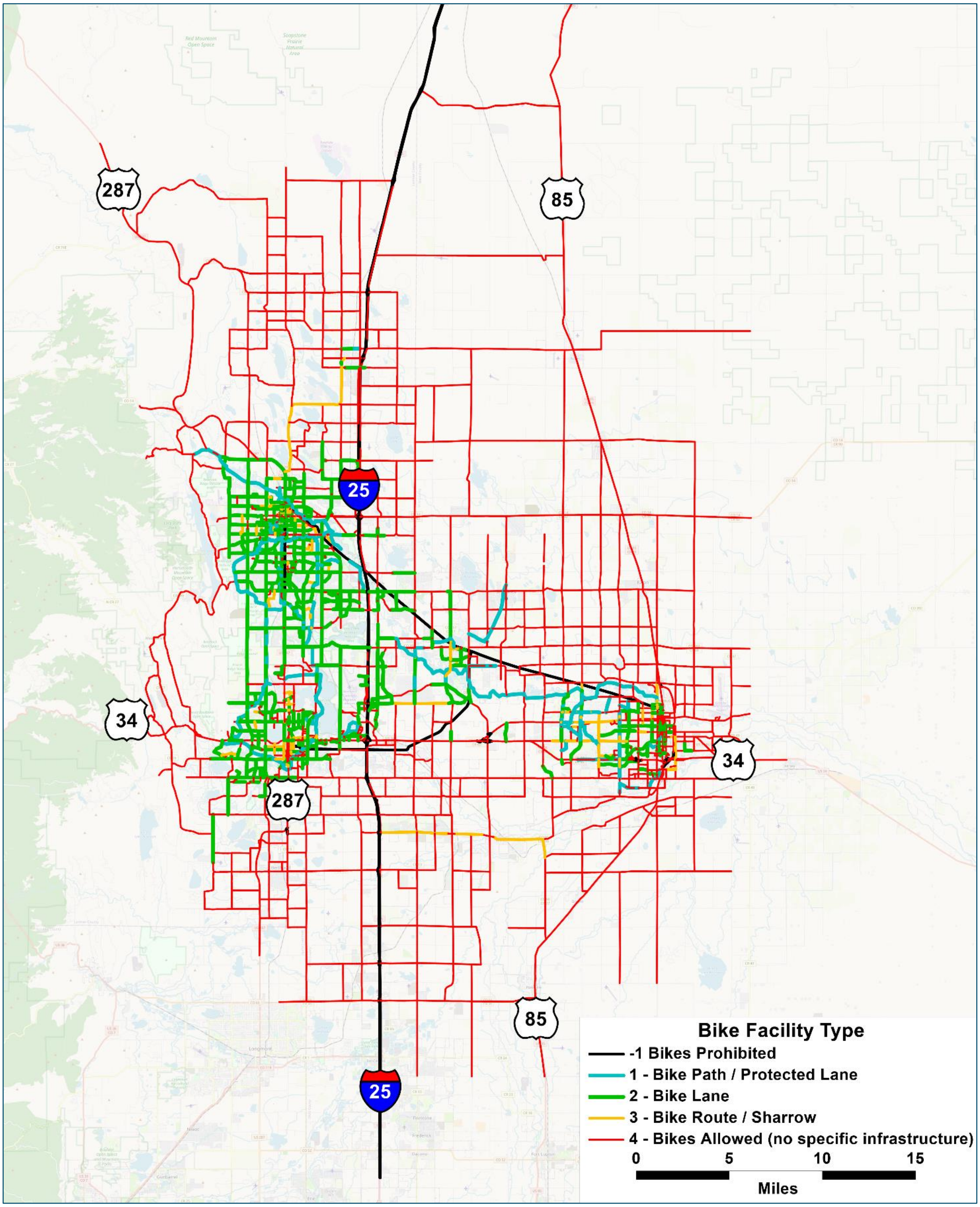
The NFR Model includes a bicycle facility type, which reflects the type of bicycle treatment on each link in the network. Bicycle facility type is defined by the network variable BikeFT and is defined as shown in **Table 2.13**. In addition, the network includes a non-motorized facilities such as bike paths, which are coded with a roadway facility type value of 61. 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 2019 base year network are shown in **Figure 2.7** through **Figure 2.11**.

## Table 2.13 Bicycle Facility Type Definitions

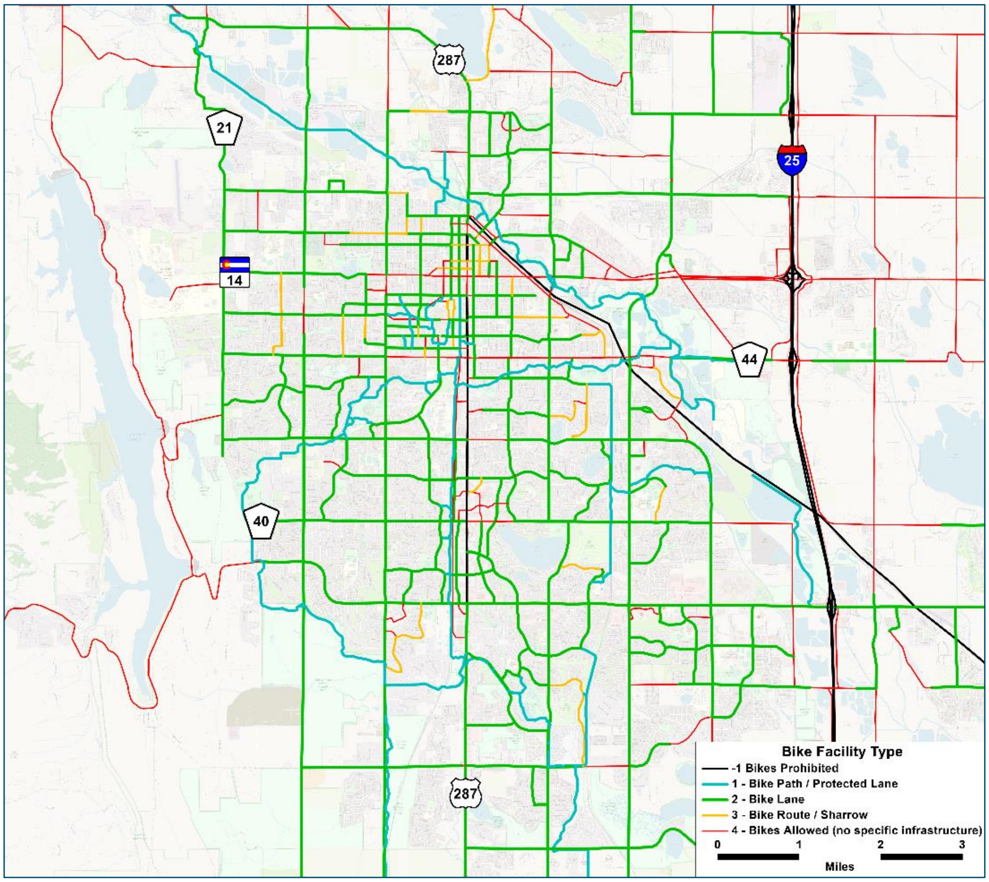
| Bicycle Facility Type | Description |
|---|---|
| 1 | Bike trails / mixed use paths / Protected bike lanes |
| 2 | Bike lanes |
| 3 | Bike routes / Sharrows |
| 4 | No specific treatment, but bikes allowed |
| -1 | Bikes prohibited |

## Figure 2.7 Bicycle Facility Types

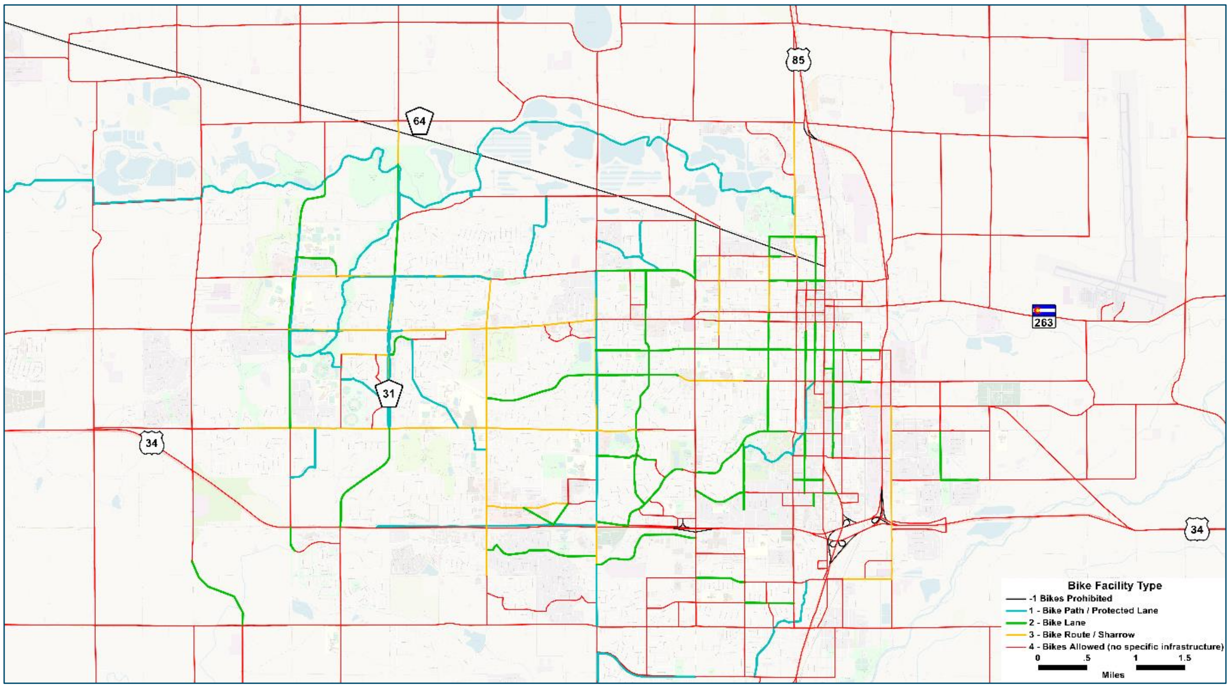
*MPO Region*



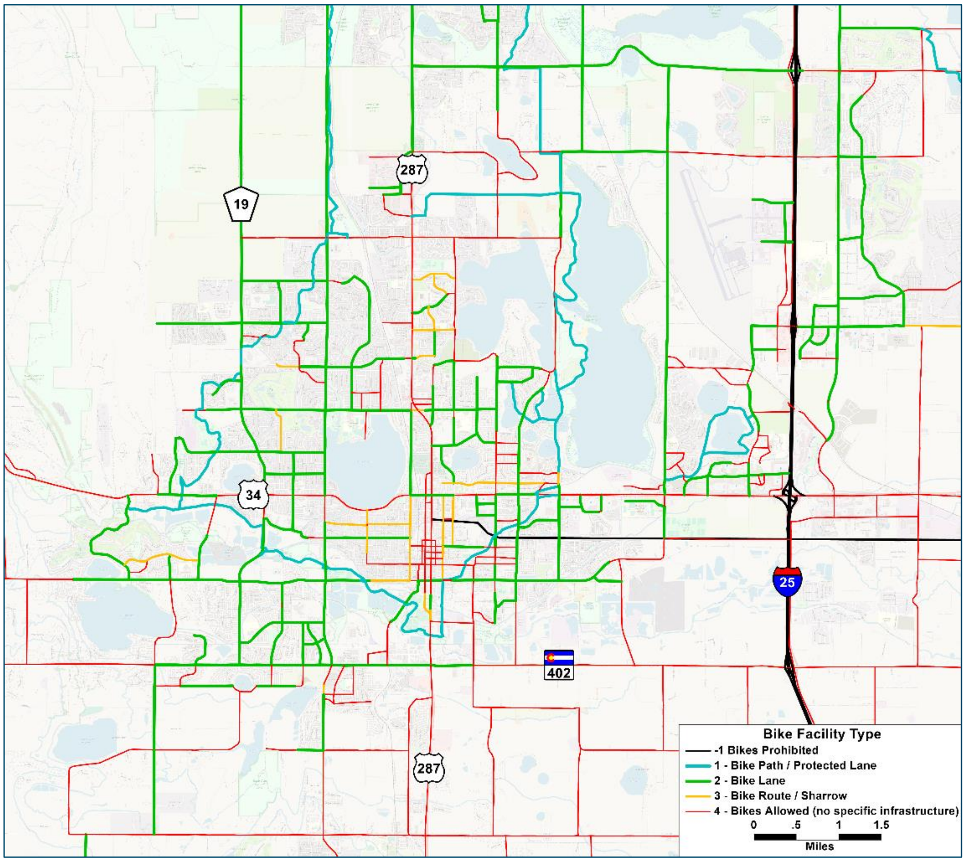
## Figure 2.8 Bicycle Facility Types
*Fort Collins*



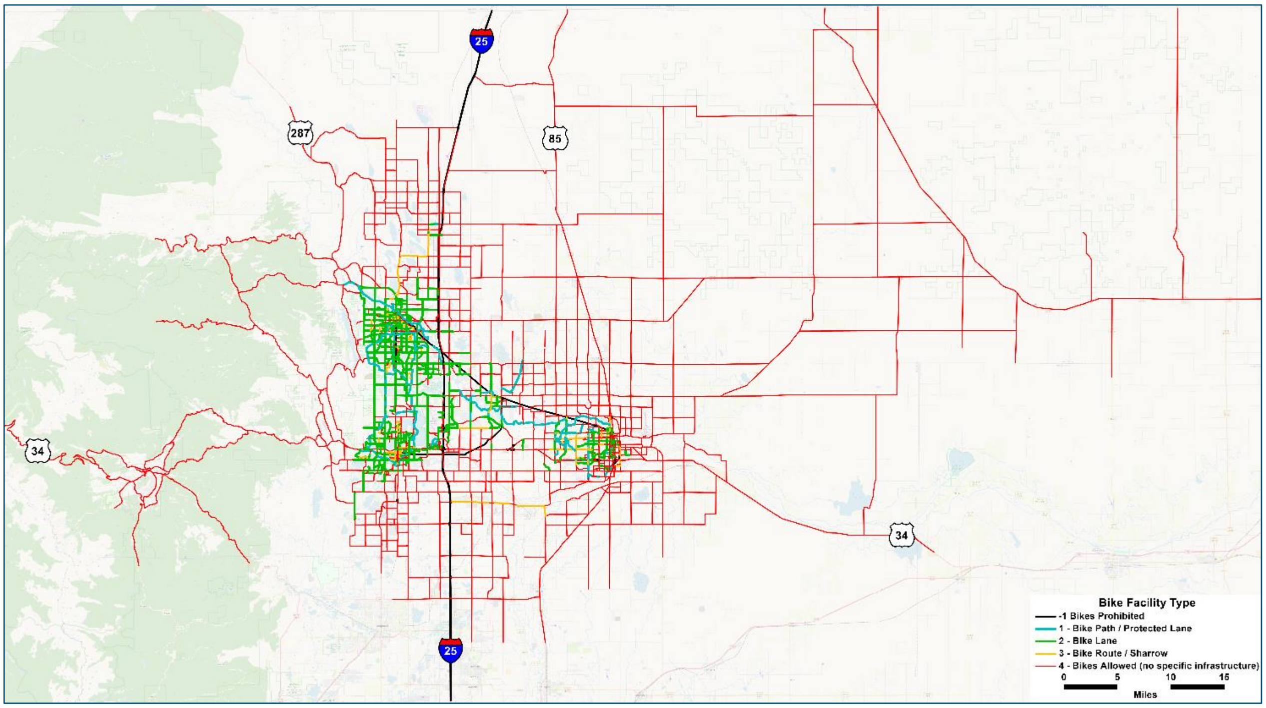

## Figure 2.9 Bicycle Facility Types
*Greeley*



## Figure 2.10 Bicycle Facility Types
*Loveland*




## Figure 2.11 Bicycle Facility Types
*Expanded Model Area*



### 2.2.9 Routable 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

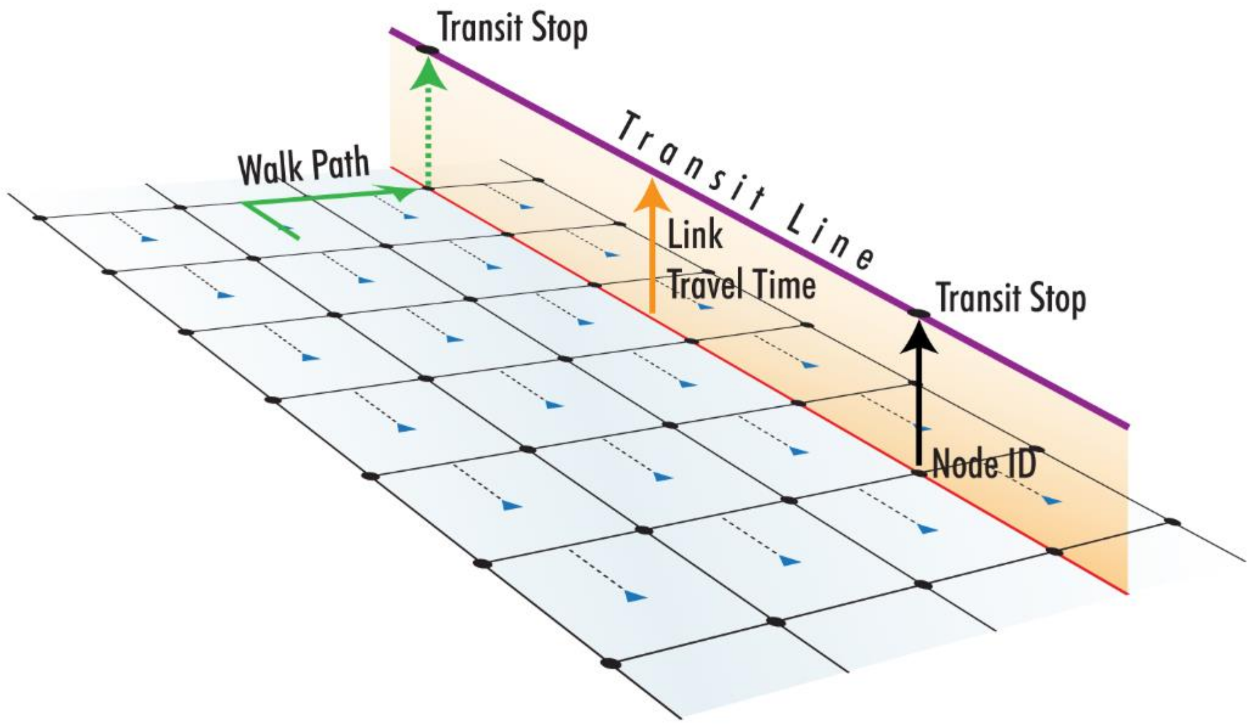
The following updates have been made to the transit networks for the 2019 model update:

- Transfort and City of Loveland Transit (COLT) routes have been updated based on 2019 service.
- Greeley-Evans Transit (GET) routes have been updated to represent a 2016 restructuring of the system.
- The interregional Bustang route has been added to the route system in 2019 (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.
- Some simplification and refinement of fields, procedures, and mode identifiers has been conducted.

## 3.1 Transit/Roadway Linkage

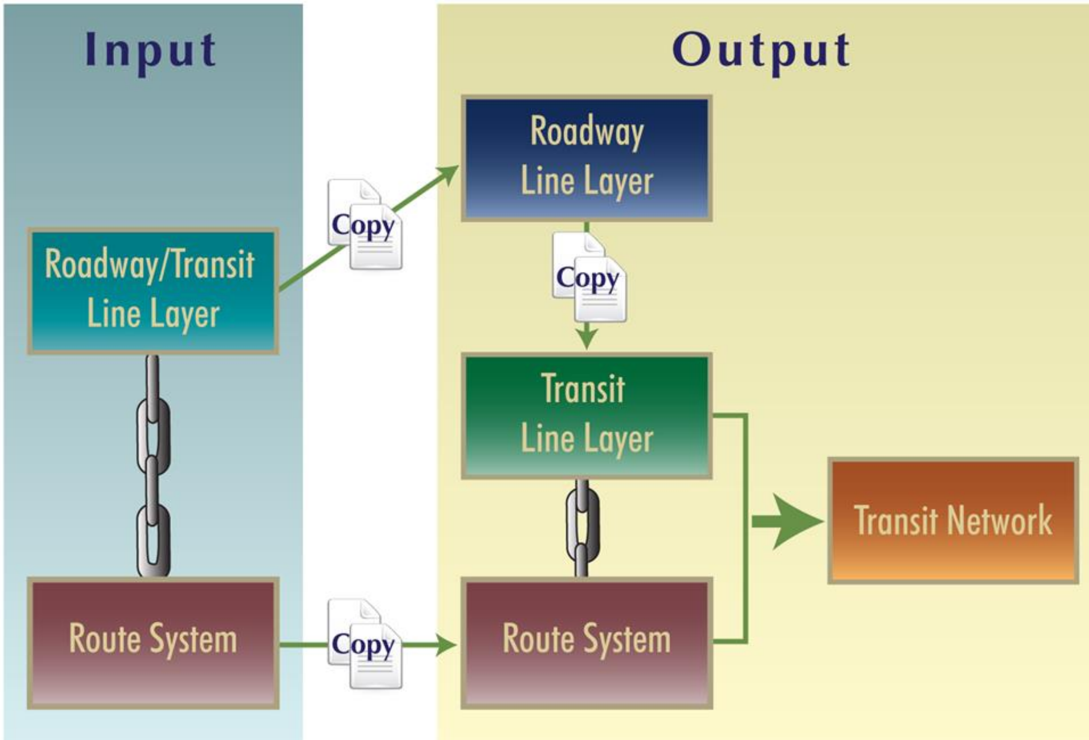
Transit networks in TransCAD are made up of two separate but connected layers: the transit route system and the transit line layer. Information from these two layers is combined as shown in **Figure 3.1** to allow representation of walk, drive, and in-vehicle components of a transit trip. Because these 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. |
| Notes | Optional field for storage of notes | This field can be useful to track or monitor route system editing activities. |

| Field Name | Description | Comments |
|---|---|---|
| Fare | Indicates the fare used in pathbuilding and mode choice | This value represents the average fare paid by non-university students.<br>Cost for 2019 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 2019 | 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<br>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., 2019, 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 2019 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 2019 base year route system are shown in **Table 3.2**.

### Table 3.2 2019 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 2019 transit routes.

## Figure 3.3 Base Year Transit Routes
*MPO Area*

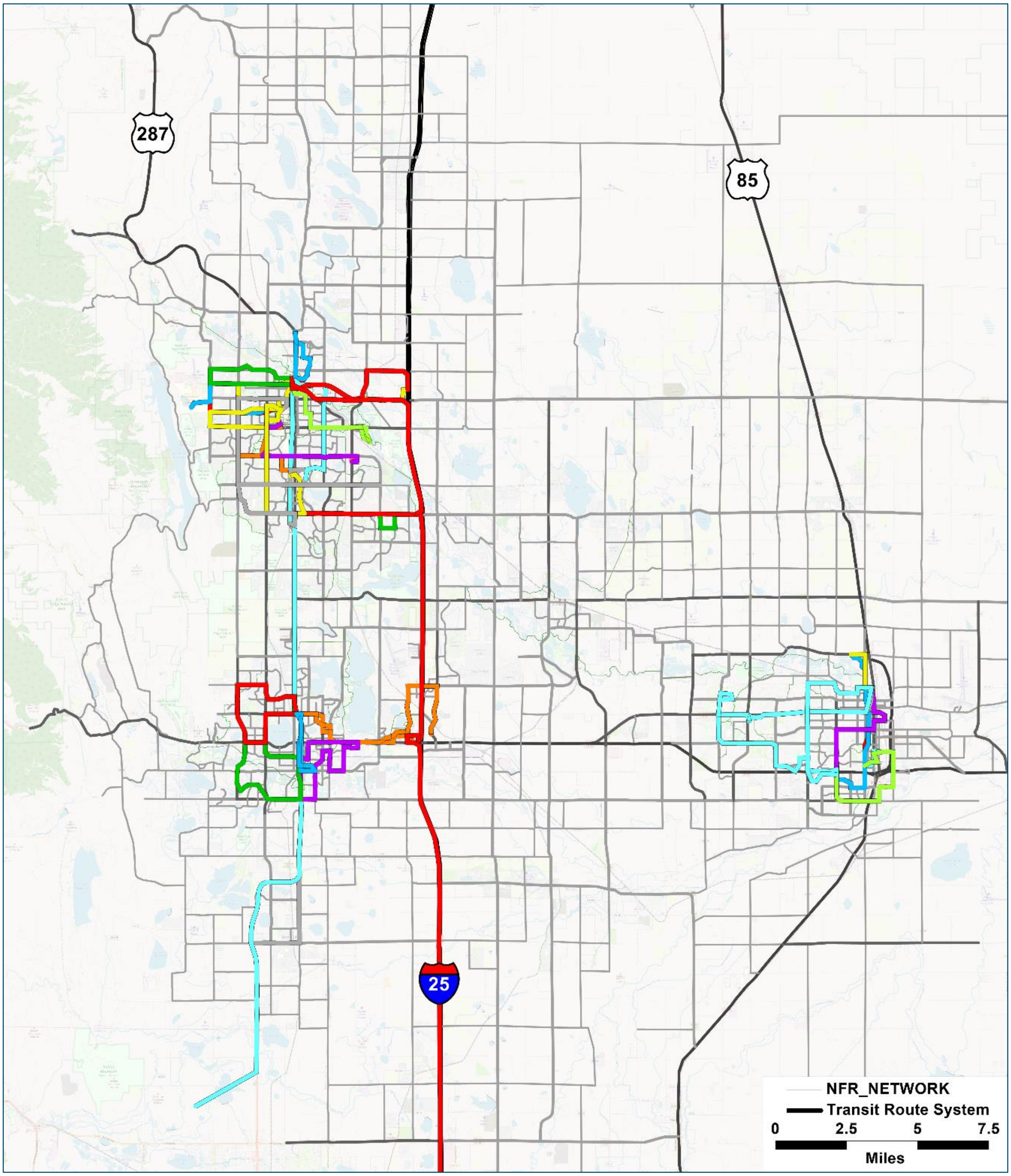
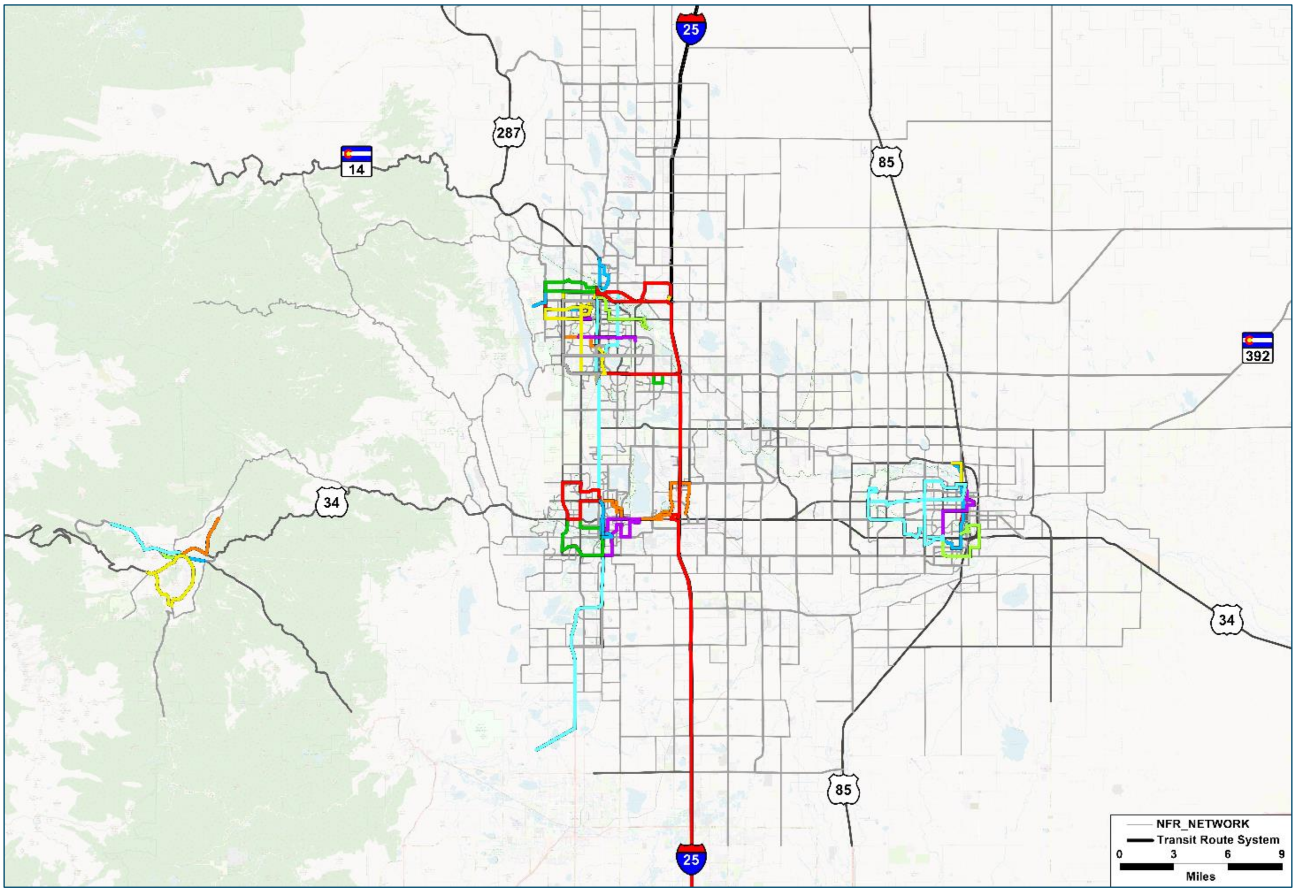


**Figure 3.4 Base Year Transit Routes**
*Expanded Model Area*




## 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<br>BA_OPTRTIM | Off-peak period transit time | Based on the off-peak link time resulting from speed feedback |
| AB_PKTRTIM<br>BA_PKTRTIM | Peak period transit time | Based on the AM congested link time resulting from speed feedback |
| AB_OPTRSPD<br>BA_OPTRSPD | Off-peak period transit speed | Calculated based on link time and length (for reference only) |
| AB_PKTRSPD<br>BA_PKTRSPD | Peak period transit speed | |
| 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*

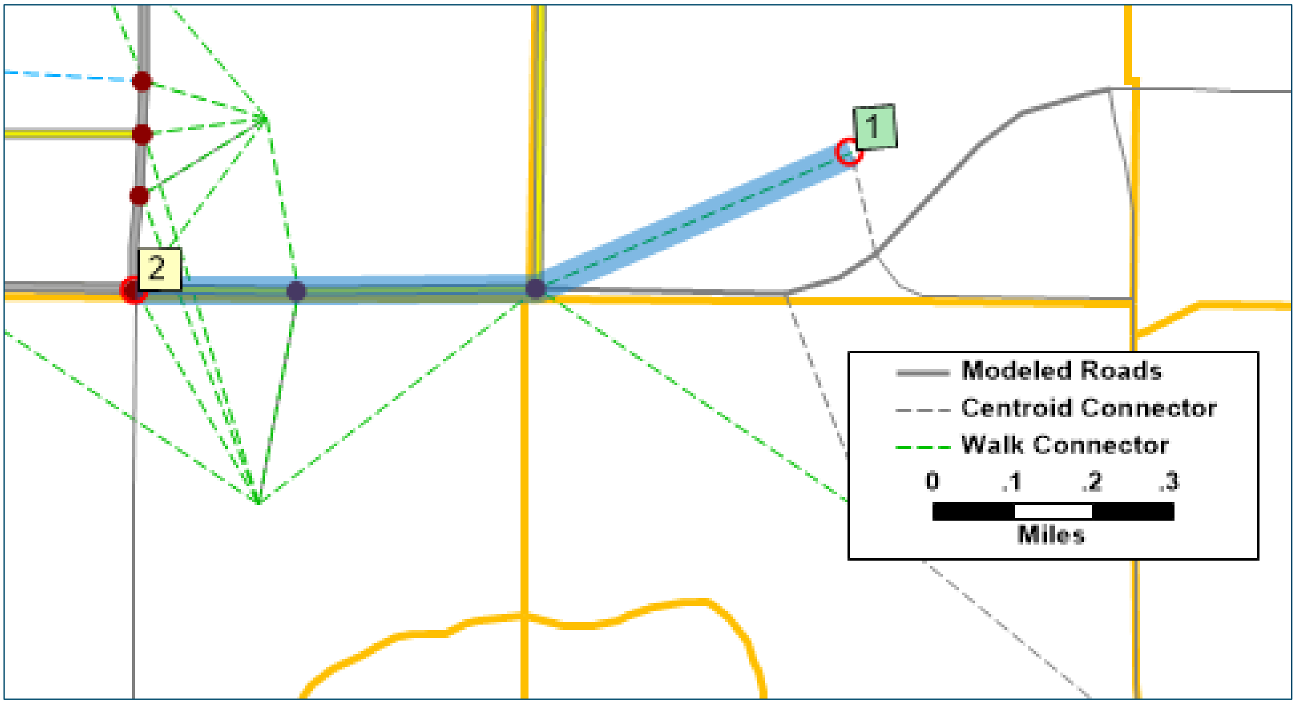
The transit line layer also represents the connection between TAZ centroids and transit route stops. Except for park-n-ride trips, all transit trips must start and end with the walk mode.[5] Several approaches are available for representing walk access to transit in TransCAD:

- ***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.

- 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[1] |
| Initial Wait Time (Long) | Initial wait time exceeding 7.5 minutes | 1[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.

1 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 U.S. 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

This model update includes minor updates to the TAZ layer and centroid connectors. The updated zone system is largely based on the traffic analysis zones developed for the 2015 model. The zone system has been expanded to include an additional portion of Weld County and to include additional zone detail in areas with planned developments requiring additional zone detail in forecast year model runs. In addition, 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 the current version of UrbanCanvas.

## 4.1 TAZ System Summary

The 2019 TAZ layer is based directly on aggregations of 2010 Census Block boundaries in a manner consistent with the 2015 model. 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 2015 definitions generally use the same zone number as the 2015 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 2015 TAZ layer.

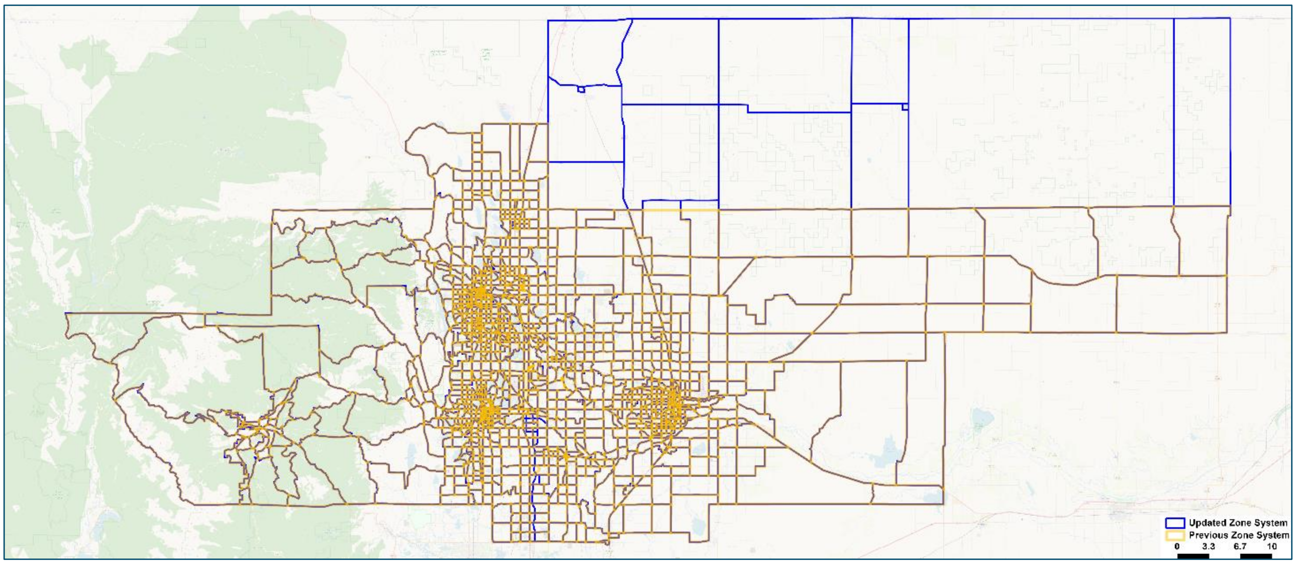
The TAZ layer is contained in a TransCAD geographic file and is a required input to the travel model. A listing of required fields in the TAZ geographic file can be found in **Table 4.1**. By design, the geographic file contains minimal data, with most information stored in separate tables that can be 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 |

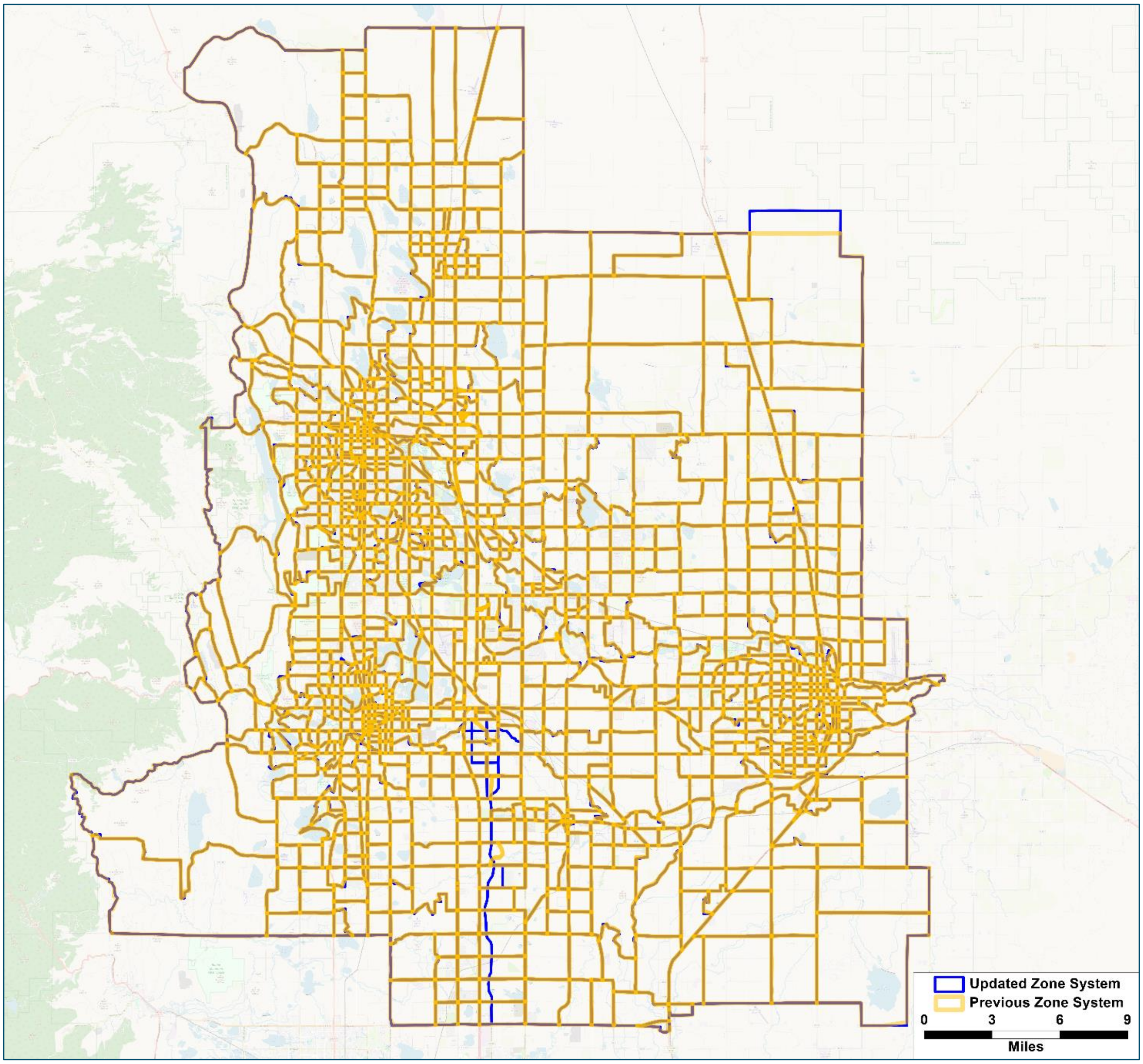
## Figure 4.1 TAZ Boundary Changes

*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**.

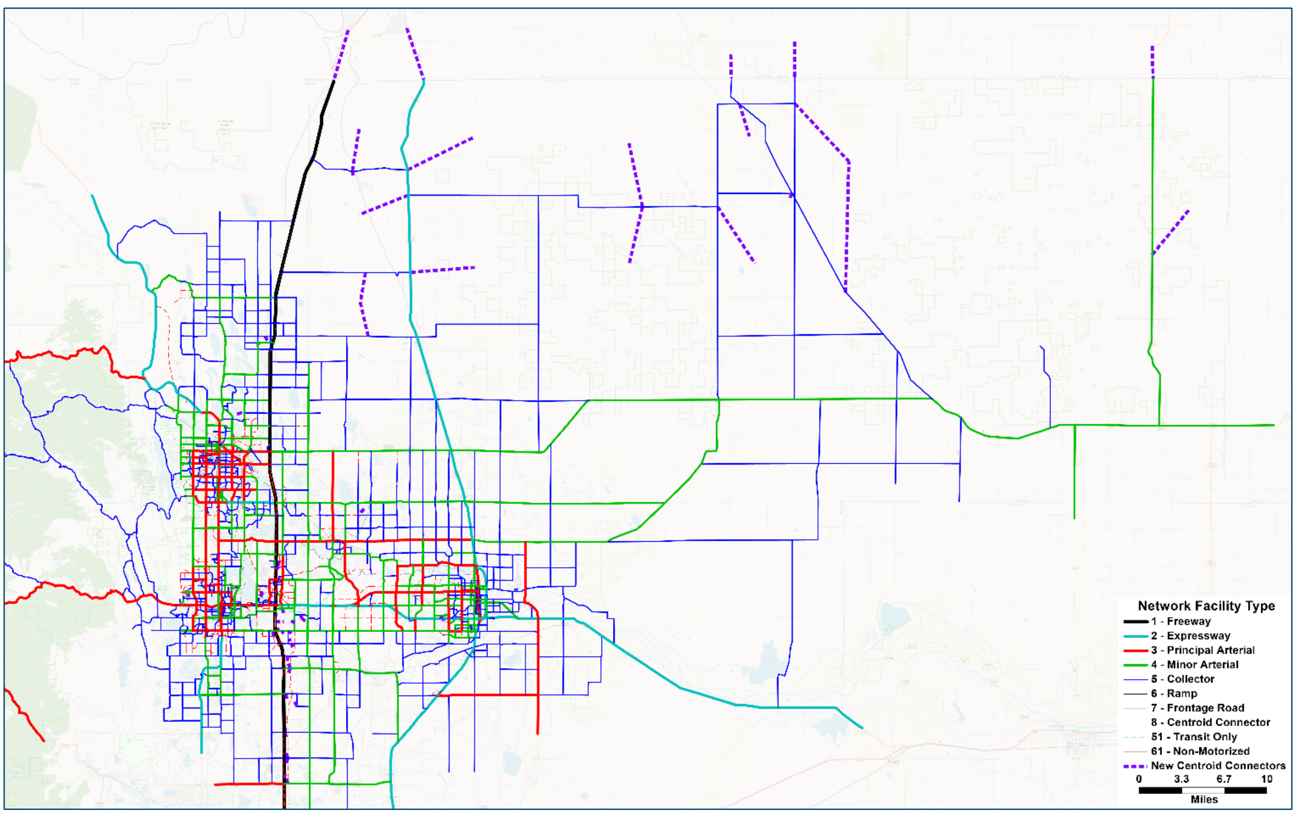
## Table 4.2 Distribution of Year 2012 and 2019 TAZs

| | 2015 Base Year Zones | | | Updated 2019 Base Year Zones | | |
|---|---|---|---|---|---|---|
| TAZs | Unexpanded | Expanded | Total | Unexpanded | Expanded | Total |
| Total number of TAZs | 1,103 | 102 | 1,205 | 1,123 | 115 | 1,238 |
| Average Size (Square Mile) | 1.04 | 19.12 | 2.6 | 1.03 | 29.3 | 3.6 |
| Average Number of Households | 174 | 110 | 168 | 188 | 92 | 179 |

| | 2015 Base Year Zones | | | Updated 2019 Base Year Zones | | |
|---|---|---|---|---|---|---|
| TAZs | Unexpanded | Expanded | Total | Unexpanded | Expanded | Total |
| Maximum Number of Households | 1,901 | 623 | 1,901 | 1,630 | 558 | 1,630 |
| Average Household Density (Households per Square Mile) | 716 | 72 | 662 | 748 | 56 | 683 |
| Maximum Household Density | 8,379 | 895 | 8,379 | 6,972 | 730 | 6,972 |
| Standard Deviation of Household Density | 1,118 | 182 | 1,086 | 1,098 | 144 | 1,066 |
| Average Employment | 248 | 76 | 234 | 214 | 99 | 203 |
| Maximum Employment | 5,559 | 1,033 | 5,559 | 5,493 | 2,717 | 5,493 |
| Average Employment Density (Jobs per Square Mile) | 1,271 | 77 | 1,170 | 1,172 | 87 | 1,071 |
| Maximum Employment Density | 55,079 | 1,468 | 55,079 | 61,545 | 2,332 | 61,545 |
| Standard Deviation of Employment Density | 3,990 | 229 | 3,832 | 3,718 | 301 | 3,556 |

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<br>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<br>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 2019 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.
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 2015 and 2019 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.

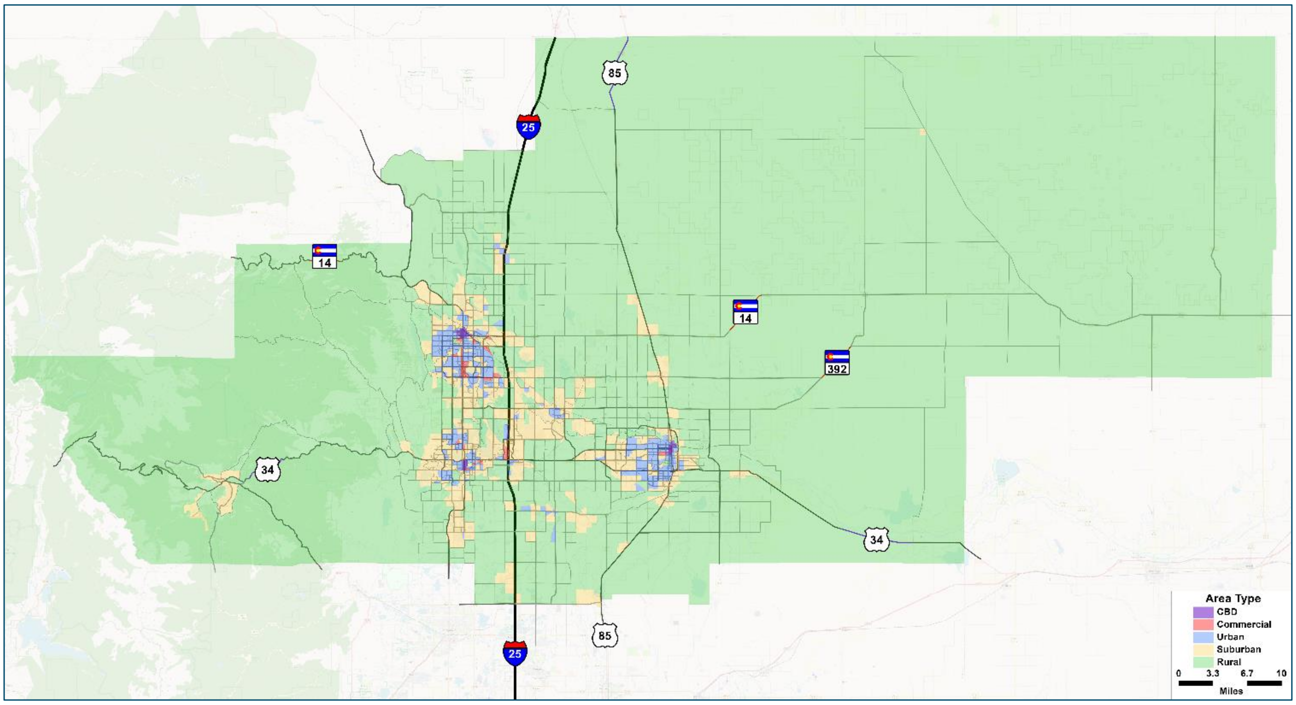
## Table 4.4 Area Type Designations

| 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.

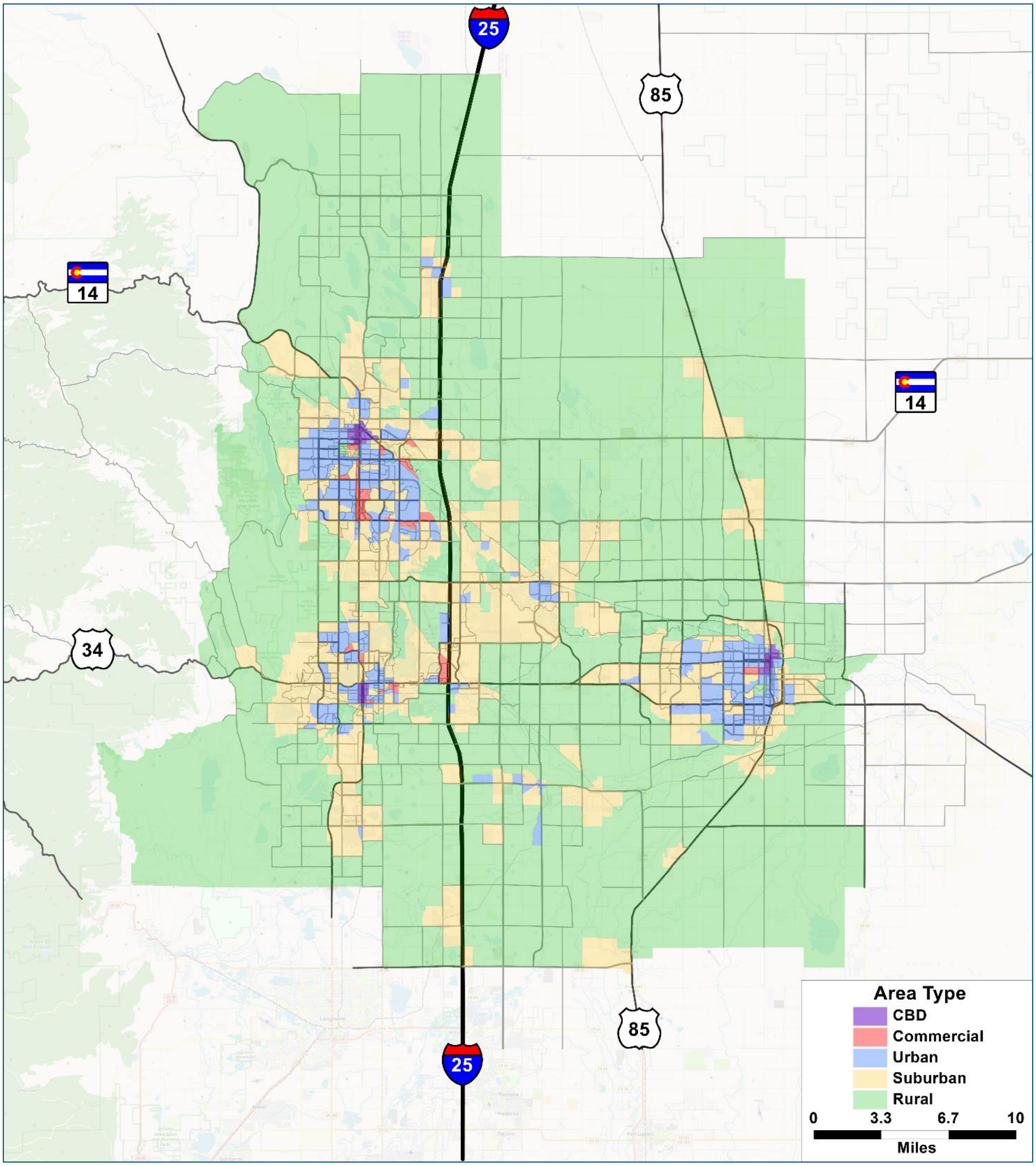
## Figure 4.4 Base Year Area Type

*Expanded Model Area*

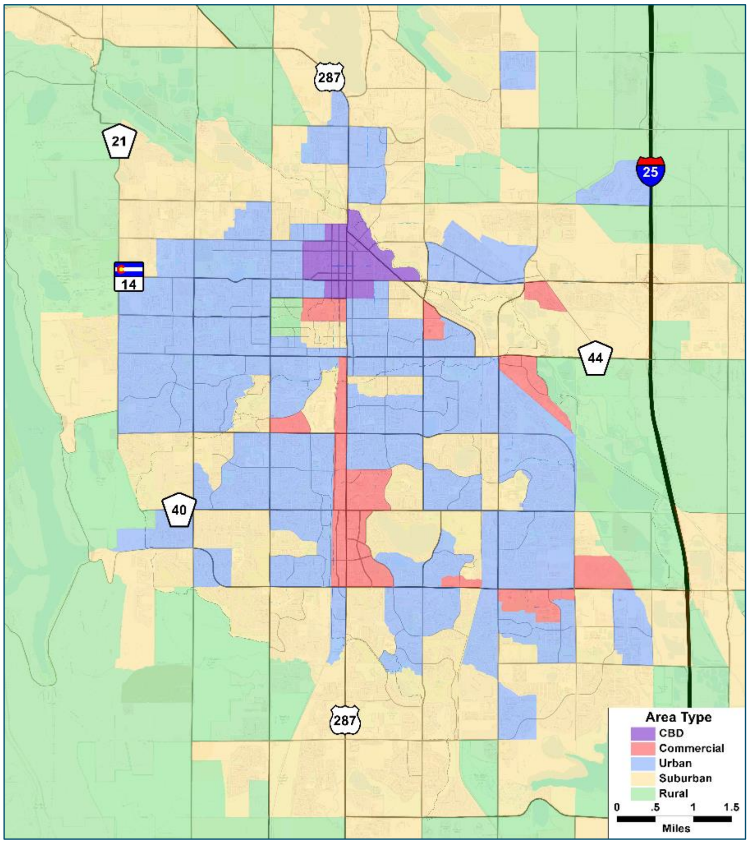


## Figure 4.5 Base Year Area Type

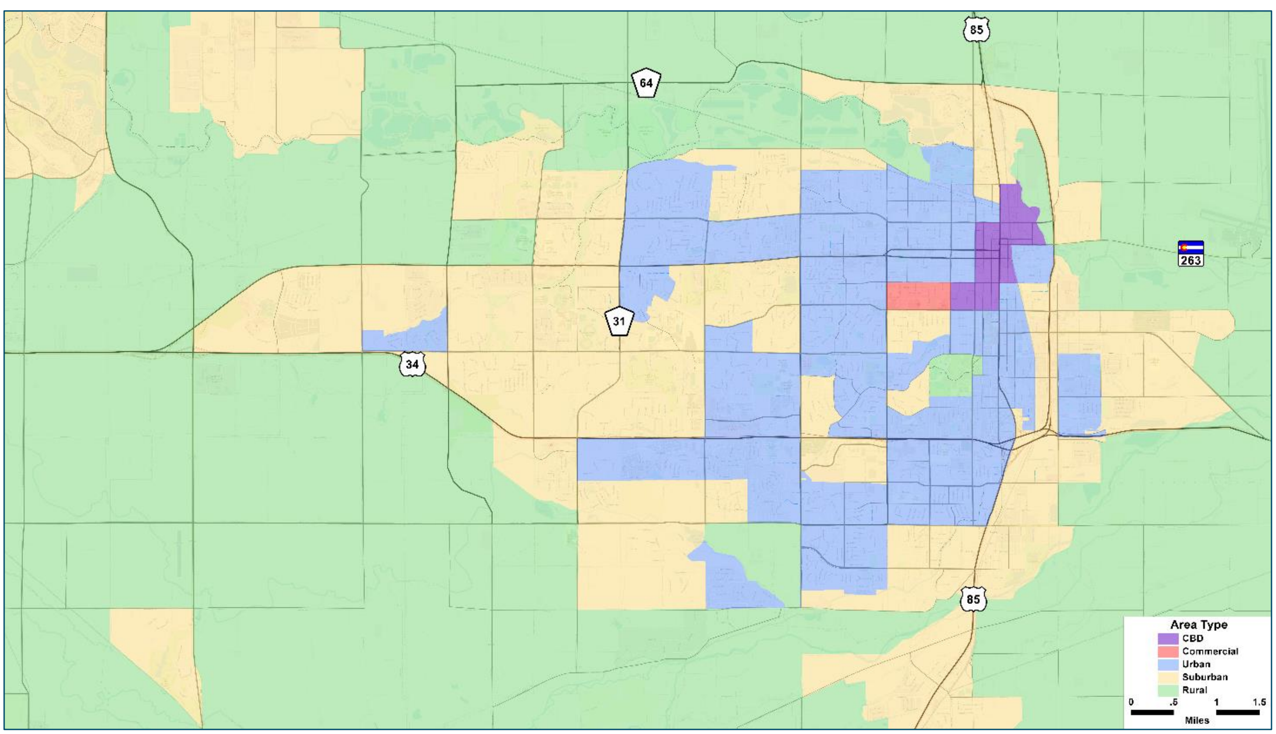
*Unexpanded MPO Region*



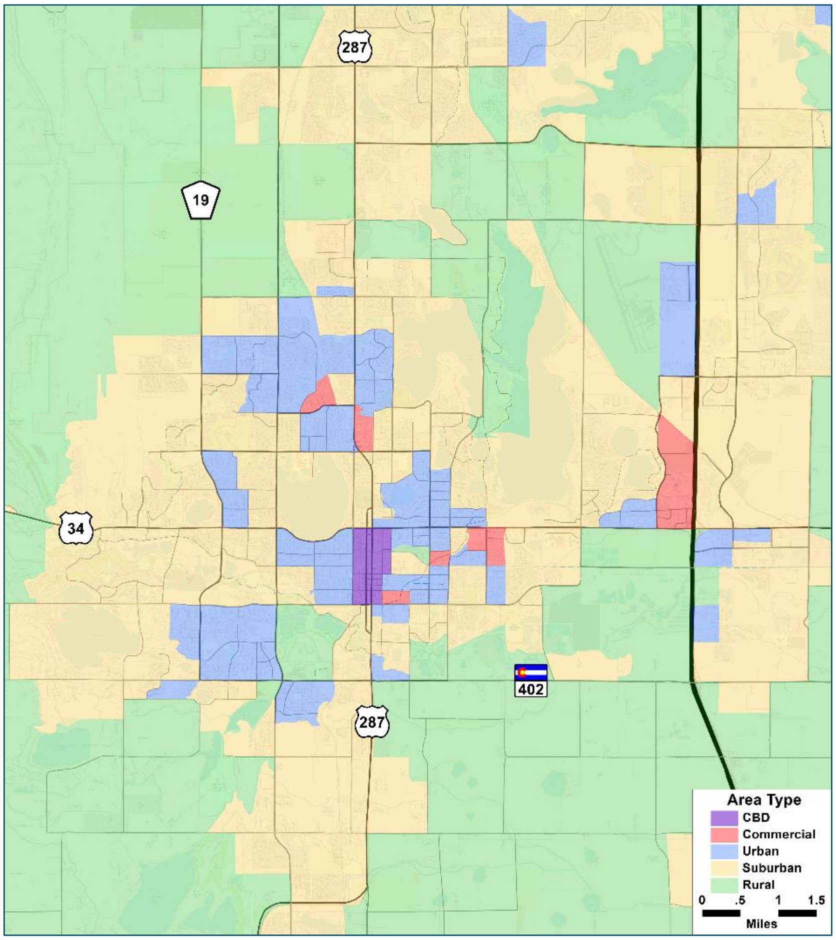
## Figure 4.6 Base Year 2019 Area Type Designations
*Fort Collins*




## Figure 4.7 Base Year 2019 Area Type Designations
*Greeley*



## Figure 4.8 Base Year 2019 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.
- Average 2-hour parking costs (assumed to be free everywhere in the NFR modeling area for 2019).

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 by 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 2019 dollars. Since all costs in the model are reflected in 2010 dollars, a Consumer Price Index (CPI) for 2019 and

2010 was applied to adjust the 2019-dollar parking costs to costs in 2010 dollars (88.5% of 2019 dollars).[6] The final average daily parking costs for Fort Collins for 2019 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 / 2019 dollars) | 0.8852 | 0.8852 | |
| 2019 Average Daily Parking Costs for 2019 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 days per year was used to estimate an average daily parking cost.[7] Adjusting the 2019 parking costs to 2010 dollars, the overall average daily parking costs for CSU students for 2019 is $2.64, as shown in **Table 4.6**.

Parking costs for CSU faculty cost $600 per year. An assumption of 215 workdays per year was used to estimate an average daily parking cost.[8] Adjusting the 2019 parking costs to 2010 dollars, the average daily parking costs for CSU students for 2019 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 2019 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 / 2019 dollars) | 0.8852 | |
| **2019 Average Daily Parking Costs for 2019 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 / 2019 dollars) | 0.8852 |
| **2019 Average Daily Parking Costs for 2019 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 / 2019 dollars) | 0.8852 |
| **2019 Average Daily Parking Costs for 2019 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 / 2019 dollars) | 0.8852 |
| **2019 Average Daily Parking Costs for 2019 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:

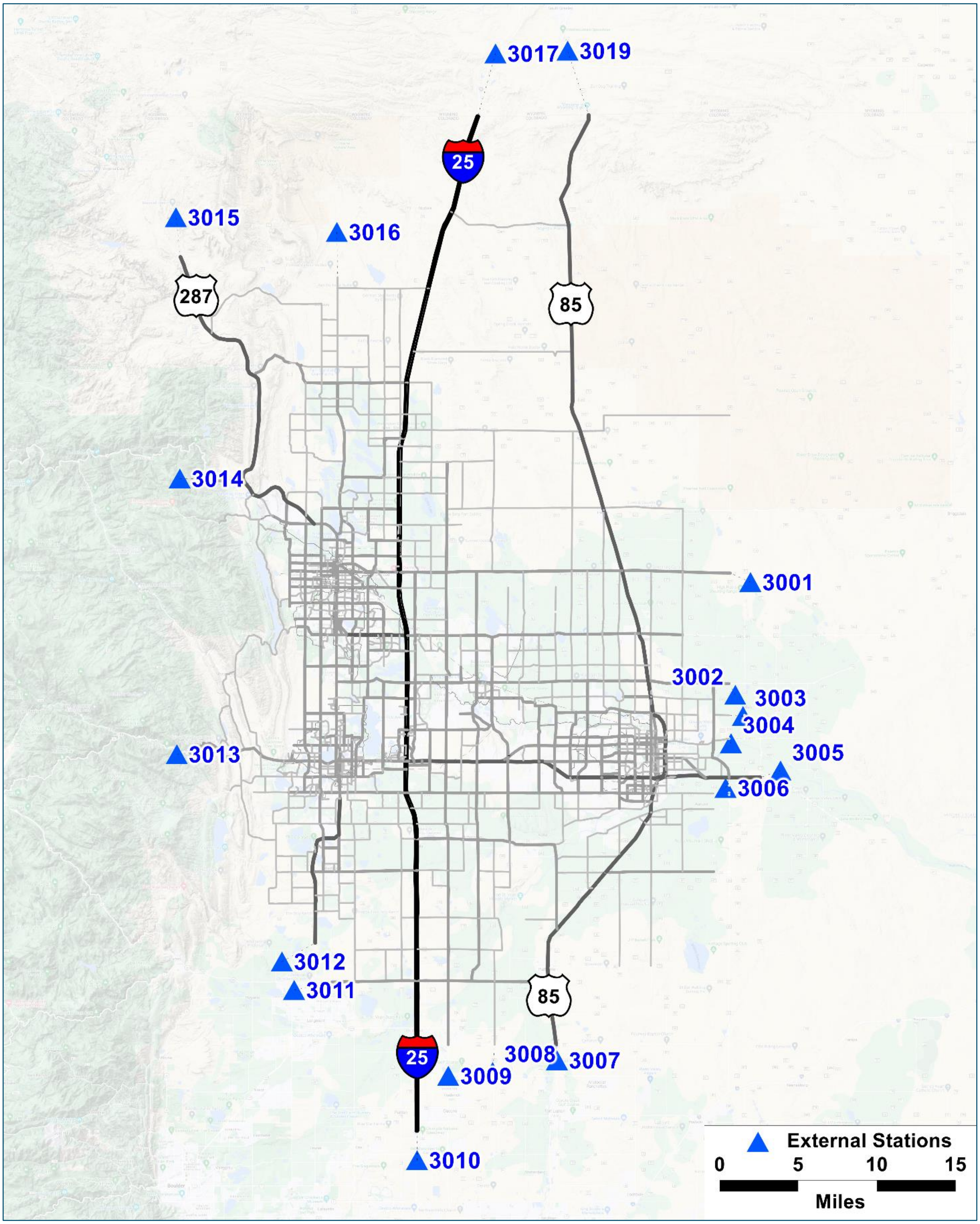
- Traffic volumes have been updated based on traffic count data collected as close to 2019 as possible.
- Several external stations have been modified from the previous mode network to account for the additional zones in Weld County.
- External station assumptions have been validated using Location Based Services (LBS) data obtained from StreetLight data.[9]
- 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.

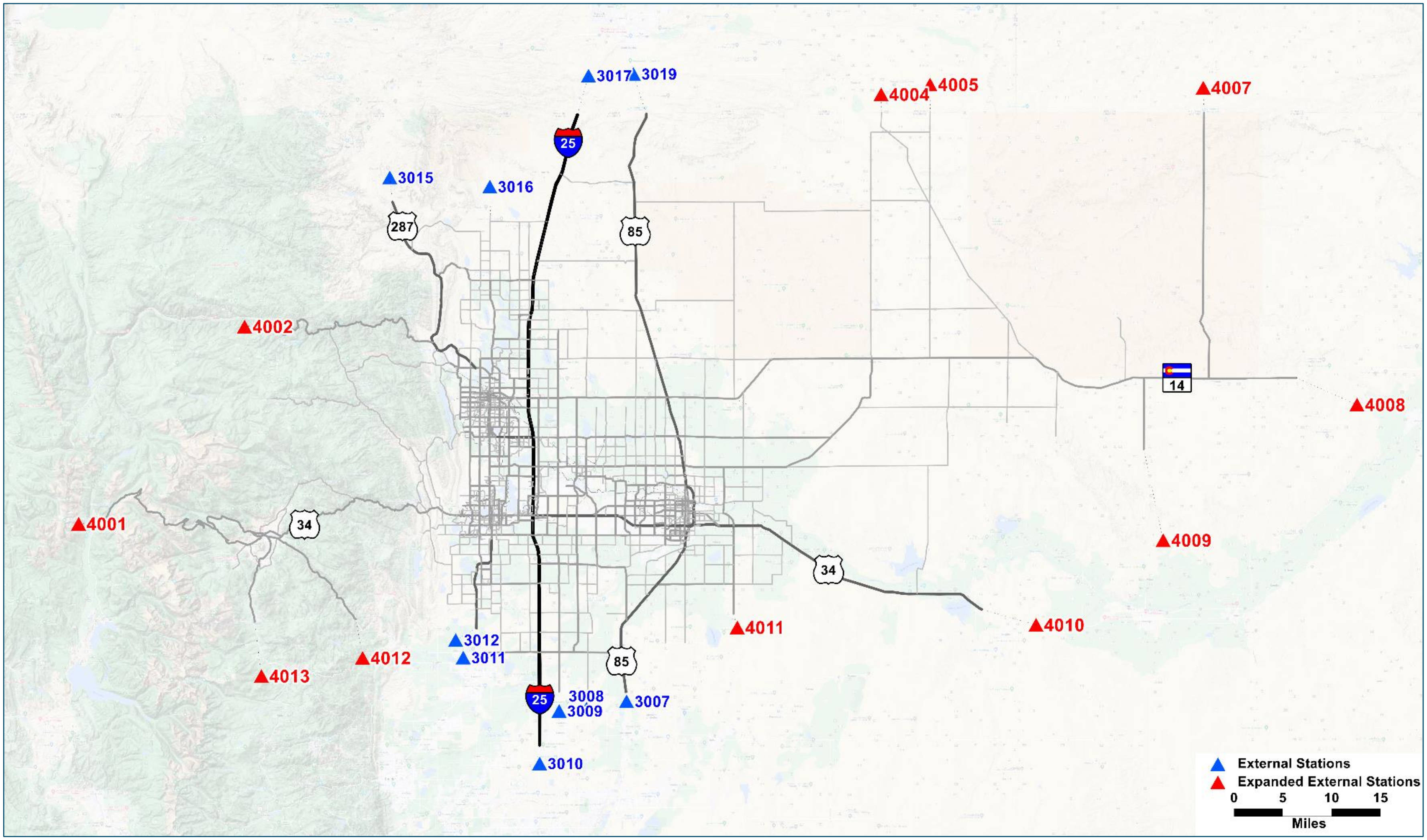
[9] CDOT obtained StreetLight Data to support refinement of the commercial vehicle portion of the model for a study of mobility in Northern Colorado.

## 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 previously calculated using the *2006 North Front Range External Travel Study* and have been updated through analysis of LBS data. Resulting assumptions 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 are removed and new external stations numbered 4001 through 4013 are 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 | 2019 Total Volume (Vehicles) | Auto EE % | Medium Truck EE % | Heavy Truck EE % |
|---|---|---|---|---|---|
| 3001 | SH 14 East | 1,625 | 13% | 20% | 20% |
| 3002 | SH 392 East | 2,649 | 10% | 0% | 20% |
| 3003 | CR 64 East | 56 | 0% | 0% | 20% |
| 3004 | SH 263 East | 4,148 | 7% | 0% | 20% |
| 3005 | U.S. 34 East | 14,488 | 11% | 2% | 2% |
| 3006 | Weld County Pkwy South | 5,937 | 9% | 0% | 0% |
| 3007 | U.S. 85 South | 24,939 | 25% | 1% | 50% |
| 3008 | CR 19 South | 1,480 | 70% | 0% | 0% |
| 3009 | CR 13 South | 4,844 | 34% | 0% | 0% |
| 3010 | I-25 South | 88,781 | 24% | 20% | 49% |
| 3011 | SH 66 West | 24,184 | 50% | 50% | 56% |
| 3012 | U.S. 287 South | 23,285 | 0% | 10% | 12% |
| 3013 | U.S. 34 West | 5,511 | 12% | 7% | 23% |
| 3014 | SH 14 West | 1,333 | 14% | 7% | 23% |
| 3015 | U.S. 287 North | 7,311 | 16% | 67% | 68% |
| 3016 | CR 15 North | 250 | 28% | 0% | 0% |
| 3017 | I-25 North | 24,719 | 58% | 55% | 74% |
| 3019 | U.S. 85 North | 3,007 | 13% | 4% | 52% |
| 4001 | U.S. 34 west expanded | 3,437 | 9% | 0% | 0% |

| External Station ID | Location | 2019 Total Volume (Vehicles) | Auto EE % | Medium Truck EE % | Heavy Truck EE % |
|---|---|---|---|---|---|
| 4002 | SH 14 west expanded | 1,513 | 16% | 0% | 52% |
| 4004 | WCR 390 North | 538 | 2% | 1% | 17% |
| 4005 | WCR 89 North | 635 | 0% | 1% | 17% |
| 4007 | SH 71 North | 1,024 | 76% | 1% | 17% |
| 4008 | SH 14 east expanded | 1,502 | 25% | 0% | 49% |
| 4009 | SH 52 east expanded | 964 | 2% | 0% | 0% |
| 4010 | U.S. 34 east expanded | 3,818 | 7% | 1% | 50% |
| 4011 | Weld County Pkwy South expanded | 5,637 | 1% | 0% | 0% |
| 4012 | U.S. 36 west expanded | 8,513 | 3% | 0% | 0% |
| 4013 | SH 7 west expanded | 3,130 | 2% | 0% | 0% |

1 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 reasonably 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 based on a combination of historical growth rates and growth rates obtained from the CDOT statewide travel model. Other assumptions, such as through tip shares and the through trip seed matrix, remain consistent with the base year but can also be adjusted if for scenario testing.

#### Seed Matrices

EE seed matrices for autos, medium trucks, and heavy trucks are based on analysis of LBS data. 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 estimated distribution of EE trips from LBS data analysis to represent 2019 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 2019 base year model.

For the expanded area, the exercise was repeated, but with a different set of external stations. 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*

| | 3001 | 3002 | 3003 | 3004 | 3005 | 3006 | 3007 | 3008 | 3009 | 3010 | 3011 | 3012 | 3013 | 3014 | 3015 | 3016 | 3017 | 3019 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **3001** | 32 | 52 | – | – | – | – | 97 | – | – | 9 | 9 | – | 1 | 5 | 5 | 1 | 6 | 61 | 278 |
| **3002** | 49 | – | – | – | – | 87 | 22 | – | – | 0 | 0 | – | 15 | 4 | 2 | 0 | 5 | 30 | 214 |
| **3003** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| **3004** | – | – | – | – | – | 37 | 49 | – | – | – | – | – | – | – | – | 0 | 0 | 6 | 91 |
| **3005** | – | – | – | – | – | – | 577 | – | – | – | – | 0 | 10 | 12 | 9 | 1 | 256 | 75 | 940 |
| **3006** | – | 88 | – | 32 | – | 1 | 195 | – | – | – | – | – | – | 0 | 0 | 0 | 0 | 1 | 317 |
| **3007** | 115 | 26 | – | 54 | 491 | 179 | 1,392 | 341 | 386 | 1,198 | 688 | – | 0 | 0 | 1 | 0 | 23 | 76 | 4,972 |
| **3008** | – | – | – | – | – | – | 386 | – | – | 18 | 57 | – | – | – | – | – | 1 | – | 461 |
| **3009** | – | – | – | – | – | – | 429 | – | – | 0 | 420 | – | 0 | 0 | 0 | 0 | 1 | 0 | 850 |
| **3010** | 11 | 0 | – | – | – | – | 1,232 | 11 | 0 | 0 | 4,082 | – | 20 | 124 | 168 | 17 | 5,826 | 25 | 11,515 |
| **3011** | 10 | – | – | – | – | – | 632 | 54 | 478 | 3,836 | 806 | – | – | 1 | 3 | 1 | 92 | 4 | 5,918 |
| **3012** | 0 | – | – | – | 0 | – | – | – | – | – | – | – | 17 | 10 | 11 | 0 | 3 | 0 | 42 |
| **3013** | 0 | 20 | – | – | 11 | – | 0 | – | 1 | 29 | – | 24 | 166 | 0 | 11 | – | 80 | 1 | 344 |
| **3014** | 4 | 4 | – | 0 | 11 | – | 1 | – | 1 | 127 | 1 | 10 | 1 | 73 | 34 | 3 | 13 | 1 | 283 |
| **3015** | 5 | 2 | – | – | 7 | 0 | 0 | – | 1 | 155 | 3 | 13 | 17 | 31 | 56 | 48 | 128 | 12 | 479 |
| **3016** | 1 | – | – | – | 1 | – | 0 | – | 0 | 16 | 0 | 0 | 0 | 1 | 34 | 1 | 49 | – | 104 |
| **3017** | 5 | 7 | – | 0 | 242 | 2 | 21 | 1 | 19 | 5,900 | 103 | 4 | 90 | 11 | 110 | 54 | 4 | – | 6,572 |
| **3019** | 68 | 34 | – | 8 | 74 | 1 | 72 | – | 0 | 28 | 3 | 0 | 1 | 2 | 10 | 2 | 5 | – | 311 |
| **Total** | **302** | **234** | **–** | **94** | **837** | **307** | **5,104** | **407** | **886** | **11,315** | **6,172** | **51** | **338** | **274** | **454** | **130** | **6,493** | **292** | **33,690** |

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 SH 14 East | 3005 U.S. 34 East | 3007 U.S. 85 South | 3010 I-25 South | 3011 SH 66 West | 3012 U.S. 287 South | 3013 U.S. 34 West | 3014 SH 14 West | 3015 U.S. 287 North | 3017 I-25 North | 3019 U.S. 85 North | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3001 | SH 14 East | 0 | 0 | 0.1 | 4.3 | 0 | 0.9 | 0 | 0 | 0 | 6.1 | 0.0 | 11.4 |
| 3005 | U.S. 34 East | 0 | 0 | 0.0 | 0.6 | 0 | 0.1 | 0 | 0 | 0 | 0.9 | 0.0 | 1.6 |
| 3007 | U.S. 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 | U.S. 287 South | 0 | 0 | 1.3 | 58.7 | 0 | 0 | 0.0 | 0.0 | 2.0 | 1.0 | 0.0 | 63.1 |
| 3013 | U.S. 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 | U.S. 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 | U.S. 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 SH 14 East | 3002 SH 392 East | 3003 CR 64 East | 3004 CR 64 East | 3005 U.S. 34 East | 3007 U.S. 85 South | 3010 I-25 South | 3011 SH 66 West | 3012 U.S. 287 South | 3014 SH 14 West | 3015 U.S. 287 North | 3017 I-25 North | 3019 U.S. 85 North | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | U.S. 34 E | 0 | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 0 | 0 | 0 | 0.0 | 0.2 | 0.0 | 0.3 |
| 3007 | U.S. 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 | U.S. 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 | U.S. 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 | U.S. 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 | 3007 | 3009 | 3010 | 3011 | 3012 | 3015 | 3016 | 3017 | 3019 | 4001 | 4002 | 4004 | 4007 | 4008 | 4009 | 4010 | 4011 | 4012 | 4013 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **3007** | – | 4 | 7 | 54 | – | – | – | 13 | – | – | 0 | – | – | – | – | – | – | – | – | 78 |
| **3009** | 5 | – | – | 419 | – | 0 | 0 | 2 | – | – | 0 | – | – | – | – | – | – | – | – | 427 |
| **3010** | 11 | – | – | 4,083 | – | 156 | 11 | 5,767 | – | – | 76 | – | – | – | – | – | – | – | – | 10,105 |
| **3011** | 56 | 478 | 3,835 | 806 | – | 3 | 0 | 86 | – | – | 0 | – | – | – | – | – | – | – | – | 5,265 |
| **3012** | – | – | – | – | – | 11 | – | 3 | – | – | 3 | – | – | – | – | – | – | – | – | 17 |
| **3015** | – | 1 | 147 | 2 | 13 | – | – | 89 | – | – | 0 | – | – | 1 | – | 3 | 0 | – | – | 257 |
| **3016** | – | 0 | 8 | 1 | – | – | – | 11 | – | – | – | – | – | – | – | 0 | – | – | – | 20 |
| **3017** | 13 | 18 | 5,844 | 98 | 4 | 71 | 11 | – | – | 9 | – | – | – | – | – | 214 | 8 | – | – | 6,289 |
| **3019** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 32 | 3 | – | – | 35 |
| **4001** | – | – | – | – | – | 0 | – | 8 | – | – | – | – | – | – | – | – | – | 106 | 18 | 132 |
| **4002** | – | 1 | 73 | 1 | 4 | – | – | – | – | – | – | – | – | 1 | – | 2 | – | – | – | 81 |
| **4004** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 9 | – | – | – | – | 9 |
| **4007** | – | – | – | – | – | – | – | – | – | – | – | – | 158 | 253 | – | – | – | – | – | 411 |
| **4008** | – | – | – | – | – | 3 | 0 | – | – | 0 | 1 | – | 261 | – | 2 | – | – | – | – | 267 |
| **4009** | – | – | – | – | – | – | – | – | – | – | – | 6 | – | 2 | – | – | – | – | – | 8 |
| **4010** | – | – | – | – | – | 4 | 0 | 221 | 32 | – | 3 | – | – | – | – | – | – | – | – | 260 |
| **4011** | – | – | – | – | – | – | 0 | 8 | 3 | – | 0 | – | – | – | – | – | – | – | – | 12 |
| **4012** | – | – | – | – | – | – | – | – | – | 97 | – | – | – | – | – | – | – | – | – | 97 |
| **4013** | – | – | – | – | – | – | – | – | – | 13 | – | – | – | – | – | – | – | – | – | 13 |
| **Total** | **86** | **502** | **9,914** | **5,465** | **20** | **248** | **23** | **6,207** | **35** | **118** | **84** | **6** | **419** | **256** | **11** | **251** | **11** | **106** | **18** | **23,780** |

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<br>U.S. 85 South | 3010<br>I-25 South | 3011<br>SH 66 West | 3012<br>U.S. 287 South | 3015<br>U.S. 287 North | 3017<br>I-25 North | 3019<br>U.S. 85 North | 4002<br>SH 14 West | 4008<br>SH 14 East | 4010<br>U.S. 34 East | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3007 | U.S. 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 | U.S. 287 south | 1.3 | 58.7 | 0 | 0 | 2.0 | 1.0 | 0.0 | 0.0 | 0 | 0 | 63.0 |
| 3015 | U.S. 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 | U.S. 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 | U.S. 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<br>U.S. 85 south | 3010<br>I-25 south | 3011<br>SH 66 west | 3012<br>U.S. 287 south | 3015<br>U.S. 287 north | 3017<br>I-25 north | 3019<br>U.S. 85 north | 4002<br>SH 14 west | 4008<br>SH 14 east | 4010<br>U.S. 34 east | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3007 | U.S. 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 | U.S. 287 south | 1.0 | 4.6 | 0 | 0 | 7.2 | 1.5 | 0.1 | 0.0 | 0 | 0 | 14.3 |
| 3015 | U.S. 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 | U.S. 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 | U.S. 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 2019 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 | U.S. 34 East | 85% | 10% | 5% |
| 3006 | Weld County Pkwy South | 86% | 10% | 4% |
| 3007 | U.S. 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 | U.S. 287 South | 87% | 9% | 4% |
| 3013 | U.S. 34 West | 95% | 4% | 1% |
| 3014 | SH 14 West | 86% | 7% | 7% |
| 3015 | U.S. 287 North | 88% | 8% | 4% |
| 3016 | CR 15 North | 88% | 8% | 4% |
| 3017 | I-25 North | 88% | 8% | 4% |
| 3019 | U.S. 85 North | 88% | 8% | 4% |
| 3007 | U.S. 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 | U.S. 287 South | 87% | 9% | 4% |
| 3015 | U.S. 287 North | 88% | 8% | 4% |
| 3016 | CR 15 North | 88% | 8% | 4% |
| 3017 | I-25 North | 88% | 8% | 4% |

| External Station ID | Location | Percent Drive Alone | Percent Shared Ride 2 | Percent Shared Ride 3+ |
|---|---|---|---|---|
| 3019 | U.S. 85 North | 88% | 8% | 4% |
| 4001 | U.S. 34 west expanded | 88% | 8% | 4% |
| 4002 | SH 14 west expanded | 89% | 8% | 4% |
| 4004 | WCR 390 North | 88% | 8% | 4% |
| 4005 | WCR 89 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 | U.S. 34 east expanded | 91% | 6% | 3% |
| 4011 | Weld County Pkwy South expanded | 86% | 10% | 4% |
| 4012 | U.S. 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 2019 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 2019 only allows travel between the NFR and Denver. Trips staying within the NFR region are not allowed on Bustang as operated in 2019. 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, or applying future year forecast data from the statewide travel model, StateFocus. The NFR Model forecast volumes are based on growth rates obtained from StateFocus 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, 2050 external station volumes were extrapolated based on historical growth rates. The resulting 2019 and 2050 external station volumes are shown in **Table 5.12.**

### Table 5.12 2050 External Station Volumes

| External Station ID | Location | 2019 Volume | 2050 Volume |
|---|---|---|---|
| 3001 | SH 14 East | 1,625 | 2,626 |
| 3002 | SH 392 East | 2,649 | 4,282 |
| 3003 | CR 64 East | 56 | 91 |
| 3004 | SH 263 East | 4,148 | 6,704 |
| 3005 | U.S. 34 East | 14,488 | 23,417 |
| 3006 | Weld County Pkwy South | 5,937 | 9,596 |
| 3007 | U.S. 85 South | 24,939 | 40,309 |
| 3008 | CR 19 South | 1,480 | 2,392 |
| 3009 | CR 13 South | 4,844 | 7,829 |
| 3010 | I-25 South | 88,781 | 143,496 |
| 3011 | SH 66 West | 24,184 | 39,088 |
| 3012 | U.S. 287 South | 23,285 | 37,635 |
| 3013 | U.S. 34 West | 5,511 | 8,907 |
| 3014 | SH 14 West | 1,333 | 2,155 |
| 3015 | U.S. 287 North | 7,311 | 11,817 |
| 3016 | CR 15 North | 250 | 404 |

| External Station ID | Location | 2019 Volume | 2050 Volume |
|---|---|---|---|
| 3017 | I-25 North | 24,719 | 39,953 |
| 3019 | U.S. 85 North | 3,007 | 4,860 |
| 3007 | U.S. 85 South | 24,939 | 40,309 |
| 3008 | CR 19 South | 1,480 | 2,392 |
| 3009 | CR 13 South | 4,844 | 7,829 |
| 3010 | I-25 South | 88,781 | 143,496 |
| 3011 | SH 66 West | 24,184 | 39,088 |
| 3012 | U.S. 287 South | 23,285 | 37,635 |
| 3015 | U.S. 287 North | 7,311 | 11,817 |
| 3016 | CR 15 North | 250 | 404 |
| 3017 | I-25 North | 24,719 | 39,953 |
| 3019 | U.S. 85 North | 3,007 | 4,860 |
| 4001 | U.S. 34 west expanded | 3,437 | 5,555 |
| 4002 | SH 14 west expanded | 1,513 | 2,445 |
| 4004 | WCR 390 North | 538 | 870 |
| 4005 | WCR 89 North | 635 | 1,026 |
| 4007 | SH 71 North | 1,024 | 1,655 |
| 4008 | SH 14 east expanded | 1,502 | 2,428 |
| 4009 | SH 52 east expanded | 964 | 1,558 |
| 4010 | U.S. 34 east expanded | 3,818 | 6,171 |
| 4011 | Weld County Pkwy South expanded | 5,637 | 9,111 |
| 4012 | U.S. 36 west expanded | 8,513 | 13,759 |
| 4013 | SH 7 west expanded | 3,130 | 5,059 |

# 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 traveler employment type and attraction place information.

## What's New

The 2019 base year model includes a new disaggregate trip production model estimated with household survey data re-expanded to 2019 ACS data. The disaggregate model generates productions based on individual person and household characteristics present in the synthesized population dataset. The resulting model is sensitive to more variables than the previous approach, considerers TAZ accessibility (a measure of density and relative congestion), and directly addresses telecommuting via a choice to commute or not commute. The commute share can be adjusted in scenario planning via a procedure to adjust the commute constant based on a user specified value.

## 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 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 6.1**, and have generally been retained from the 2012 base year model.

## Table 6.1 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 | Manufacturing | Basic / Industrial |
| 32 | | 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, U.S. Census list of NAICS Codes (https://www.census.gov/cgi-bin/sssd/naics/naicsrch?chart=2017).

### *6.1.2 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.

### 6.1.3 Zone Level Input Data

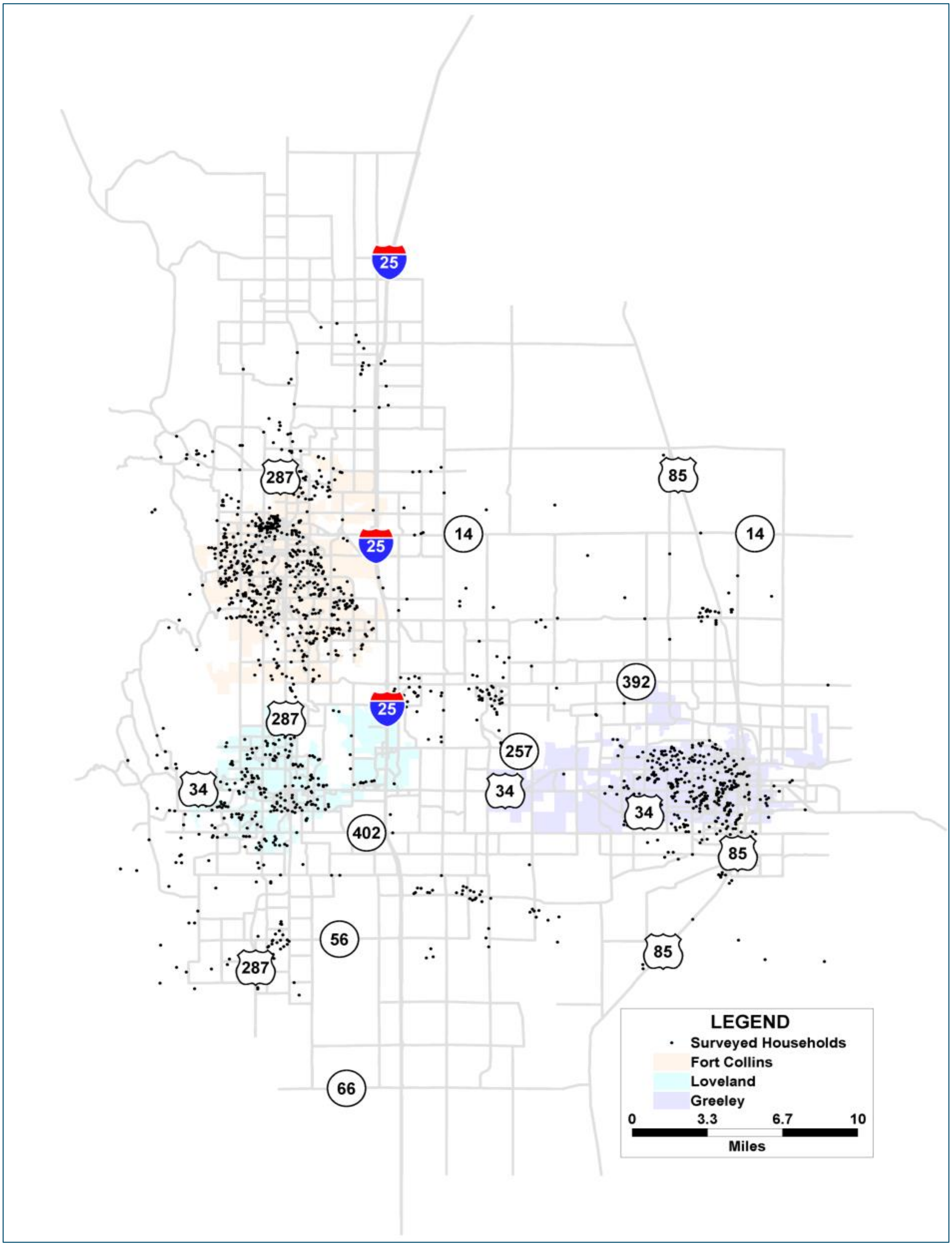
In addition to data produced by UrbanCanvas, the travel model requires K-12 school enrollment data in all applicable TAZs and the number of lodging units for TAZs in the Estes Park area. School enrollment in 2019 is from the National Center for Education Statistics (NCES) and includes all K-12 public schools. New schools planned as of 2018 were included in forecast year datasets. Forecasted enrollment for interim years and the 2050 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 including 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 U.S. 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).
- 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 6.2**.

## Table 6.2 Household Expansion Factors by Subregion

| 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 6.3**, with trips by day of travel shown in **Table 6.4**. Trip purposes were identified based on the origin and destination activity for each trip using the relationship shown in **Table 6.5**. 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 6.3 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% |
| HBSc | 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 HBSc trips and reduce HBO trips.

## Table 6.4 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 6.5 Trip Purpose Definitions Based on Reported Activity

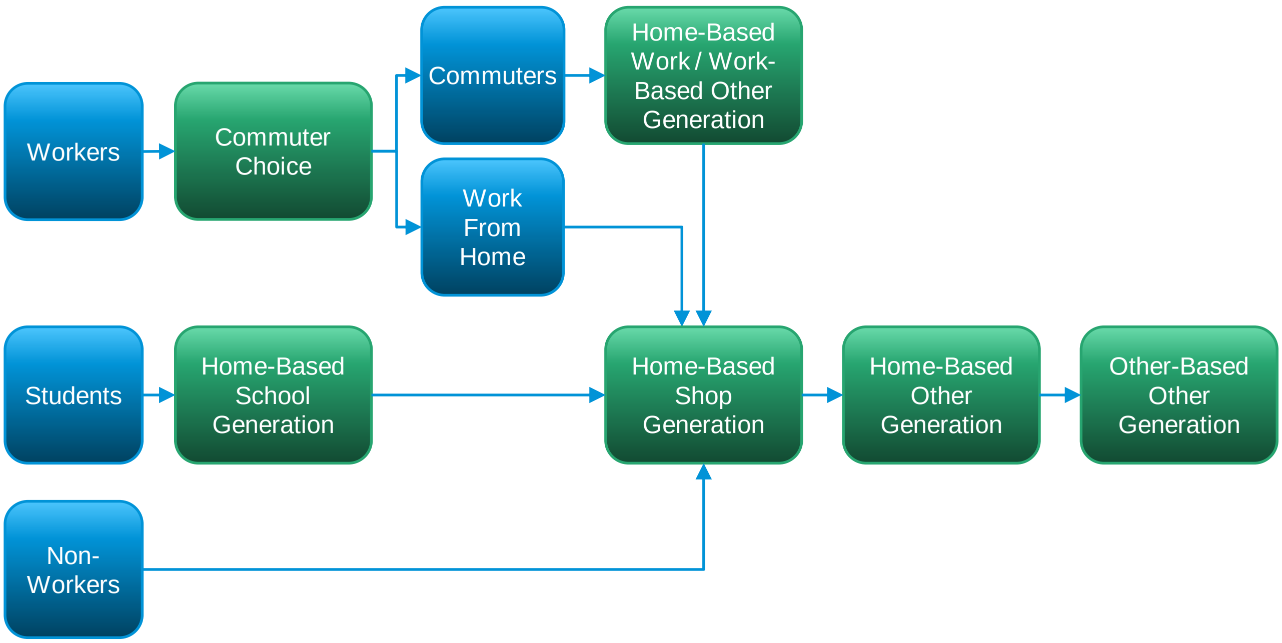
| From Activity\ To Activity | Working at home/Other home activities | Work/Work activities | Business related | Shopping/Drive Thru/Dining Outside Home | Attending Class or other School Activities (K-12) | All Other |
|---|---|---|---|---|---|---|
| Working at home/Other home activities | N/A | HBW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

## 6.4 Trip Productions

Trip generation estimates the number of trips by purpose made by each person on an average weekday. The 2019 base year model generates trips individually for each person in the synthetic population using a series of sub-models. These are run in the order shown in **Figure 6.2**. Each person enters the procedure based on their type—worker, student, or other. During model validation, trip rate factors of 1.55 were applied to the HBW, HBS, HBO, WBO, and OBO trip purposes. Factors were applied after aggregation of trip generation results to the TAZ level.

### Figure 6.2 Trip Generation Process Flow Chart




The commuter choice model determines if workers will commute to work or work from home. Commuters generate HBW and WBO trips which are generated together to better reflect individual work travel patterns. Students may or may not make school trips, which are generated in the HBSc and HBU trip generation models. All person types can make HBSh, HBO, and OBO trips. The trip generation sub-models are run in the sequential order shown in Figure 6.2 so that later sub-models can take results from earlier sub-models into account. For example, the HBS generation model includes a variable indicating whether a person makes work trips. Most sub-models are multinomial logit models (MNL), except commuter choice which is a binary logit model and HBSc generation which uses simple trip rates. (The binary logit model is a specialized case of the multinomial logit model where there are only two alternatives.)

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 the logit model, the probability of choosing a particular alternative *i* is given by the following formula:

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

where:

$P(i)$ = probability of choosing alternative *i*

$U_i$= utility of alternative *i*
exp = exponential function

The utility function $U_i$ represents the relative attractiveness of alternative *i* compared to other alternatives and is expressed as a linear function:

$$U_i = B_{0i} + B_{1i}X_{1i} + B_{2i}X_{2i} + \dots + B_{ni}X_{ni}$$

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 alternative *i*. In addition to the qualitative attributes, which describe how good the attractions of zone *i* are, there is also a quantitative term $B_{0i}$ which represents the characteristics of alternative *i* that may not be able to be observed or quantified but are important in representing the attractiveness of an alternative..

The true values of the parameters $B_{ki}$ are unknown to the analyst. The application uses maximum likelihood estimates for these parameters. The parameter estimation is done through a statistical process using the observed choices and the values of the variables $X_{ki}$ (in this case from the 2009 household travel survey (HTS) data set). The objective is to maximize the probability that the estimated parameters reflect the true parameters. This is done through the calculation of a likelihood function, which is represented in the estimation software by its logarithm, i.e., the “log likelihood,” which takes on a negative value. Different sets of variables are tested and their log likelihood values compared; the final set of chosen parameter estimates reflects the largest (least negative) log likelihood value among sets of parameter estimates that reasonably reflect the choice process.

The significance of the estimate for each individual parameter $B_{ki}$ is measured through the t-statistic. The t-statistic estimated for each parameter has the same sign as the parameter itself reflects the probability that the estimate is “significant,” i.e., significantly different from zero. The higher the absolute value of the t-statistic, the greater the probability that the parameter is significant. A t-statistic of 1.645 reflects a 90 percent probability of significance; a t-statistic of 1.90 reflects a 95 percent probability of significance. Sometimes a parameter estimate is accepted even if the t-statistic is relatively low, if the estimated parameter value is reasonable and it is important to include the variable for model application.

### 6.4.1 Estimation Dataset

All models were estimated using the 2009 household travel survey (HTS) with updated weights based on 2019 demographics. Updated weights reflect the following categories as obtained from 2019 ACS data:

- Household size.
- Household workers.
- Residence type.
- Income.
- Sub-region.

### 6.4.2 Variables

The trip production model utilizes Individual and household characteristics that are simulated by the population synthesizer along with land-use variables that describe characteristics of an individual's residential location included in the zonal file. In addition, model estimation considered information from household survey records about the number of trips made that have purposes different than the purpose being considered. A variety of variables were tested in the models to determine how they might affect the likelihood of making a specific type of trip or combination of trips. Multiple candidate models were defined, tested, and evaluated for each sub-model, with the final specified models including a variety of derivations and combinations of available variables. One of the variables used by the model is income, which is grouped into 5 categories for disaggregate trip generation, while the aggregate destination and mode choice models apply 3 categories for the HBW trip purpose. Income groups for the trip generation model and for subsequent models are shown in **Table 6.6**.

The trip generation estimation process considered the density of nearby households and employment through use of and accessibility indices. These indices use peak congested travel time, accounting for the effect of increased congestion reducing the accessibility of activities. The population and employment accessibility indices are calculated using the equations below.

$$EmpAI_i = \sum\nolimits_{zones=j} log\left(1 + Emp_j \cdot e^{-0.05*TT_{i,j}}\right)$$

$$PopAI_i = \sum\nolimits_{zones=j} log\left(1 + Pop_j \cdot e^{-0.05*TT_{i,j}}\right)$$

$$Emp_j = Total\ employment\ in\ zone\ j$$

$$Pop_j = Total\ population\ in\ zone\ j$$

$$TT_{i,j} = Peak\ travel\ time\ between\ zone\ i\ and\ zone\ j$$

## Table 6.6 Household Income Categories

| 2009$ | 2019$ | Trip Generation Group | Mode and Destination Choice Group |
|---|---|---|---|
| $0–$14,999 | $0–$18,531 | 1 | 1 |
| $15,000–$19,999 | $18,532–$24,709 | 1 | 1 |
| $20,000–$29,999 | $24,710–$37,063 | 1 | 1 |
| $30,000–$39,999 | $37,064–$49,418 | 2 | 2 |
| $40,000–$49,999 | $49,419–$61,773 | 2 | 2 |
| $50,000–$59,999 | $61,774–$74,128 | 3 | 2 |
| $60,000–$74,999 | $74,129–$92,660 | 3 | 2 |
| $75,000–$99,999 | $92,661–$123,547 | 4 | 2 |
| $100,000–$134,999 | $123,548–$166,789 | 5 | 3 |
| $135,000–$149,999 | $166,790–$185,321 | 5 | 3 |
| $150,000+ | $185,322+ | 5 | 3 |

### 6.4.3 Commuter Choice Model

The Commuter Choice model, run only for workers, determines which workers take at least one work trip (i.e., commute) on the activity day. This is modeled through a binary logit model with the choice of commuting to work or not commuting to work. Because household survey does not identify why workers did not commute on a specific day, workers not commuting to work represent people either working from home or not working on the modeled travel day. Most workers in the estimation dataset (72 percent) commuted to work.

The following variables were tested in the model:

- Income.
- Age.
- Household size.
- Household vehicles.
- Household workers.
- Worker and student status (full/part-time).
- Population accessibility.
- Employment accessibility.

**Table 6.7** shows the model specification for the Commuter Model.

## Table 6.7 Commuter Model Estimation Results

| | Coefficient | t-stat |
|---|---|---|
| Alternative Specific Constant (ASC) for Commuter | 1.487 | 8.62 |
| Individuals aged 16–18 | -1.607 | -5.73 |
| Individuals aged 19–24 | -0.544 | -2.49 |
| Household has no vehicles | -1.239 | -2.13 |
| Number of household workers[1] | -0.337 | -4.24 |
| Household Income $37,064–$61,774 | 0.046 | 0.26 |
| Household Income $61,774–$92,661 | 0.191 | 1.14 |
| Household Income $92,661–$123,548 | 0.428 | 2.33 |
| Household Income $123,548+ | 0.266 | 1.64 |

Notes: Log Likelihood: -1,277

Number of records: 1,983

[1] Households with more than three workers were given a value of 3.

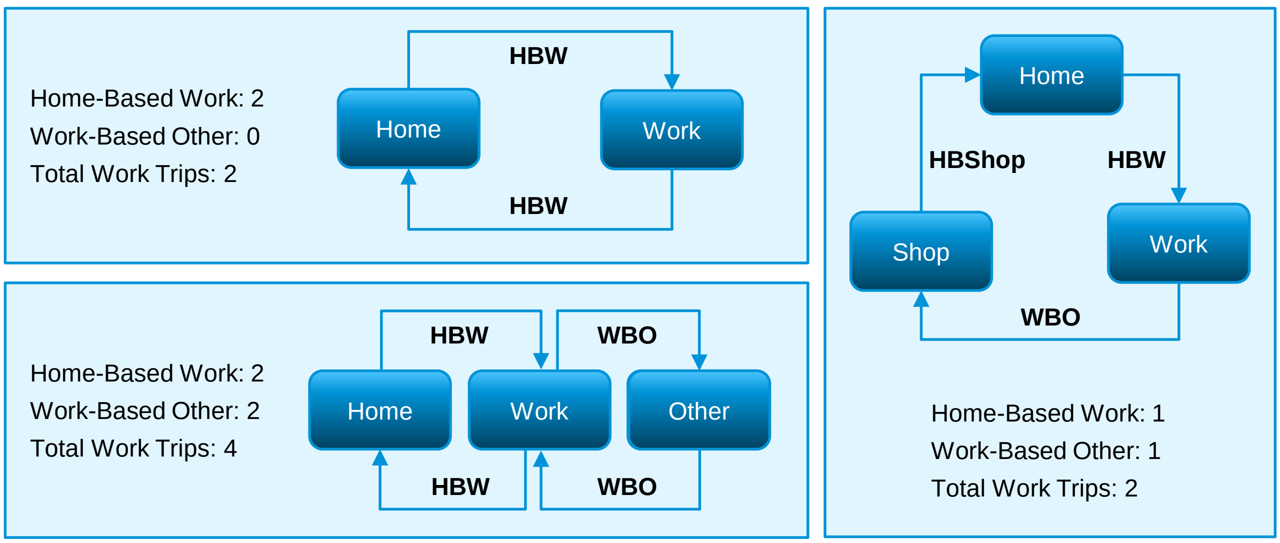
The positive estimate for the alternative specific constant (ASC) indicates that most choose to commute. Workers under 25 are less likely to commute, especially 16- to 18-year-olds, as shown by the magnitude of their negative coefficient estimates. Workers in households without vehicles or with higher numbers of workers also commuted less. The tendency to commute increased with income but peaked with the $92K to $123K group and fell for those within higher household incomes. However, these variables also interact with each other. More workers (negative coefficient), for example, correlates to higher income (positive coefficient) meaning the effects of each cannot be considered independently.

### 6.4.4 Home-Based Work and Work-Based Other Generation Model (Work Trips Model)

The work trips model is an MNL model which predicts the combination of HBW and WBO trips a Commuter will undertake on the representative travel day. Often these types of trips are modeled separately and even independently. The NFR Model combines them to directly reflect the choice to commute to and from work a specific number of times**. Figure 6.3** shows examples of travel patterns including work stops. The most common is the first which includes only a HBW trip to work and a HBW return trip from work to home (top left). WBO trips can include leaving and returning to work (bottom left) or a stop that occurs after work before reaching home (right).

The dependent variable represents 15 possible choices, as shown in **Table 6.8**.

## Figure 6.3 Examples of Work Trip Patterns




## Table 6.8 Work Trip Alternatives and Weighted HTS Shares

| | Weighted HTS Shares | | | |
|---|---|---|---|---|
| | 0 WBO | 1 WBO | 2 WBO | 3 WBO |
| 0 HBW | – | 0.6% | 7.3% | 1.2% |
| 1 HBW | 2.4% | 19.0% | 1.0% | 4.1% |
| 2 HBW | 45.3% | 1.4% | 6.3% | 1.9% |
| 3 HBW | 5.0% | 3.6% | 0.6% | 0.4% |

Commuters may make 0 HBW or 0 WBO trips, but at least one must be non-zero. Odd numbers of work trips (e.g., 1 HBW/2 WBO, 3 HBW/0 WBO, etc.) indicate that the person went to work but did not leave or left without first arriving. While this is counterintuitive except in the case of overnight workers, they were included because they were represented in the survey data for 14 percent of workers. Given how the trip generation model is applied, this does not pose an issue for the NFRMPO model.

The following variables were tested in the model:

- Household income.
- Age.
- Household size.
- Household vehicles.
- Household workers.
- Household vehicles minus household workers.
- Population accessibility index.
- Employment accessibility index.
- Number of WBO trips.
- Number of HBW trips.

**Table 6.9** provides the specification for the Work Trips Model.

## Table 6.9 Home-Based Work and Work-Based Other Model Estimation Results

| | Estimate | t-stat |
|---|---|---|
| ASC for HBW 1, WBO 0 | 0 | – |
| ASC for HBW 0, WBO 1 | -0.930 | -2.294 |
| ASC for HBW 0, WBO 2 | 1.478 | 5.916 |
| ASC for HBW 0, WBO 3 | -0.386 | -1.147 |
| ASC for HBW 1, WBO 1 | 2.030 | 11.081 |
| ASC for HBW 1, WBO 2 | -0.981 | -3.063 |
| ASC for HBW 1, WBO 3 | 0.396 | 1.762 |
| ASC for HBW 2, WBO 0 | 3.243 | 12.661 |
| ASC for HBW 2, WBO 1 | -0.871 | -2.864 |
| ASC for HBW 2, WBO 2 | 0.560 | 2.365 |
| ASC for HBW 2, WBO 3 | -0.708 | -2.408 |
| ASC for HBW 3, WBO 0 | 0.399 | 1.660 |
| ASC for HBW 3, WBO 1 | 0.013 | 0.052 |
| ASC for HBW 3, WBO 2 | -1.819 | -4.471 |
| ASC for HBW 3, WBO 3 | -2.337 | -4.787 |
| Number of HBW trips in alt by HH Vehicles minus HH Workers | 0.073 | 1.387 |
| Number of WBO trips in alt by HH Vehicles minus HH Workers | 0.107 | 2.548 |
| 0 HBW trips in alt by employment accessibility of home | -0.369 | -4.401 |
| 1 HBW trips in alt by employment accessibility of home | -0.134 | -2.474 |
| 2 HBW trips in alt by population accessibility of home, 0 WBO trips | -0.168 | -3.081 |

Note: Number of records: 1,479
Log likelihood: -2,599

This model includes the individual alternatives as ASCs and other variables with the number of HBW or WBO trips associated with an alternative. Having more vehicles relative to workers increased the tendency to make HBW and WBO trips, though the effect was stronger for WBO. As employment accessibility at home increased the likelihood of having WBO trips increased. Employment and population accessibility decreased the chances of having exactly 1 and 2 HBW trips, respectively.

### 6.4.5 Home-Based Shop Generation

The HBSh trips model is a MNL which predicts the number of HBSh trips a person will take with the choice of 0, 1, 2, or 3+ trips. **Table 6.10** shows the weighted distribution of number of shop trips in the HTS. In addition to person type (commuter, K-12 student, non-commuting worker) and population accessibility index, the model considers the number of WBO trips.

## Table 6.10 Weighted Home-Based Shop Trips Shares

| Number of Trips | Share |
|---|---|
| 0 | 71% |
| 1 | 16% |
| 2 | 11% |
| 3+ | 3% |

The following variables were tested in the model:

- Household income.
- Person type.
- Household vehicles.
- Household workers.
- Number of WBO trips.
- Number of HBW trips.
- Number of total work trips.
- Household vehicles minus household workers.
- Population accessibility index.
- Employment accessibility index.

**Table 6.11** provides the specification for the Home-Based Shop Model.

## Table 6.11 Home-Based Shop Model Estimation Results

| | Estimate | t-stat |
|---|---|---|
| ASC for HBS 0 | 0 | – |
| ASC for HBS 1 | -1.213 | -15.540 |
| ASC for HBS 2 | -1.216 | -14.057 |
| ASC for HBS 3 | -2.223 | -16.844 |
| Is K-12 Student, alt HBS = 1 | -0.708 | -5.557 |
| Is K-12 Student, alt HBS = 2 | -1.479 | -8.838 |
| Is K-12 Student, alt HBS = 3 | -1.817 | -5.983 |
| Is Commuter, alt HBS = 1 | -0.773 | -5.873 |
| Is Commuter, alt HBS = 2 | -1.182 | -7.582 |
| Is Commuter, alt HBS = 3 | -1.827 | -5.941 |
| Is Commuter by number of WBO trips, alt HBS = 1 | 0.553 | 7.784 |
| Is Commuter by number of WBO trips, alt HBS = 2 | 0.380 | 4.104 |

| | Estimate | t-stat |
|---|---|---|
| Is Commuter by number of WBO trips, alt HBS = 3 | 0.548 | 3.150 |
| Is non-commuting worker by Pop AI by number of HBS (alt) | -0.041 | -2.505 |

Note: Number of records: 3,686

Log likelihood: -3,149

Children and commuters were likely to take fewer home based shopping trips. Shop trips for commuters did increase if they took work-based trips. Non-commuting workers in more densely populated areas (i.e., with a higher population accessibility index) took fewer home-based shopping trips.

### *6.4.6 Home-Based Other Generation Model*

The HBO trips model is a MNL which predicts each person's number of HBO trips with the choice of 0, 1, 2, 3+. HBO is defined as any trip with one end at home that is not made for the purpose of work, school, or shopping. **Table 6.12** shows the weighted distribution of number of HBO trips in the HTS. In addition to person type and household characteristics, the model considers the number of HBS and WBO trips.

### Table 6.12 Weighted Home-Based Other Trips Shares

| Number of Trips | Share |
|---|---|
| 0 | 51% |
| 1 | 15% |
| 2 | 20% |
| 3+ | 14% |

The following variables were tested in the model:

- Household Income.
- Person type.
- Household vehicles.
- Household workers.
- Number of WBO trips.
- Number of HBO trips.
- Number of total work trips.
- Number of HBShop trips.
- Household vehicles minus household workers.
- Population accessibility index.
- Employment accessibility index.
- Ratio of peak accessibility index to off-peak accessibility index.

**Table 6.13** provides the specification for the Home-Based Other Model.

## Table 6.13 Home-Based Other Model Estimation Results

| | Estimate | t-stat |
|---|---|---|
| ASC for HBO 0 | 0 | – |
| ASC for HBO 1 | -1.62 | -21.28 |
| ASC for HBO 2 | -1.14 | -14.92 |
| ASC for HBO 3 | -1.75 | -16.97 |
| HH Income above $123,548 by number of HBO (alt) | 0.080 | 2.02 |
| HH Income $61,774–$123,548 by number of HBO (alt) | 0.175 | 5.02 |
| Is Commuter, alt HBO = 1 | -0.343 | -2.79 |
| Is Commuter, alt HBO = 2 | -0.675 | -5.91 |
| Is Commuter, alt HBO = 3 | -1.009 | -6.84 |
| Number of HBS trips, alt HBO = 1 | 0.467 | 8.35 |
| Number of HBS trips, alt HBO = 2 | 0.146 | 2.54 |
| Number of HBS trips, alt HBO = 3 | 0.360 | 5.97 |
| Is Commuter by number of WBO trips, alt HB0= 1 | 0.609 | 7.83 |
| Is Commuter by number of WBO trips, alt HBO = 2 | 0.451 | 5.64 |
| Is Commuter by number of WBO trips, alt HB0 = 3 | 0.720 | 8.07 |
| Number of HH Vehicles minus Number of Workers by number of HBO (alt) | 0.057 | 3.21 |

Note: Number of records: 3,686

Log likelihood: -4,361

People in medium income ($61–123k) households had a higher tendency to take HBO trips, followed by high income ($124k+). As in HBS, commuters took fewer home-based other trips. The number of HBO trips made correlated directly with WBO trips and indirectly with HBS trips. People in households with more vehicles relative to workers took more HBO trips.

### *6.4.7 Other-Based Other Trips*

The other-based other (OBO) trips model is a MNL which predicts each person's number of trips (0, 1, 2, or 3+) without home or work trip ends. **Table 6.14** shows the weighted distribution of number of OBO trips in the HTS. The model takes into account person type and the number of home-based trips made by the individual.

## Table 6.14 Weighted Other-Based Other Trips Shares

| Number of Trips | Share |
|---|---|
| 0 | 64% |
| 1 | 17% |
| 2 | 10% |
| 3+ | 10% |

The following variables were tested in the model:

- Person type.
- Number of WBO trips.
- Number of HBW trips.
- Number of HBO trips.
- Number of HBS trips.
- Number of total work trips.
- Population accessibility index.
- Employment accessibility index.

**Table 6.15** provides the specification for the Other-Based Other Model.

### Table 6.15 Other-Based Other Model Estimation Results

| | Estimate | t-stat |
|---|---|---|
| ASC for OBO 0 | 0 | – |
| ASC for OBO 1 | -2.66 | -22.76 |
| ASC for OBO 2 | -3.27 | -23.51 |
| ASC for OBO 3 | -3.37 | -27.63 |
| Is Commuter, alt OBO = 1 | 0.51 | 3.70 |
| Is Commuter, alt OBO = 2 | 0.26 | 1.61 |
| Is K-12 Student, alt OBO = 1 | 0.68 | 5.45 |
| Is K-12 Student, alt OBO = 2 | 0.59 | 4.03 |
| Is non-commuting worker, alt OBO >= 1 | -0.24 | -1.85 |
| Number of HBO trips, alt OBO = 1 | 0.71 | 15.78 |
| Number of HBO trips, alt OBO = 2 | 0.85 | 15.59 |
| Number of HBO trips, alt OBO = 3 | 1.01 | 17.92 |
| Number of HBS trips, alt OBO >= 1 | 0.94 | 18.15 |
| Number of HBW trips, alt OBO >= 1 | -0.35 | -5.61 |

Note: Number of records: 3,686
Log likelihood: -3,270

Commuters and students took more OBO trips, while non-commuting workers took fewer. The number of OBO trips correlated positively with making more home-based other and HBS trips, but negatively with making more HBW trips.

## *6.4.8 Home-Based and University School Generation Model*

The HBSc and HBU trip generation is based on simple average number of trips by age group. **Table 6.16** shows the weighted distribution of number of school trips made by students in the HTS. **Table 6.17** provides the home-based school and home-based university trip rates.

### Table 6.16 Weighted Home-Based School and University Trips Shares *Students Only*

| Number of Trips | Share |
|---|---|
| 0 | 38% |
| 1 | 16% |
| 2 | 46% |

### Table 6.17 Home-Based School Model Trip Rates

| | HBSch | HBU |
|---|---|---|
| School trip rate by age group, 0–15 | 1.30 | 0 |
| School trip rate by age group, 16–18 | 1.35 | 0 |
| School trip rate by age group, 19–24 | 0 | 0.28 |
| School trip rate by age group, 25–99 | 0 | 0.43 |

The two age groups of students under 19 had very similar rates of school trips, around 1.3 trips per student. This accounts for students who did not go to school that day and those who had school trips which were not home based, such as trips that included other stops between school and home. The rate was much lower for college aged and older students. Rates are separated into HBSc trips for students 18 and under, and HBU trip productions for students over 18.

Trip productions for the HBU purpose serve as production allocation rates. During the trip distribution step, HBU trips are distributed using a singly constrained process, which allocates HBU trip productions to TAZs based on proximity to CSU and UNC.

## 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 re relocate the production and 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 6.4**. 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 6.18**.

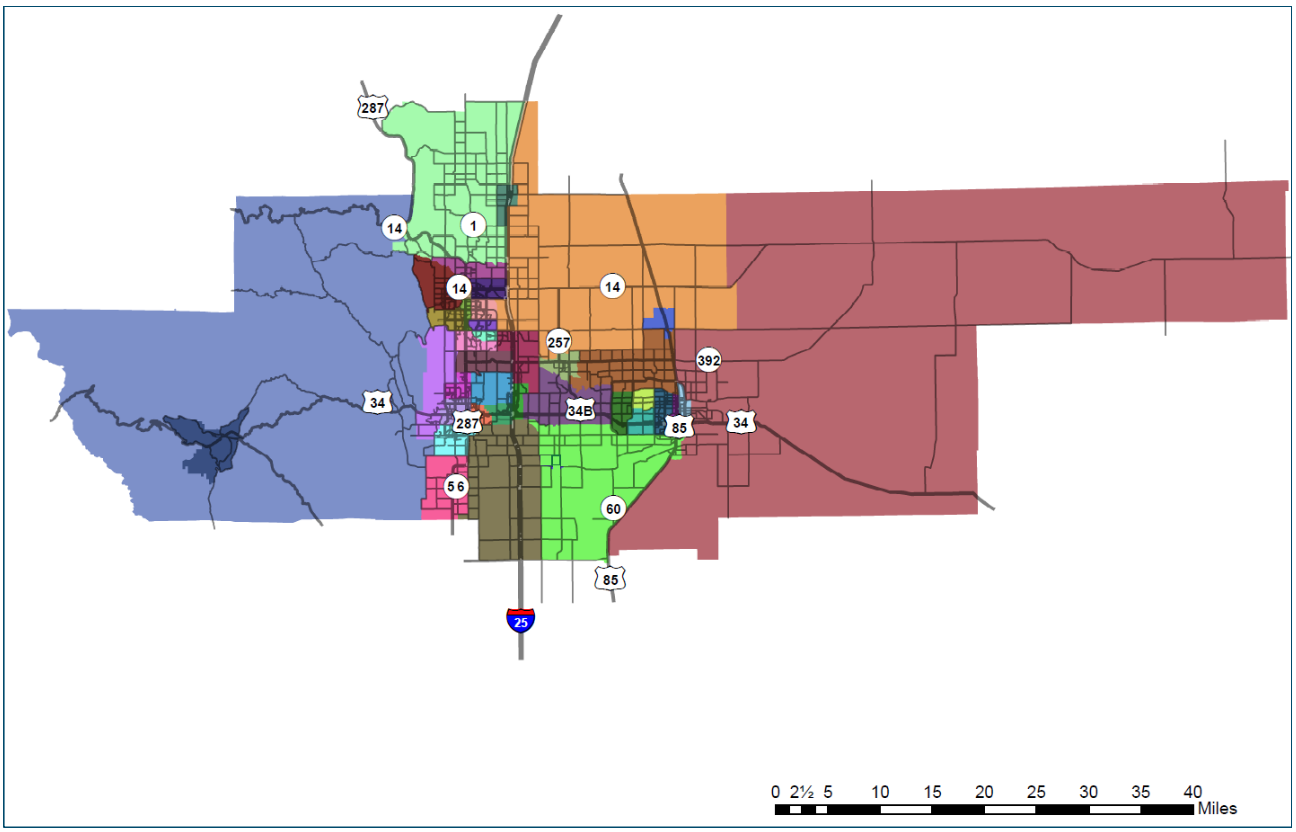
## Table 6.18 Trip Attraction Rates

| 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 2015 Base Year Regional Travel Model Documentation, updated to include HBSc trips for the 2015 base year model.

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

## Figure 6.4 Trip Attraction Regression Districts




Source: NFR 2012 Base Year Regional Travel Model Documentation.

## 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 6.19**. 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 6.19** 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 6.19 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 6.20**.

## Table 6.20 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 to non-home locations.

# 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. The three special generators included in the model are 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 2015 base year model. Special generator values have been updated to reflect updated 2019 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 judgment 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) | 3,625 | 7,252 | 15,955 |
| Fall River (TAZ 1018 and 1019) | 1,915 | 3,830 | 8,427 |
| Wild Basin (TAZ 2100) | 462 | 922 | 2,027 |

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 | 189 | 55 | 55 | 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 | 6,458 | 1,907 | 1,907 | 253 |
| WBO | Productions | 0 | 0 | 0 | 0 |
| | Attractions | 0 | 0 | 0 | 0 |
| OBO | Productions | 434 | 128 | 128 | 102 |
| | Attractions | 434 | 128 | 128 | 102 |
| LBO | Productions | 174 | 51 | 51 | 30 |
| | Attractions | 1,304 | 384 | 384 | 507 |

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

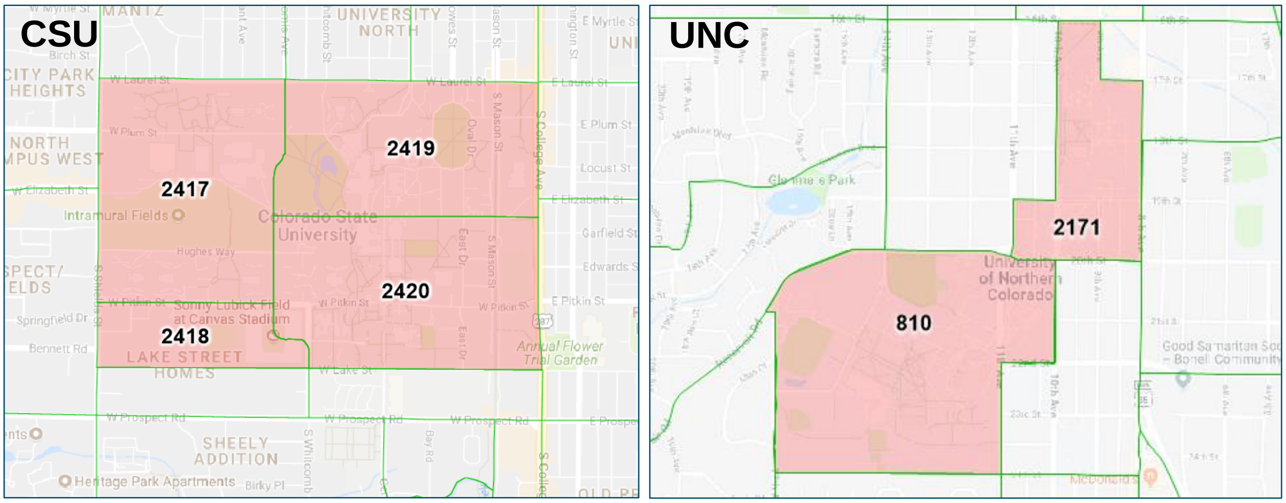
## 7.2 Universities

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 2019 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 | 1,884 | 598 |
| Staff | 5,715 | 1,119 |
| **Total Employment** | **7,599** | **1,717** |

## Table 7.4 University Enrollment Summary

| Student Type | CSU Students | % CSU Students | UNC Students | % UNC Students |
|---|---|---|---|---|
| On-Campus | 12,037 | 42% | 2,973 | 23% |
| Off-Campus | 16,815 | 58% | 9,957 | 77% |
| **Total Enrollment** | **28,852** | **100%** | **12,930** | **100%** |

CSU enrollment data represents resident instruction students in Fall 2019.

Source: Institutional Research, Planning & Effectiveness, CSU, 09/02/22

UNC enrollment represents total enrollment in Fall 2019.

Source: University of Northern Colorado 2019 Fall Final Enrollment Profile

### 7.2.4 Special Generator Values

Trips for the CSU and UNC special generators are based on special generator studies conducted for CSU and UNC. 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 | 2,648 |
| | Attractions | 1.6 | Total Employment | 12,158 |
| HBS | Productions | 0.2 | On Campus Students | 2,407 |
| | Attractions | n/a | n/a | 0 |
| HBU | Productions | n/a | n/a | 0 |

| Trip Purpose | Production/Attraction | Trip Rate | Unit | CSU Special Generator Value |
|---|---|---|---|---|
| | Attractions | 3.8 | Off Campus Students | 63,897 |
| HBO | Productions | 0.5 | On Campus Students | 6,019 |
| | Attractions | n/a | n/a | 0 |
| WBO | Productions | 0.37 | Total Employment | 2,812 |
| | Attractions | 0.19 | Off Campus Students | 3,195 |
| OBO | Productions | 0.25 | Off Campus Students | 4,204 |
| | Attractions | 0.25 | Off Campus Students | 4,204 |

## 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 | 832 |
| | Attractions | 1.47 | Total Employment | 2,524 |
| HBS | Productions | 0.8 | On Campus Students | 2,378 |
| | Attractions | n/a | n/a | 0 |
| HBU | Productions | n/a | n/a | 0 |
| | Attractions | 3.5 | Off Campus Students | 34,850 |
| HBO | Productions | 1.3 | On Campus Students | 3,865 |
| | Attractions | n/a | n/a | 0 |
| WBO | Productions | 0.37 | Total Employment | 635 |
| | Attractions | 0.19 | Off Campus Students | 1,892 |
| OBO | Productions | 0.25 | Off Campus Students | 2,489 |
| | Attractions | 0.25 | Off Campus Students | 2,489 |

### *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 2050. The resulting special generator values are shown in **Table 7.7**.

## Table 7.7 2050 University Special Generator Values

| Trip Purpose | Production/Attraction | CSU Special Generator Value | UNC Special Generator Value |
|---|---|---|---|
| HBW | Productions | 4,269 | 832 |
| | Attractions | 19,602 | 2,524 |
| HBS | Productions | 3,881 | 2,378 |
| | Attractions | 0 | 0 |
| HBU | Productions | 0 | 0 |
| | Attractions | 103,018 | 34,850 |
| HBO | Productions | 9,703 | 3,865 |
| | Attractions | 0 | 0 |
| WBO | Productions | 4,533 | 635 |
| | Attractions | 5,151 | 1,892 |
| OBO | Productions | 6,777 | 2,489 |
| | Attractions | 6,777 | 2,489 |

# 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 2016 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 0**.

## 8.2 Truck Trip Distribution

The NFR Model distributes truck trips using a gravity model, which is consistent with guidance in the FHWA's Quick Response Freight Manual (QRFM).[11,12] 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 | 23.11 | Light Trucks (not explicitly modeled) |
| Pickup Truck | 15.82 | | |
| Van (Cargo or minivan) (4 wheels) | 19.89 | | |
| Single Unit 2-axle | 16.52 | 18.30 | Medium (Single Unit) Trucks |
| Single Unit 3-axle | 18.86 | | |
| 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.

The model Uses a destination choice model for most trip purposes, and a gravity model for home-based university (HBU) trips and home-based school (HBSc) trips. 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.

## What's New

The 2019 Base Year NFR Model retains the methodology and structure developed for the 2015 base year model and has been recalibrated using trip patterns developed using LBS data.

## 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 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 were not any toll facilities in the NFR region in 2019. 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 (see Section 6.4 for a description of logit models and parameter estimation). The utility functions for the destination choice model are represented by the following equation:

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

For destination choice models, the term $A_i$ 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 nonlinearities 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** and **Figure 9.2** (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.

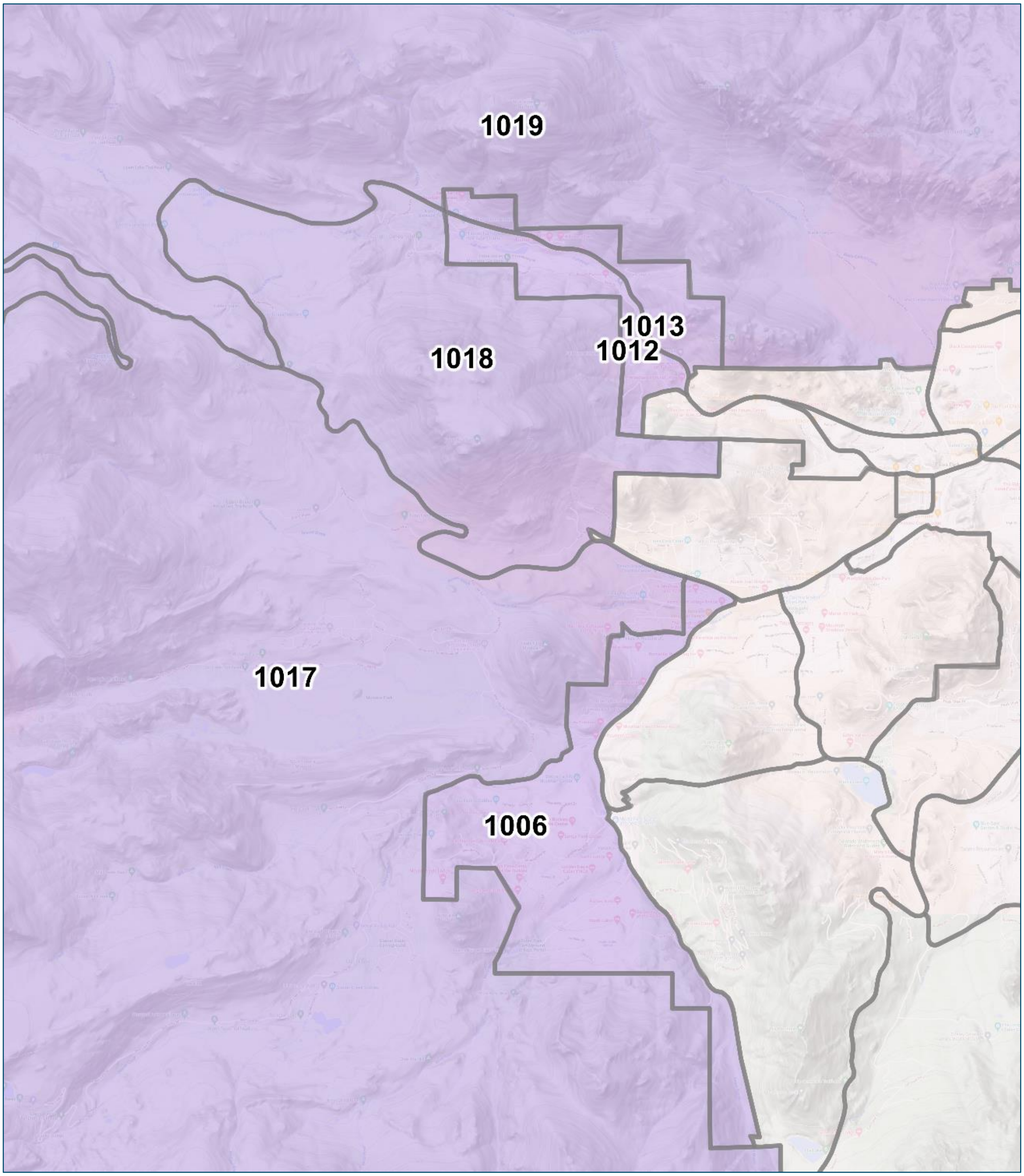
***Accessibility to Other Attractions***

For the home-based work model, the explanatory data includes measures 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 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.

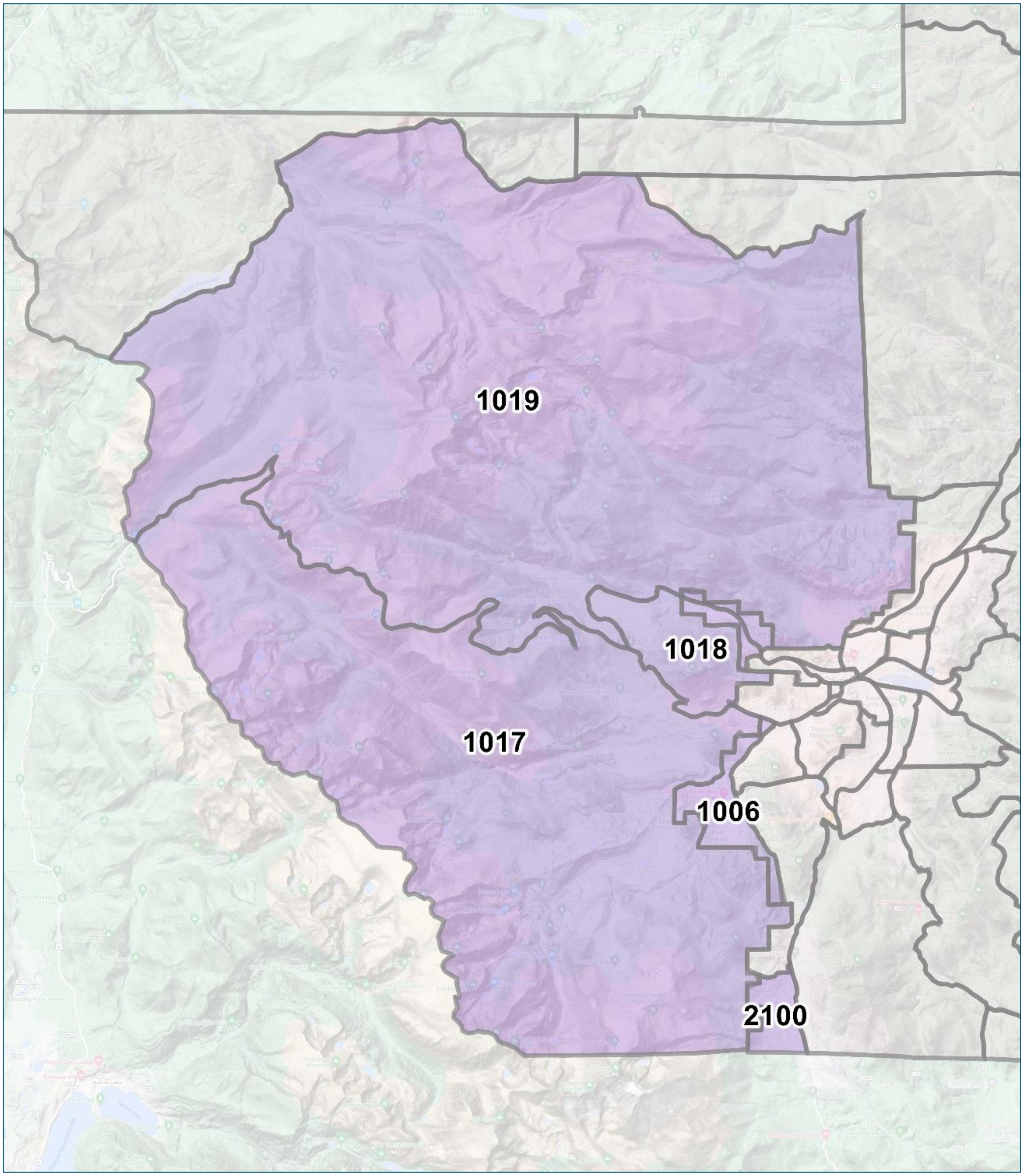
Each destination choice also includes a quantitative factor, which gives the number of attractions in a particular zone. For each trip purpose model other than Home-Based Work, the number of attractions for each zone is derived from the number of productions computed in the trip generation model. For 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

*Detail*



## Figure 9.2 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 9.3** 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[1] | 0.02451 | 0.00523 | 4.68 | 0.0 |
| | WBO Attractions within 3 mi, up to 20K[1] | -0.04857 | 0.00343 | -14.16 | 0.0 |

1 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 |
| | RockyMtnNatlPark | 5.627 | 0.338 | 16.65 | 0.0 |
| | Network Distance, up to 3 mi, High Income[1] | 0.137 | 0.0378 | 3.63 | 0.0 |

1 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 | |

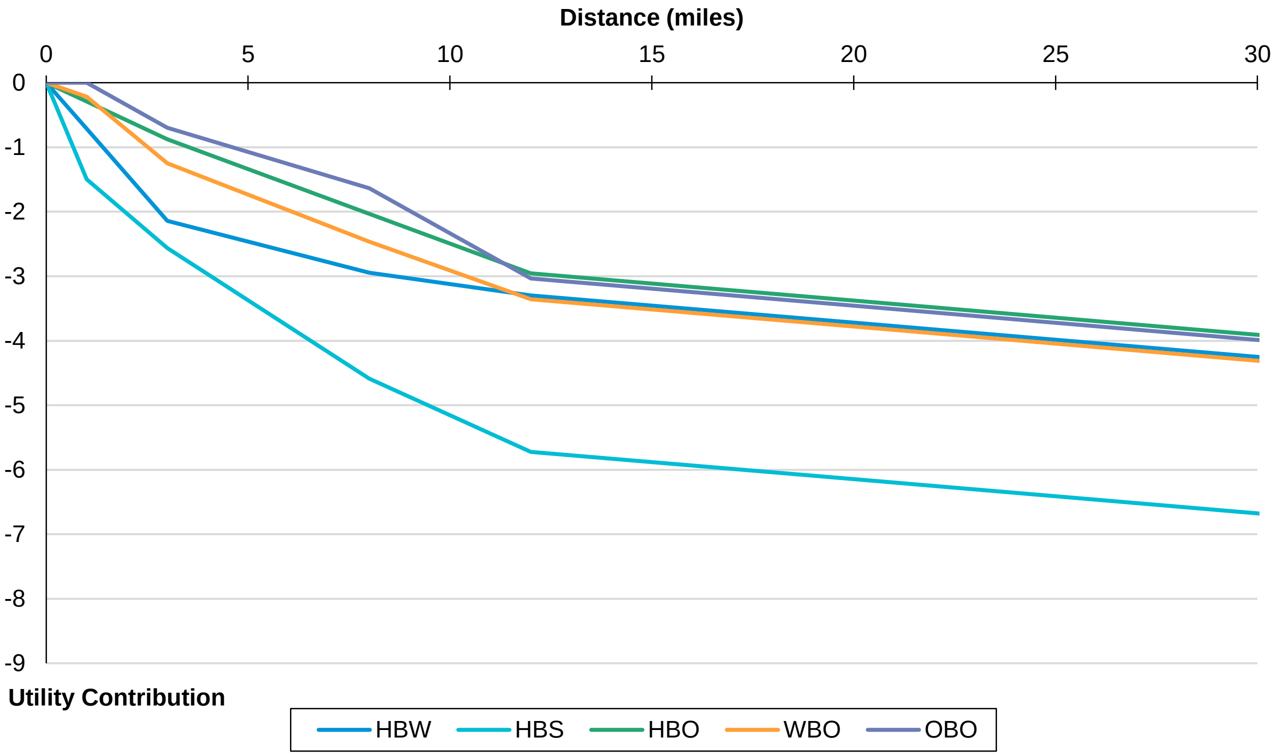
## Table 9.12 Other Based Other Destination Choice Model Parameters

| 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 |
| | RockyMtnNatlPark | 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 9.3 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*

$\alpha, \beta, \gamma$ = *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% |
| HBSc | 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 onboard 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 systemwide onboard 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 onboard 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 2019 mode choice transit calibration targets, discussed later in this Chapter.

## Table 10.2 2019 Fixed Route Boardings

| Operator | Average Weekday Boardings |
|---|---|
| Transfort | 12,590 |
| Greeley Evans Transit (GET) | 2,558 |
| City of Loveland Transit (COLT) | 380 |
| Interregional | 841 |
| **Total** | **16,369** |

Source: Data provided by NFR area transit agencies.

Note: The interregional routes FLEX and Bustang are operated by Transfort and CDOT, respectively.

## Table 10.3 Transit Onboard 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[1] | 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[1] | 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 onboard transit survey.
GET and COLT ridership from 2008 NFRMPO onboard transit survey.

[1] COLT and GET onboard 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 2014, 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 interregional bus service stops at park-n-ride lots located along I-25. Future parking lots were included based on Transfort's Transit Master Plan, the Transit Development Program (TDP), and expected stops for the Great Western Railway.

The 2017 Transfort onboard 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 Onboard 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 Bicycle Level of Traffic Stress

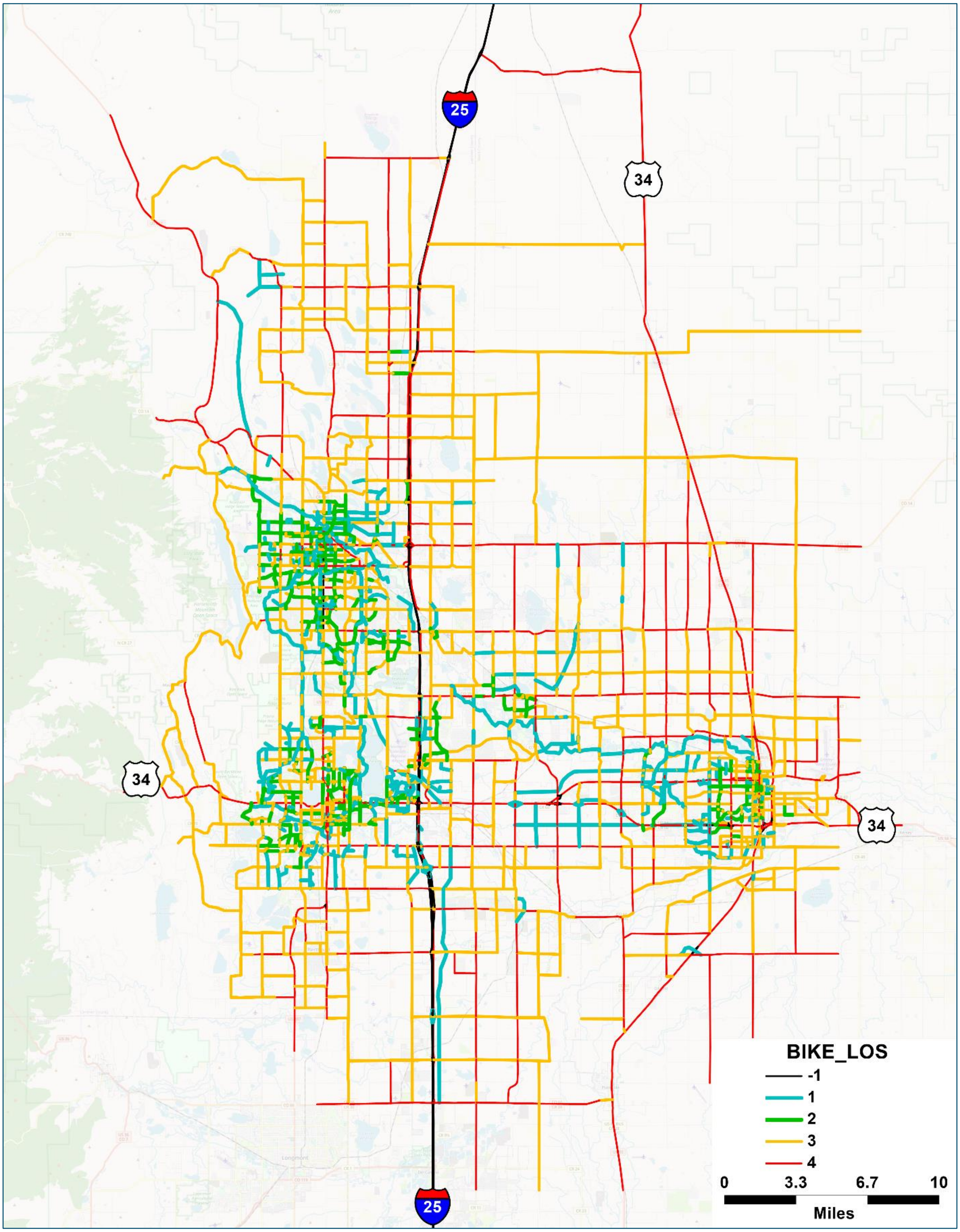
The mode choice model uses Bicycle Level of Traffic stress in determining the Bicycle mode utility. The Bicycle Level of Traffic Stress values are shown in **Table 10.7**. Bicycle Level of Traffic Stress is defined by the Bicycle Facility Type in combination with the number of lanes, traffic speed, and traffic volume on the link. This provides the model with more information than Bicycle Facility Type alone, and results in a model that is more sensitive to traffic conditions and gaps in the bicycle network. The resulting Bicycle Level of Traffic Stress values for a base year model run are shown in **Figure 10.1** to **Figure 10.5**.

### Table 10.6 Bicycle Level of Traffic Stress Definitions

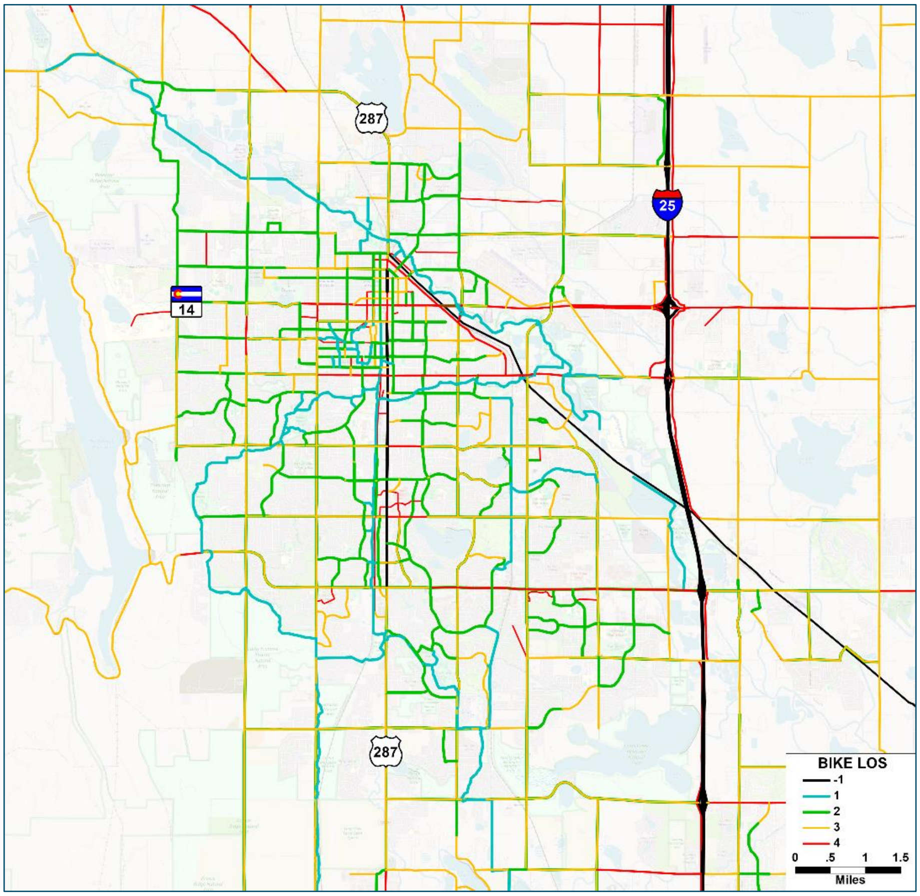
| Bicycle LOS | Description |
|---|---|
| -1 | Bicycles not allowed |
| 1 | Comfortable for anyone |
| 2 | Comfortable for regular bike commuter |
| 3 | Comfortable for confident road cyclist |
| 4 | Not comfortable for anyone |
| 5 | Not suitable for cycling |

## Figure 10.1 Bicycle Level of Traffic Stress—Base Year

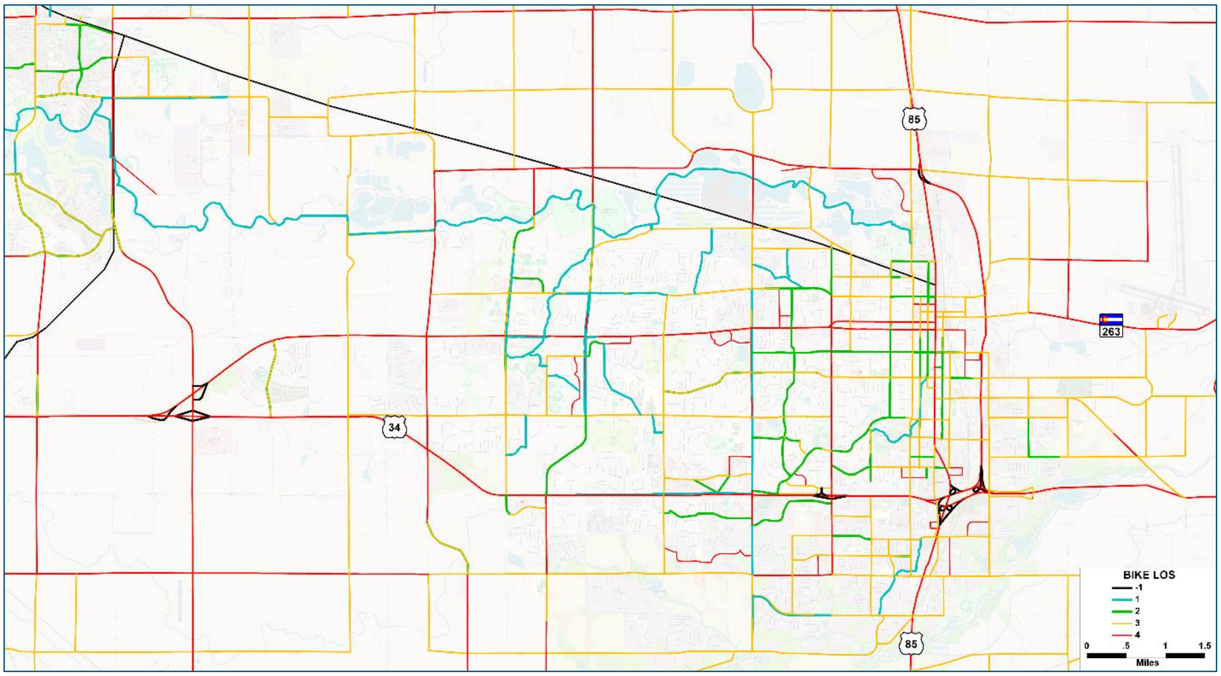
*MPO Region*



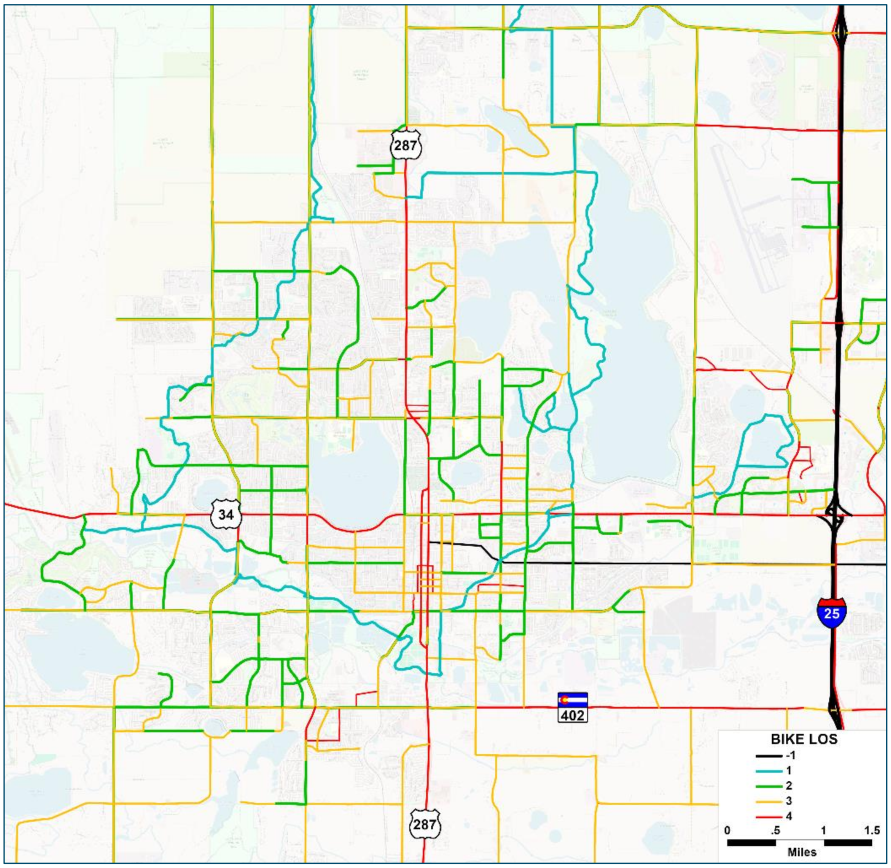
## Figure 10.2 Bicycle Level of Traffic Stress—Base Year
*Fort Collins*



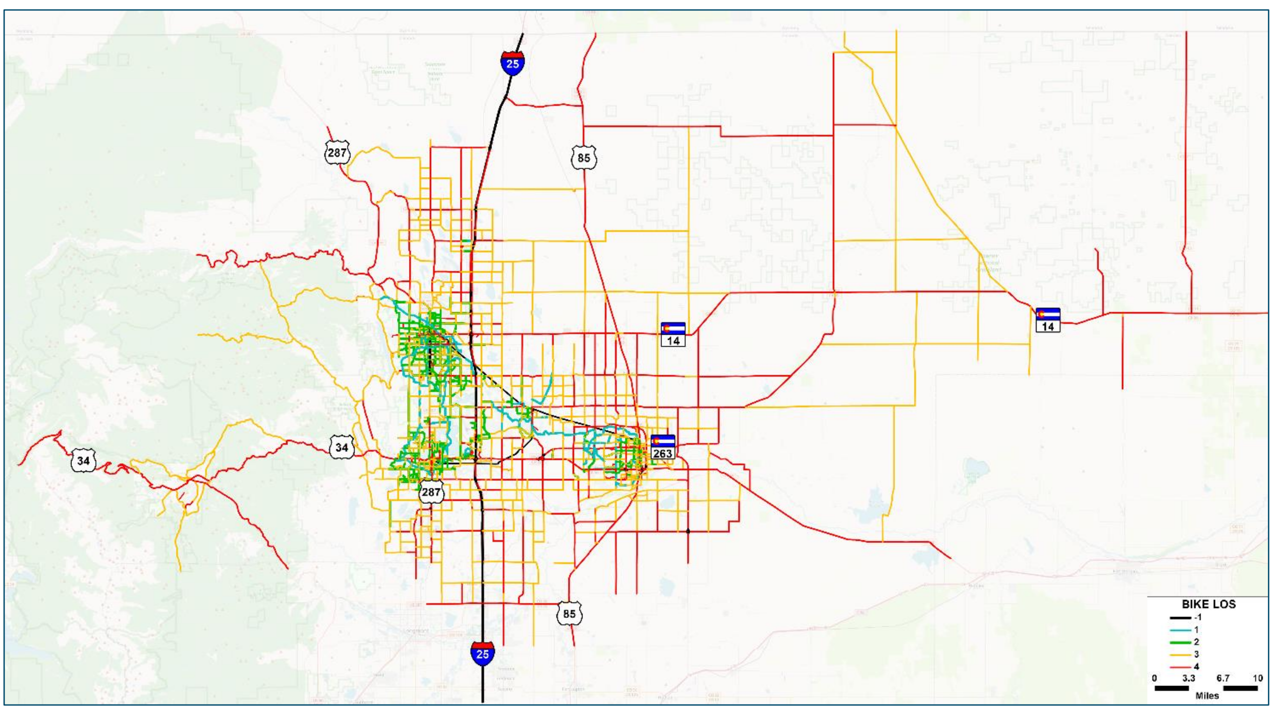

## Figure 10.3 Bicycle Level of Traffic Stress—Base Year
*Greeley*



## Figure 10.4 Bicycle Level of Traffic Stress—Base Year
*Loveland*




## Figure 10.5 Bicycle Level of Traffic Stress—Base Year
*Expanded Model Area*



The skimming process creates two paths for each zone pair, a “low-stress” path consisting only of links where the Bicycle Level of Traffic Stress is 1 or 2, and a shortest path allowing links of Bicycle Traffic Stress 1, 2, 3, or 4. Links where the Bicycle Level of Traffic Stress is greater than 4 or where bicycles are not allowed are not be used by either path. In building both shortest paths, the bicycle travel time is weighted by the Bicycle Level of Traffic Stress values to account for the relative attractiveness of higher and lower stress links.

The mode choice model includes the ratio of shortest path travel time to the low-stress travel time (the diversion ratio) as a term in the bicycle mode utility. This results in a lower positive contribution to the utility when significant diversion is required to follow the low-stress path as compared to the shortest path, and a higher positive contribution to the utility when little or no diversion is necessary to follow the low-stress path.

## 10.3 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.

$$u_i = c_1 X_{1i} + c_2 x_{2i} + c_3 x_{3i} + \dots + c_n x_{ni}$$

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 $i$

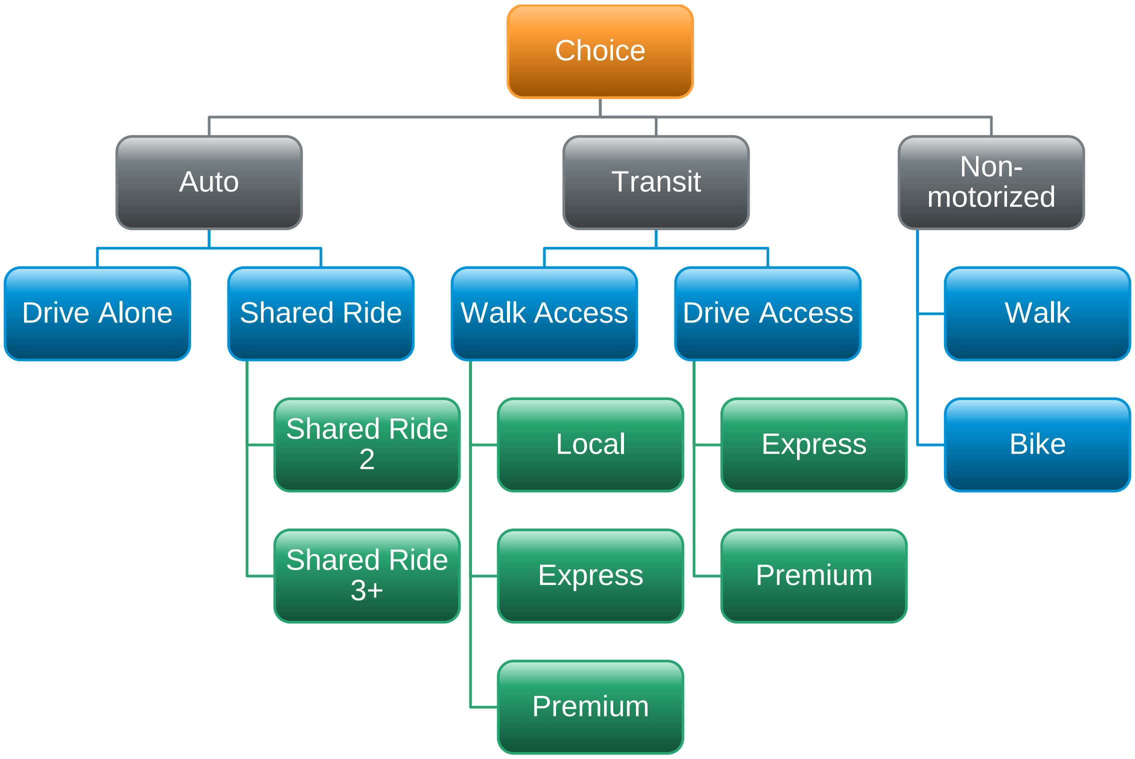
$\theta_i$ = The nesting coefficient for intermediate mode $i$

$\theta_m$ = 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 10.6**, 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 10.6 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 onboard 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.

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

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

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 onboard 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 10.7**, 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 10.7 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.

### *10.3.1 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 onboard 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 10.8** 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 multifamily 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 10.8 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 10.9**.

### Table 10.9 Income Market Segmentation

| Income Group | Implied Value of Time ($/hour) | Resulting Coefficient |
|---|---|---|
| Low | 2.4 | -0.621 |
| Medium | 7.0 | -0.214 |
| High | 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.

## *10.3.2 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

### 10.3.3 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 10.10**. Model constants ( $K_m$) calibrated to reproduce observed mode shares in the North Front Range are shown in **Table 11.11**.

**Drive Alone Utility:**

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

**Shared Ride 2 Utility:**

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

**Shared Ride 3+ Utility:**

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

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

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

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

**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:**

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

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) |
| *Pdensity* | = Production zone activity density in activity per acre |

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

## Table 10.10 Mode Choice Model Coefficients

| Coefficient | Value |
|---|---|
| In-Vehicle Travel Time (IVTT) | -0.025 |
| Long wait time (LWAIT) | -0.038 |
| Out of Vehicle Travel Time (OVTT) | -0.050 |
| Cost (low income, HBU) | -0.621 |
| Cost (med income) | 0.000 |
| Cost (high income) | 0.000 |
| CBD Dummy (Shared Ride) | 0.000 |
| CBD Dummy (Walk Access) | 0.010 |
| CBD Dummy (Drive Access) | 0.010 |
| Production Density (Shared Ride) | 0.000 |
| Production Density (Walk Access) | 0.000 |
| Production Density (Drive Access) | 0.000 |
| Attraction Density (Shared Ride) | 0.000 |
| Attraction Density (Walk Access) | 0.000 |
| Attraction Density (Drive Access) | 0.000 |
| Walk Time (TT) | -0.050 |
| Bike Time (TT) | -0.150 |
| Diversion Ratio | 0.950 |
| Access Mode, Share-Ride Nesting Coefficient | 0.700 |
| Sub-mode nesting coefficient | 0.500 |

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 10.11 Mode Choice Model Constants

| Mode | HBW Low Income | HBW Medium Income | HBW High Income | HBU | HBS | HBO | HBSc | WBO | OBO |
|---|---|---|---|---|---|---|---|---|---|
| Drive Alone | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Shared Ride | -2.47 | -2.47 | -2.47 | -3.89 | -0.45 | -0.34 | 0.24 | -1.98 | -0.34 |
| Shared Ride 3 | -0.17 | -0.17 | -0.17 | 2.72 | 0.06 | 0.51 | 0.51 | 0.05 | 0.37 |
| Transit | -3.38 | -4.46 | -5.03 | -5.14 | -4.24 | -3.40 | -3.71 | -4.17 | -3.18 |
| Drive Access | -1.36 | -1.36 | -1.36 | -0.01 | -2.55 | -1.54 | 0.00 | -1.60 | -1.68 |
| Express | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Drive Access Express | 0.53 | 0.53 | 0.53 | 0.00 | 0.00 | 0.03 | 0.00 | 0.17 | 0.34 |
| Premium | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Walk | -0.86 | -0.86 | -0.86 | -0.36 | -1.52 | -0.53 | 0.39 | -1.78 | -1.65 |
| Bike | -1.00 | -1.00 | -1.00 | 0.14 | -0.55 | 0.66 | 1.33 | -0.57 | 0.19 |

### *10.3.4 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.

## 10.4 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, traffic and transit assignment procedures in this version of the model remain relatively unchanged from the 2015 base year model.

## 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.

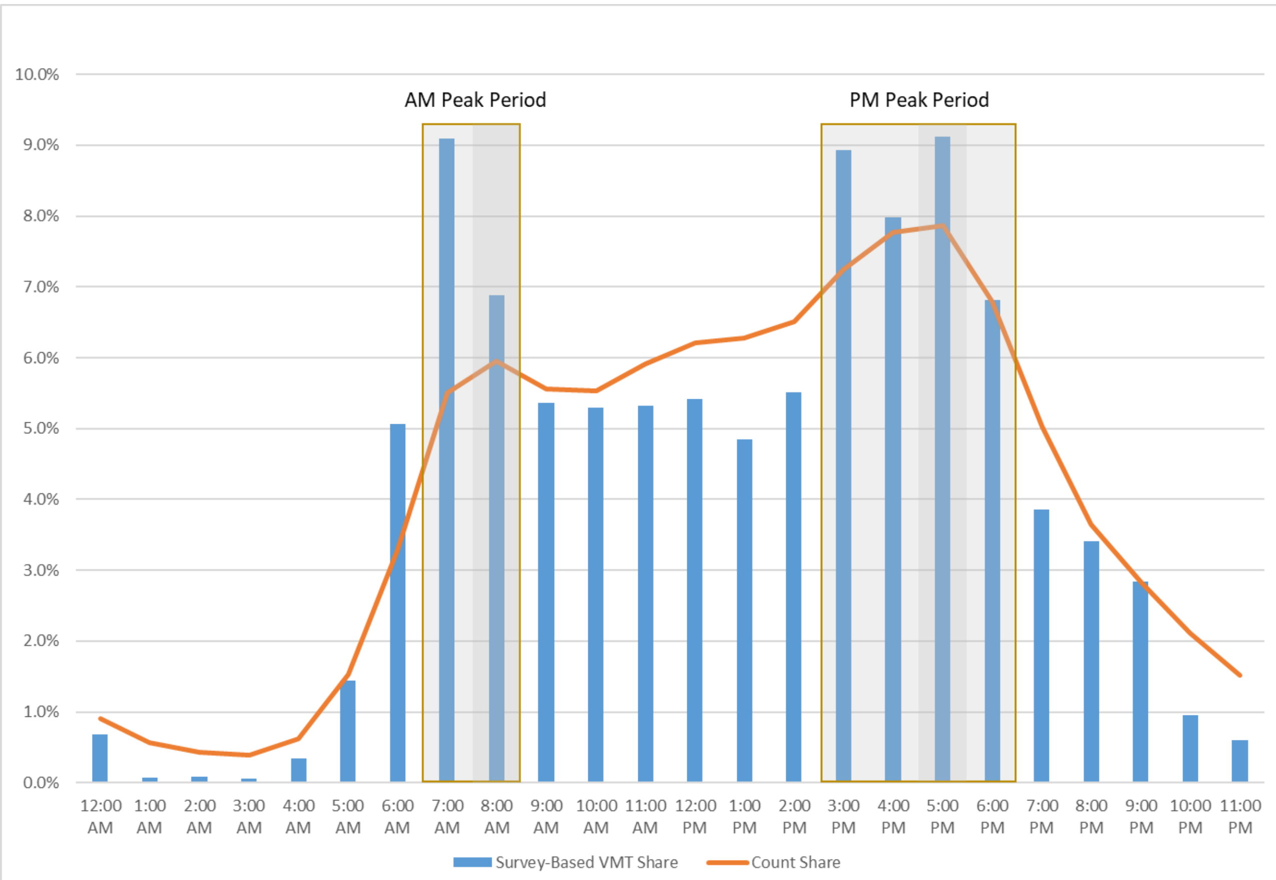
### Table 11.1 Travel Model Time Periods and Sub-Periods

| 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: 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 2019 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: 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 | 0.06 | 0.06 |
| PM | 0.097 | 0.587 | 0.363 | 0.572 | 0.125 | 0.583 | 0.354 | 0.392 | 0.046 | 0.485 | 0.67 | 0.106 | 0.44 | 0.44 |
| 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) |
| $\alpha$ | = Coefficient alpha |
| $\beta$ | = Exponent beta |

Ultimate roadway capacities for links in the NFR Model roadway network are defined in **Section 2.2.6**. 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 | 6 / 0.9 | 5.63 / 0.75 | 5.25 / 0.6 | 5.25 / 0.5 | 5 / 0.4 |
| 2—Expressway | 3 / 0.9 | 3 / 0.9 | 3 / 0.9 | 3 / 0.9 | 3 / 0.9 |
| 3—Principal Arterial | 3 / 0.9 | 3 / 0.9 | 3 / 0.9 | 3 / 0.9 | 3 / 0.9 |
| 4—Minor Arterial | 3 / 0.9 | 3 / 0.9 | 3 / 0.9 | 3 / 0.9 | 3 / 0.9 |
| 5—Collector | 2 / 0.6 | 2 / 0.6 | 2 / 0.6 | 2 / 0.6 | 2 / 0.6 |
| 6—Ramps | 5 / 0.55 | 5 / 0.55 | 5 / 0.55 | 5 / 0.55 | 5 / 0.55 |
| 7—Frontage Road | 2 / 0.45 | 2 / 0.45 | 2 / 0.45 | 2 / 0.45 | 2 / 0.45 |
| 8—Centroid Connector | 7 / 0.15 | 7 / 0.15 | 7 / 0.15 | 7 / 0.15 | 7 / 0.15 |

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.

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

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 1990s 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 <u>not</u> 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 onboard 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 subregional 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) | 1.0 |
| Home-Based University (HBU) | 1.0 |
| Work-Based Other (WBO) | 1.55 |
| Other-Based Other (OBO) | 1.55 |
| Medium Truck | 0.4 |
| Heavy Truck | 0.8 |
| Lodging-Based Other | 1.0 |

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.

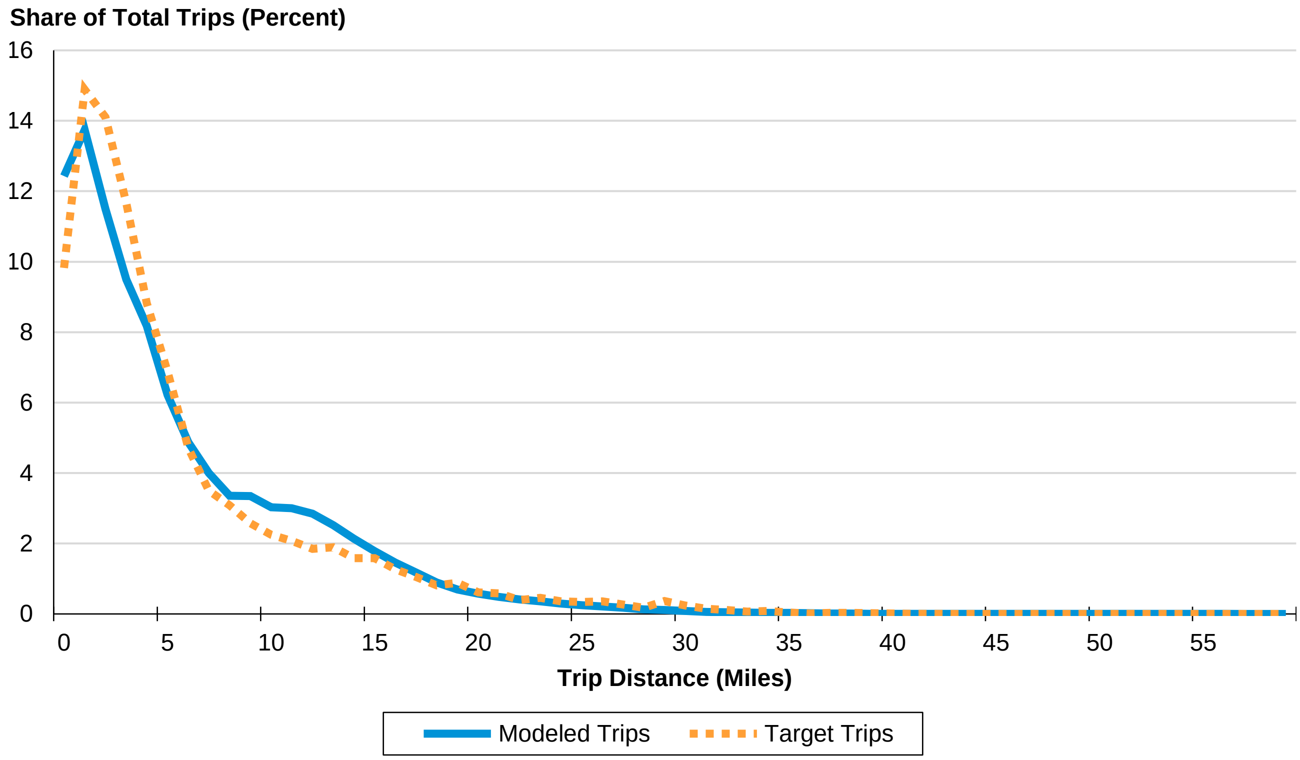
A comparison of average trip lengths by trip purpose is shown in **Table 12.3**, with trip length frequency distributions for each trip purpose shown in **Figure 12.1** through **Figure 12.6**.

## Table 12.3 Average Trip Lengths *by Trip Purpose*

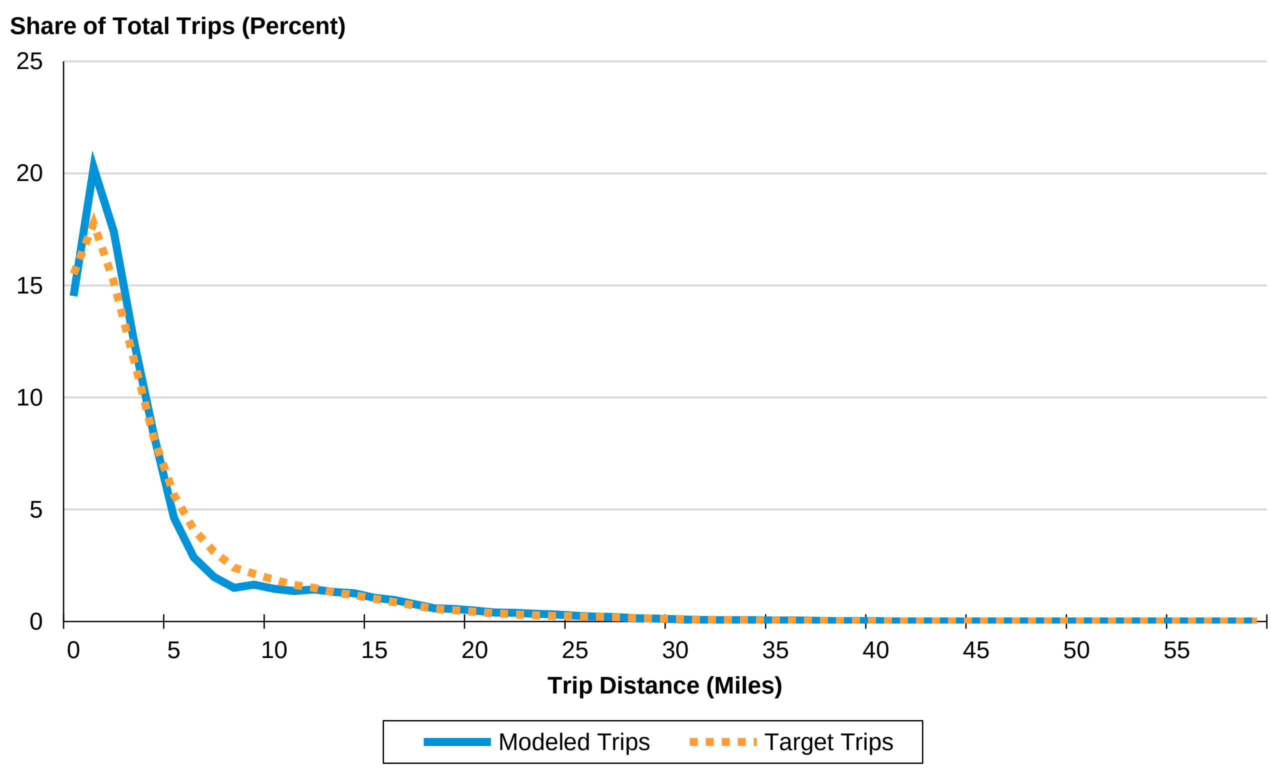
| | Average Trip Length | | |
|---|---|---|---|
| Purpose | Modeled | Target | Percent Difference |
| HBW | 6.33 | 6.25 | 1% |
| HBS | 4.93 | 5.05 | -2% |
| HBU | 5.75 | 5.61 | 2% |
| HBO | 5.09 | 5.05 | 1% |
| HBSc | 3.95 | 3.47 | 14% |
| WBO | 4.48 | 4.72 | -5% |
| OBO | 4.00 | 4.47 | -10% |

Source: NFR Model Output Files, LOCUS data and 2010 FRTC Survey Data

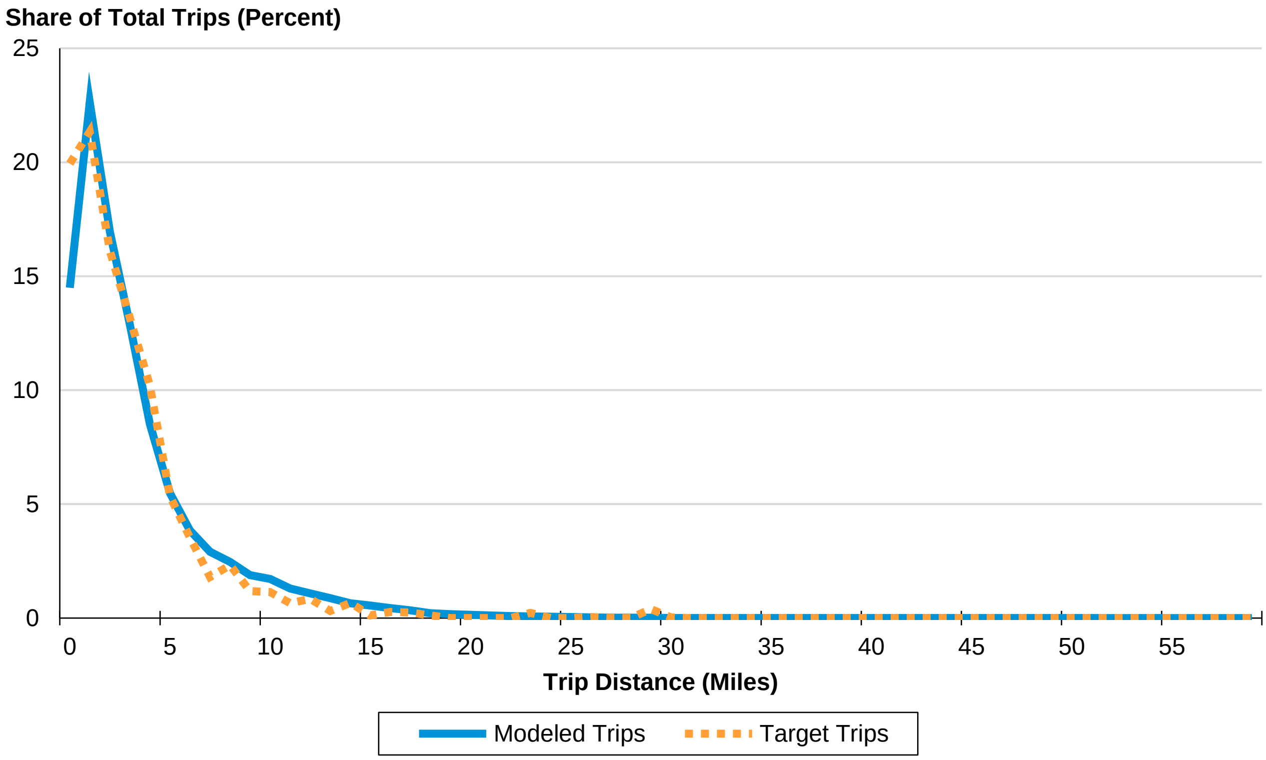
## Figure 12.1 Home-based Work Trip Length Frequency Distribution



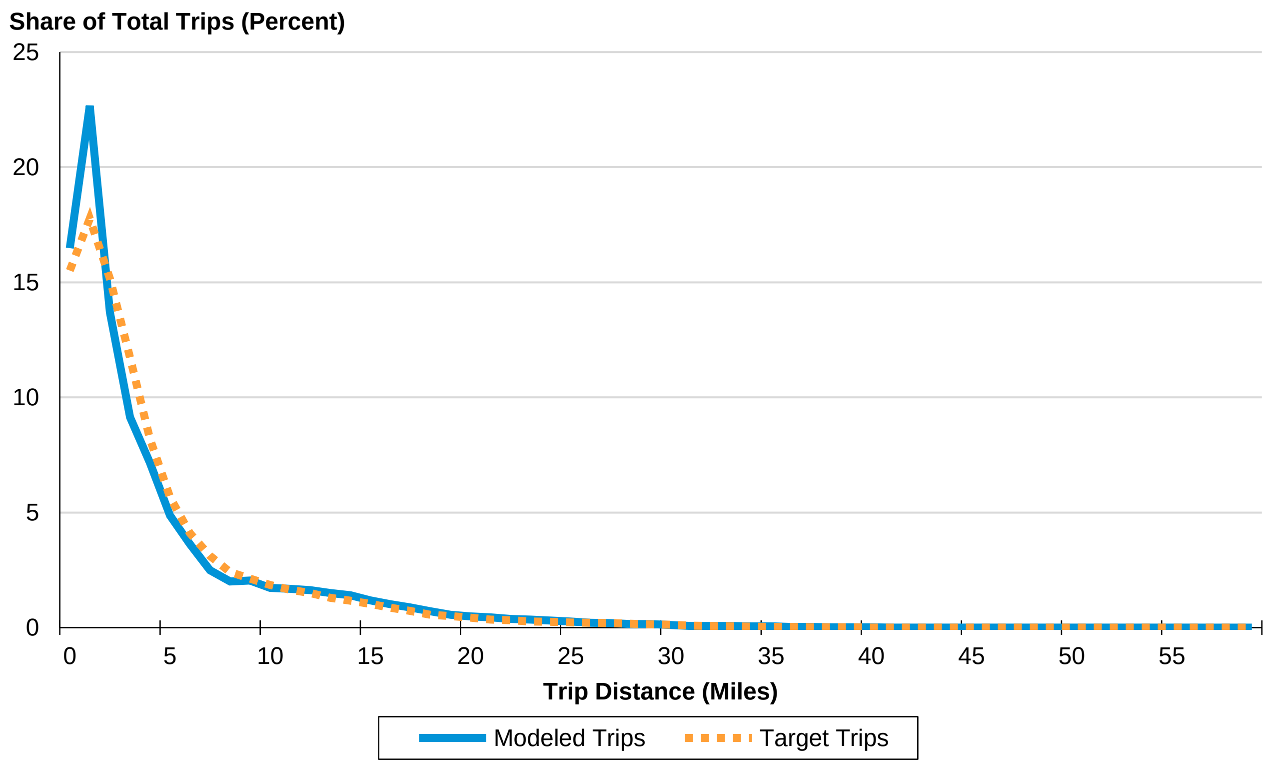

## Figure 12.2 Home-based Shop Trip Length Frequency Distribution



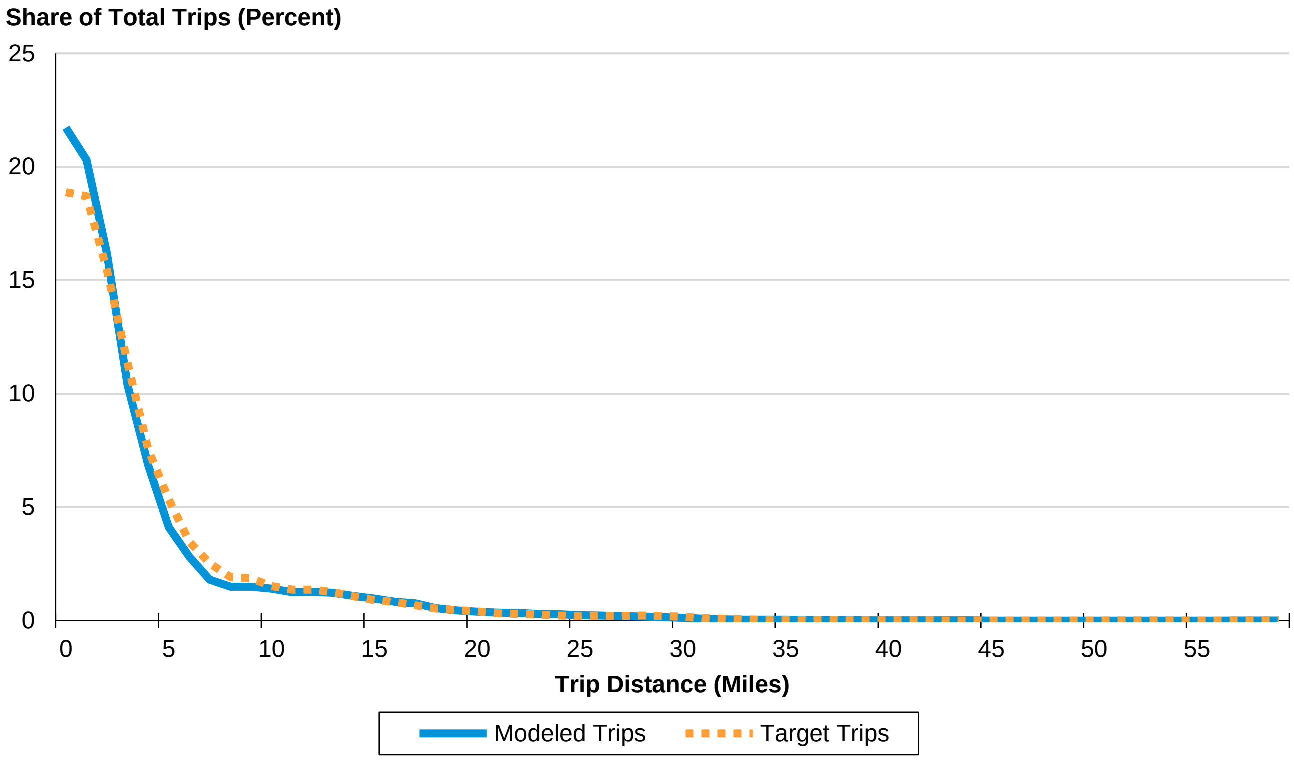
## Figure 12.3 Home-based School Trip Length Frequency Distribution



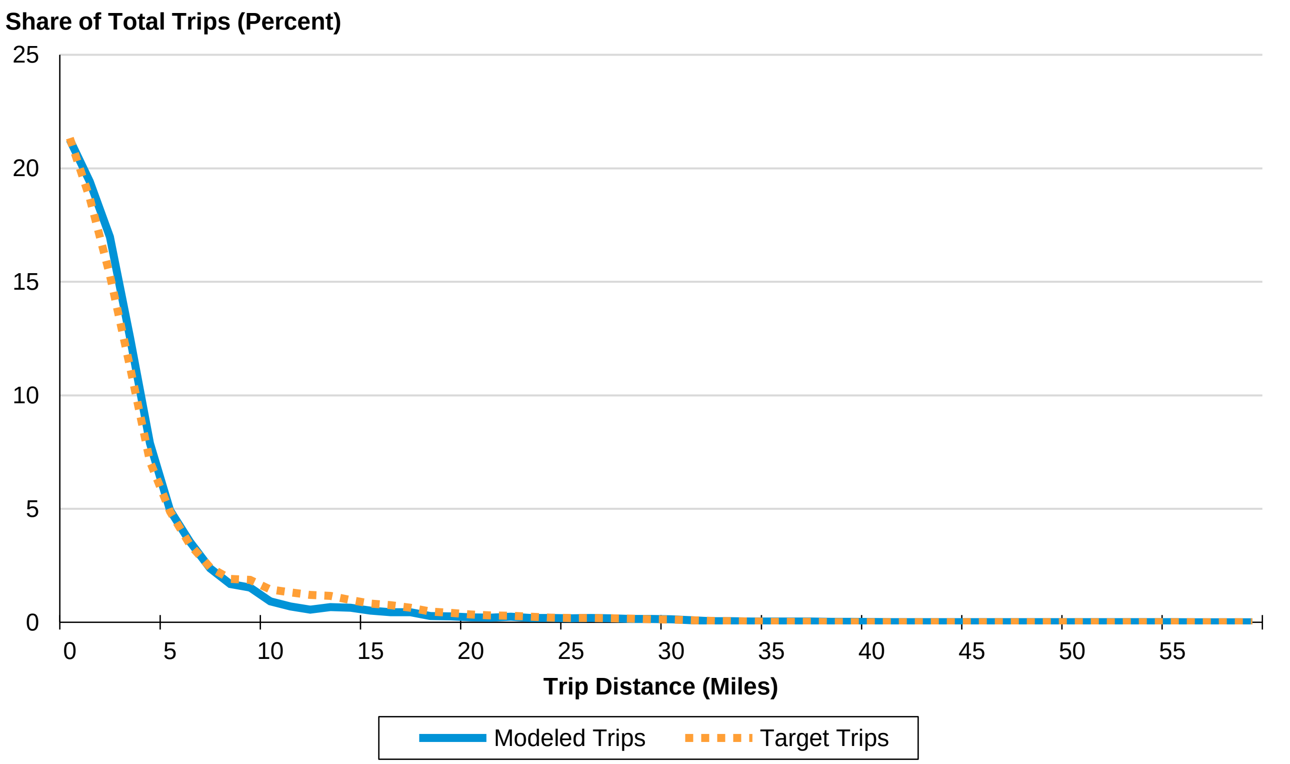

## Figure 12.4 Home-based Other Trip Length Frequency Distribution



## 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 U.S. 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 U.S. 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 (U.S. 34, SH 7, and U.S. 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

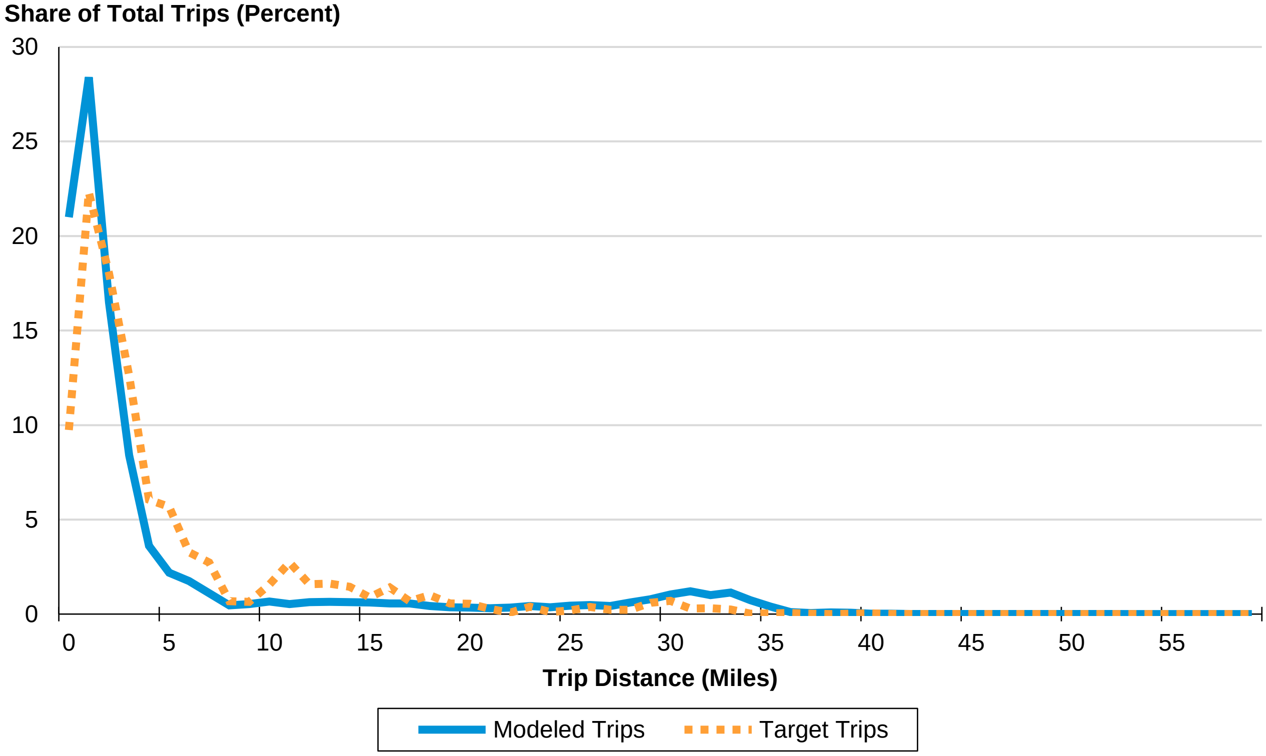
| Parameter | North Front Range Region | Estes Park |
|---|---|---|
| Alpha ($\alpha$) | 650 | 750 |
| Beta ($\beta$) | 0.45 | 0.5 |
| Gamma ($\gamma$) | 0.12 | 0.25 |

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.

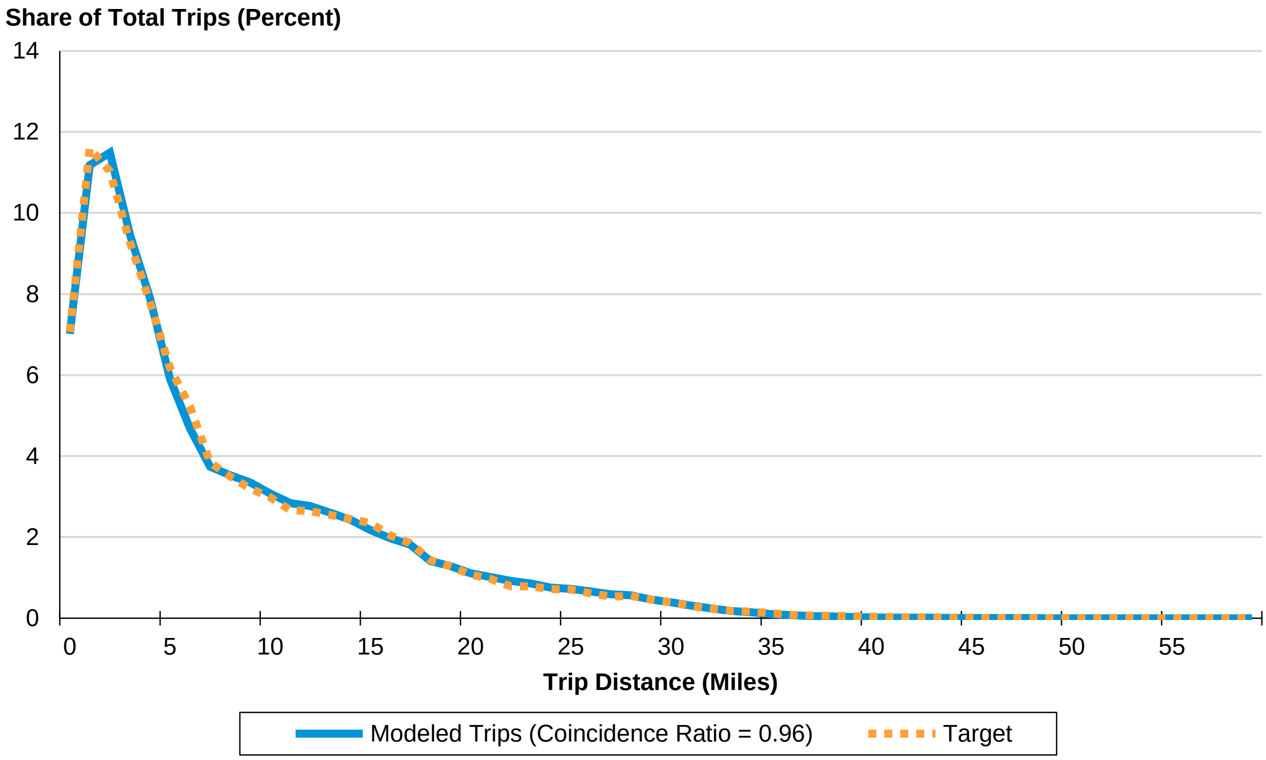
## Figure 12.7 Home-based University Trip Length Frequency Distribution



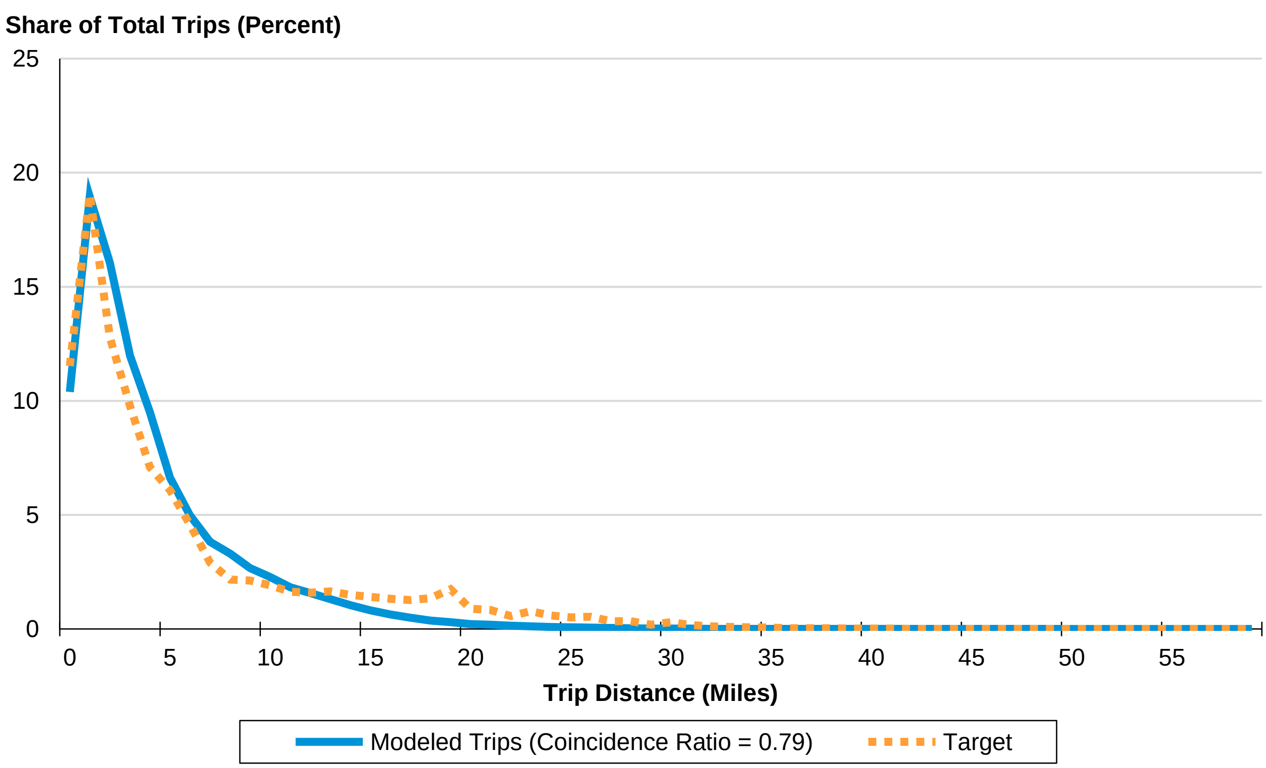

### *12.2.4 Truck Trip Distribution*

The 2015 base year model utilized truck trip tables obtained by CDOT and shared with the NFRMPO. This dataset is comprised of GPS-based origin-destination trip tables for medium and heavy trucks. This data provided the information necessary to calibrate the truck trip length distribution model. The resulting trip length frequency distributions are shown in **Figure 12.8** and **Figure 12.9**. Truck trip distribution has been retained from the 2015 mode because new calibration data was not available for the 2019 base year update.

## 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

| | Difference in Mode Shares (Modeled—Target) | | | | | |
|---|---|---|---|---|---|---|
| Purpose | 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% |
| HBSc | 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 and mode choice calibration targets.

## 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 | 28 | 107% | 104% | +/- 10% |
| Expressway | 65 | 97% | 96% | +/- 10% |
| Principal Arterial | 374 | 102% | 102% | +/- 10% |
| Minor Arterial | 615 | 103% | 101% | +/- 15% |
| Collector | 1,077 | 89% | 104% | +/- 25% |
| CBD | 103 | 105% | 106% | n/a |
| Commercial Corridor | 66 | 101% | 99% | n/a |
| Urban | 587 | 97% | 98% | n/a |
| Suburban | 624 | 103% | 101% | n/a |
| Rural | 801 | 101% | 98% | n/a |
| **Total** | **2,181** | **100%** | **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

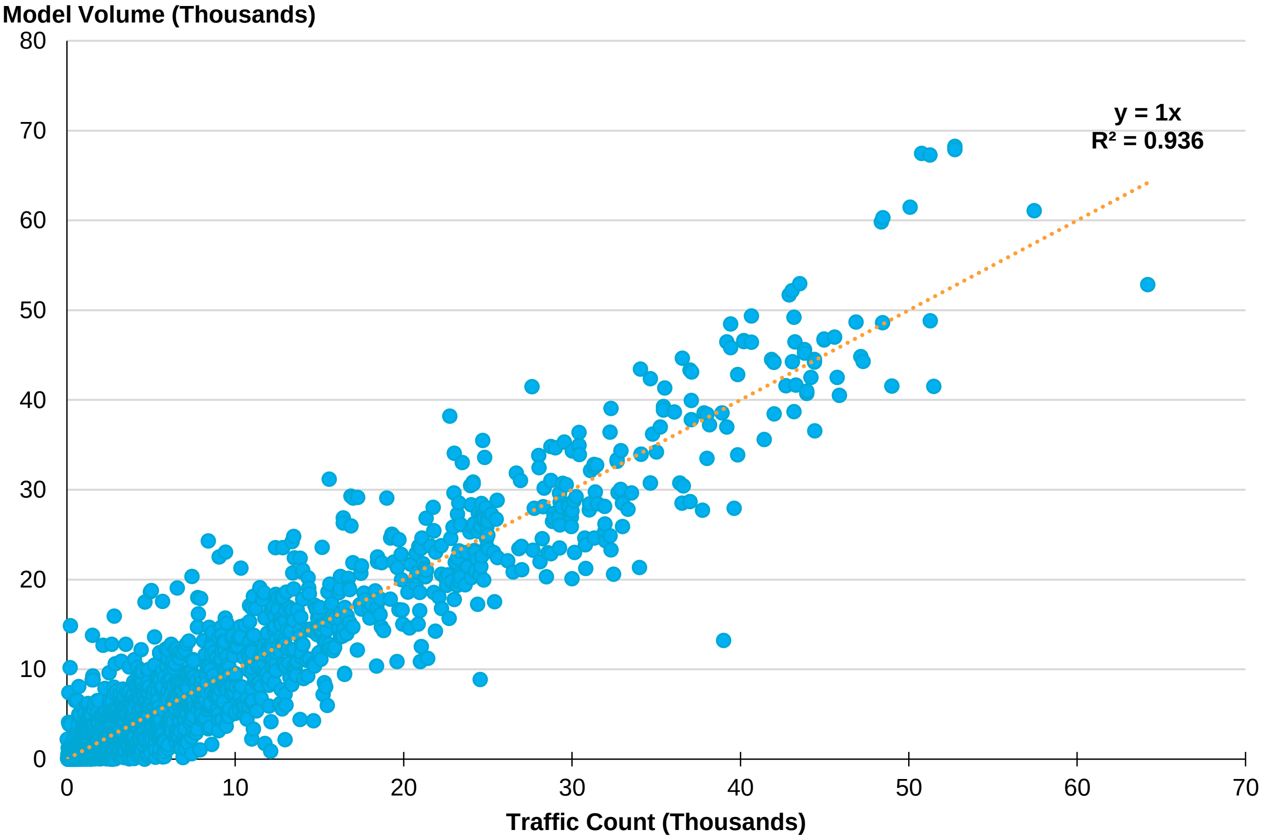
| Link Type | VMT | VHT | Average Speed |
|---|---|---|---|
| Freeway | 3,851,354 | 53,293 | 72.8 |
| Expressway | 2,095,081 | 41,970 | 50.9 |
| Principal Arterial | 3,583,588 | 106,587 | 33.8 |
| Minor Arterial | 2,771,613 | 74,704 | 35.3 |
| Collector | 1,129,950 | 35,460 | 29.6 |
| Ramp | 103,918 | 2,709 | 44.7 |
| Frontage Road | 104,385 | 2,317 | 45.3 |
| Centroid Connector | 1,477,361 | 48,967 | 30.2 |
| CBD | 254,577 | 10,952 | 22.9 |
| Commercial Corridor | 306,322 | 11,704 | 24.4 |
| Urban | 3,447,907 | 114,245 | 26.9 |
| Suburban | 4,999,056 | 117,296 | 33.7 |
| Rural | 6,109,387 | 111,810 | 39.4 |

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 regionwide, 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 | 28 | 3,955 | 12% | < 20% |
| Expressway | 65 | 7,162 | 24% | < 30% |
| Principal Arterial | 374 | 5,186 | 26% | < 30% |
| Minor Arterial | 615 | 3,480 | 48% | < 40% |
| Collector | 1,077 | 1,761 | 90% | n/a |
| CBD | 103 | 4,660 | 46% | n/a |
| Commercial Corridor | 66 | 4,804 | 22% | n/a |
| Urban | 587 | 4,237 | 36% | n/a |
| Suburban | 624 | 3,446 | 42% | n/a |
| Rural | 801 | 1,961 | 64% | n/a |
| **Total** | **2,181** | **3,365** | **43%** | **< 40%** |

## Table 12.9 RMSE Statistics *by Volume Group*

| Volume Group | Number of Counts | RMSE | % RMSE |
|---|---|---|---|
| 0—1,000 | 655 | 1,462 | 130.50% |
| 1,000—5,000 | 594 | 2,193 | 67.90% |
| 5,000—10,000 | 358 | 3,203 | 47.40% |
| 10,000—20,000 | 284 | 4,820 | 37.90% |
| 20,000—30,000 | 164 | 5,723 | 23.60% |
| 30,000—50,000 | 101 | 5,429 | 14.90% |
| 50,000—and up | 12 | 12,786 | 25.30% |
| All Links | 2,168 | 3,367 | 43.10% |

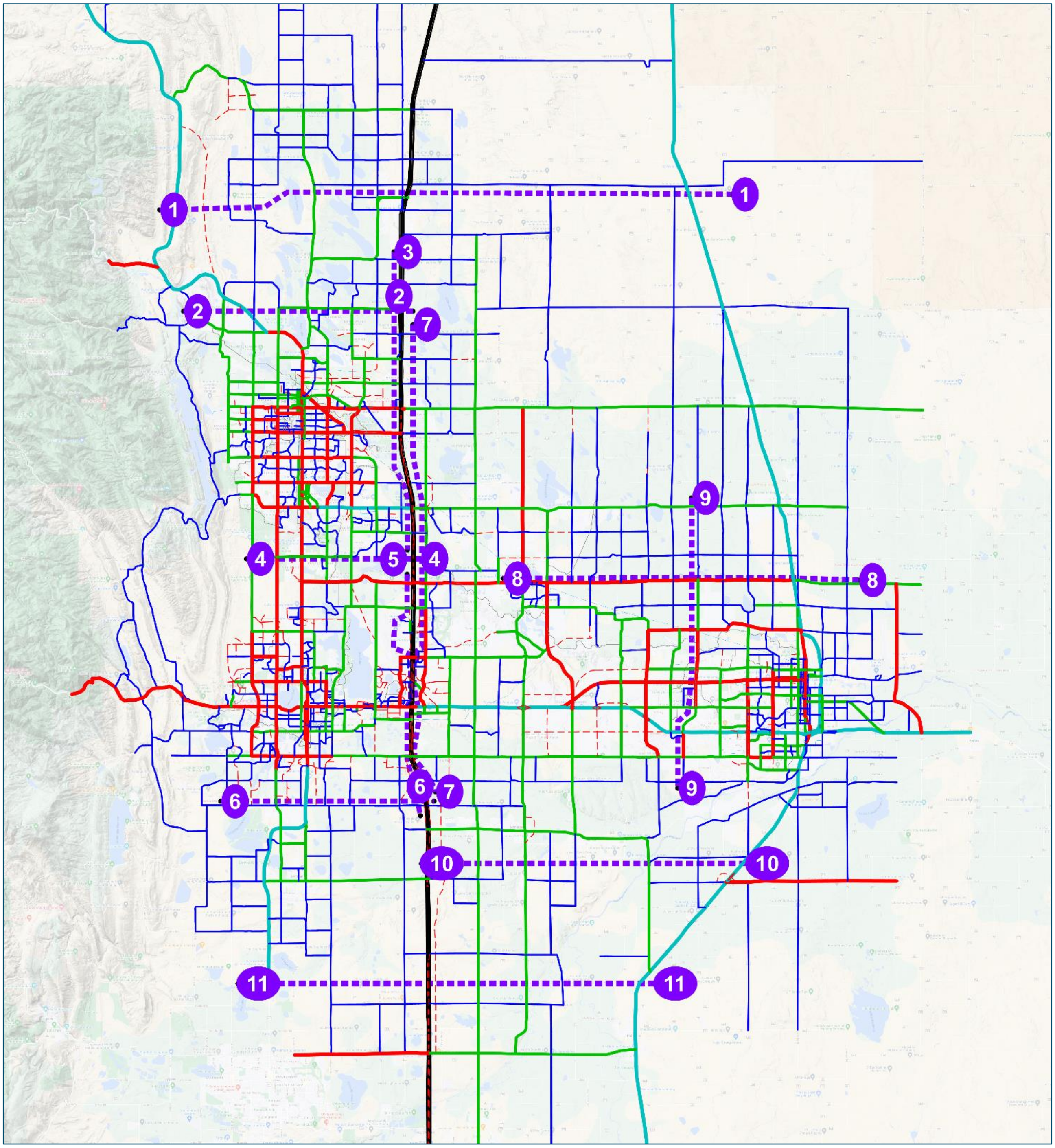
### *12.4.3 Screenline Analysis*

The NFR Model includes 11 screenlines, shown in **Figure 12.11**. Screenlines capture distinct regional or interregional 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.

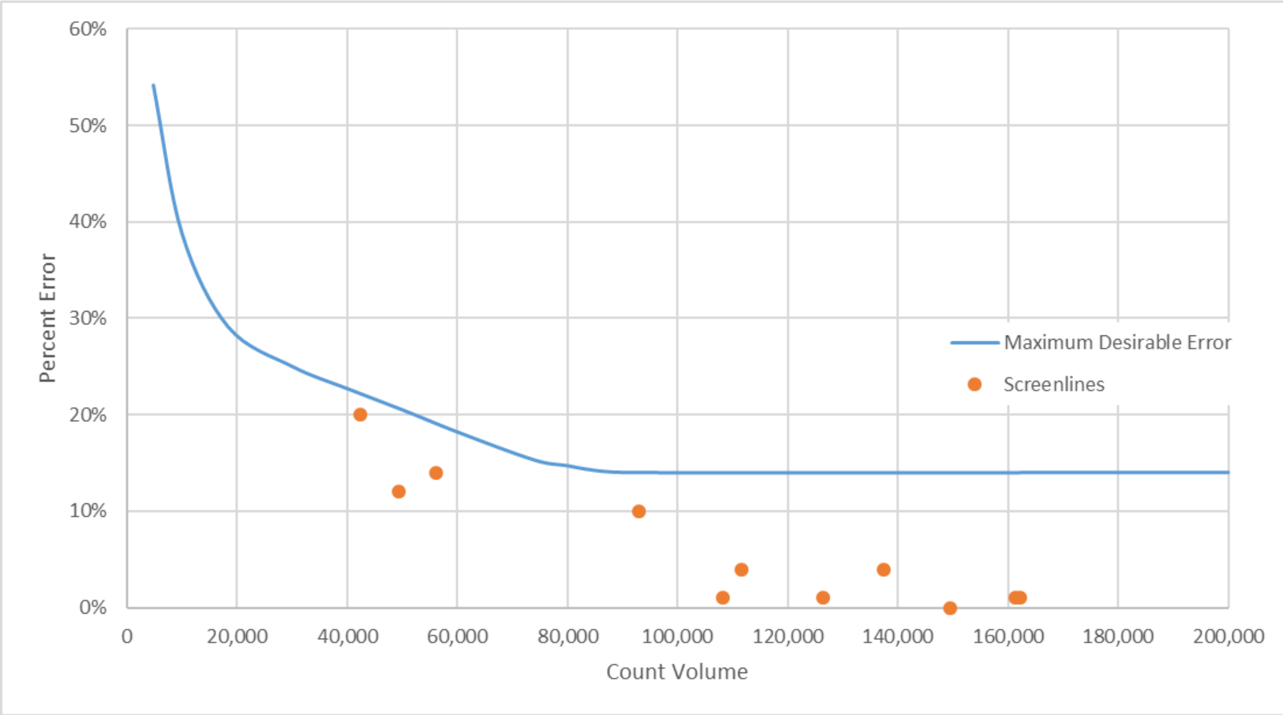
## Table 12.10 NFR Model Screenline Analysis

| Screenline | Model Volume | Observed Volume | % Error | Maximum Desirable Error |
|---|---|---|---|---|
| 1—North Boundary | 50,898 | 43,086 | 18% | 22% |
| 2—North of Fort Collins | 66,704 | 56,115 | 19% | 19% |
| 3—East of Fort Collins | 158,436 | 138,709 | 14% | 14% |
| 4—South of Fort Collins | 181,998 | 158,327 | 15% | 14% |
| 5—East of Loveland | 101,584 | 92,757 | 10% | 14% |
| 6—South of Loveland | 117,181 | 111,837 | 5% | 14% |
| 7—East of I-25 | 184,816 | 161,707 | 14% | 14% |
| 8—North of Greeley | 52,200 | 55,502 | -6% | 19% |
| 9—West Greeley | 147,602 | 141,997 | 4% | 14% |
| 10—South of Greeley | 36,929 | 38,706 | 95% | -5% |
| 11—South Boundary | 138,700 | 153,826 | -10% | 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 | 380 | 940 | 560 | 147% |
| GET | 2,558 | 1,628 | -930 | -36% |
| Transfort | 12,590 | 12,101 | -489 | -4% |
| CDOT | 841 | 953 | 112 | 13% |
| **Total** | **16,369** | **15,622** | **-747** | **-5%** |