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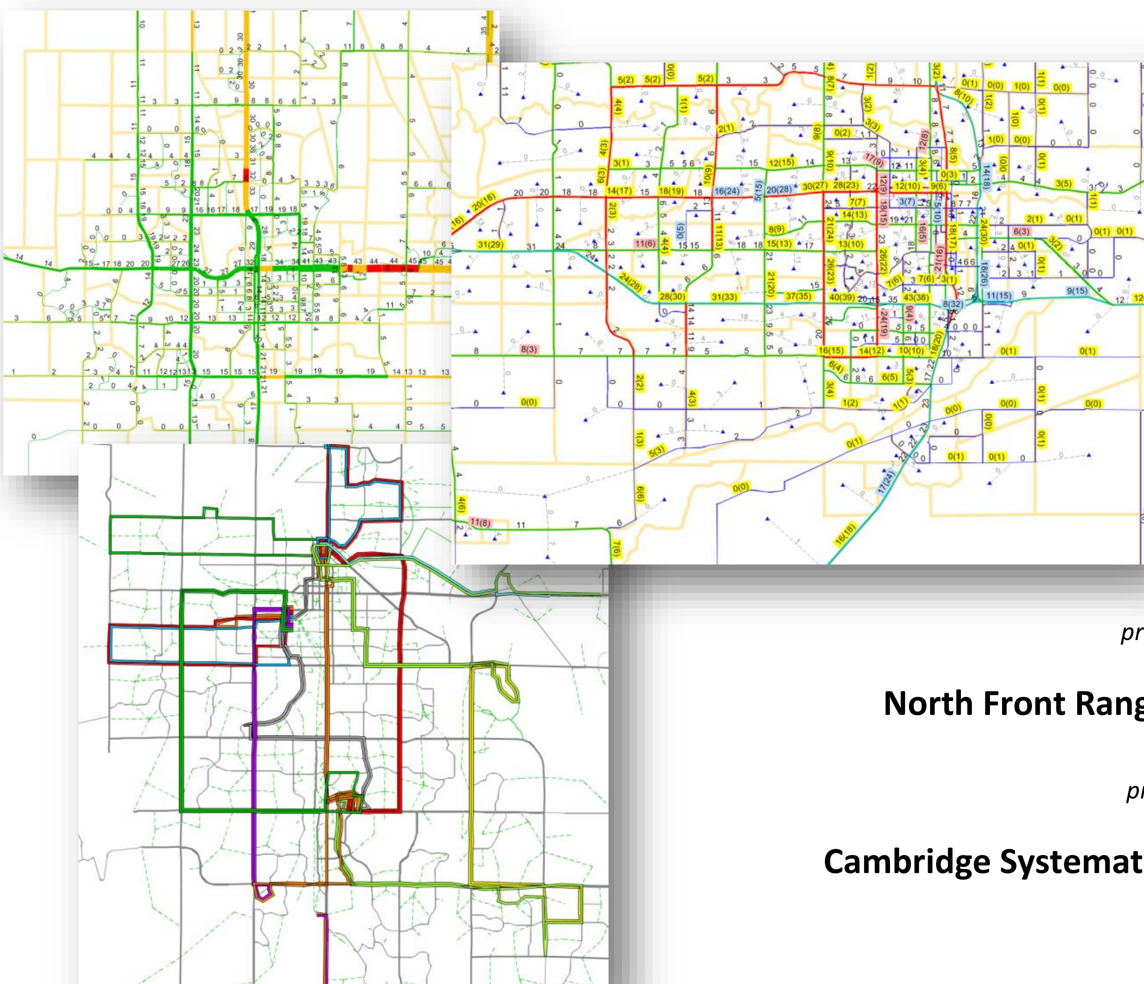
North Front Range 2012 Base Year Regional Travel Model

Technical Documentation



prepared for

North Front Range MPO

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1.0 INTRODUCTION

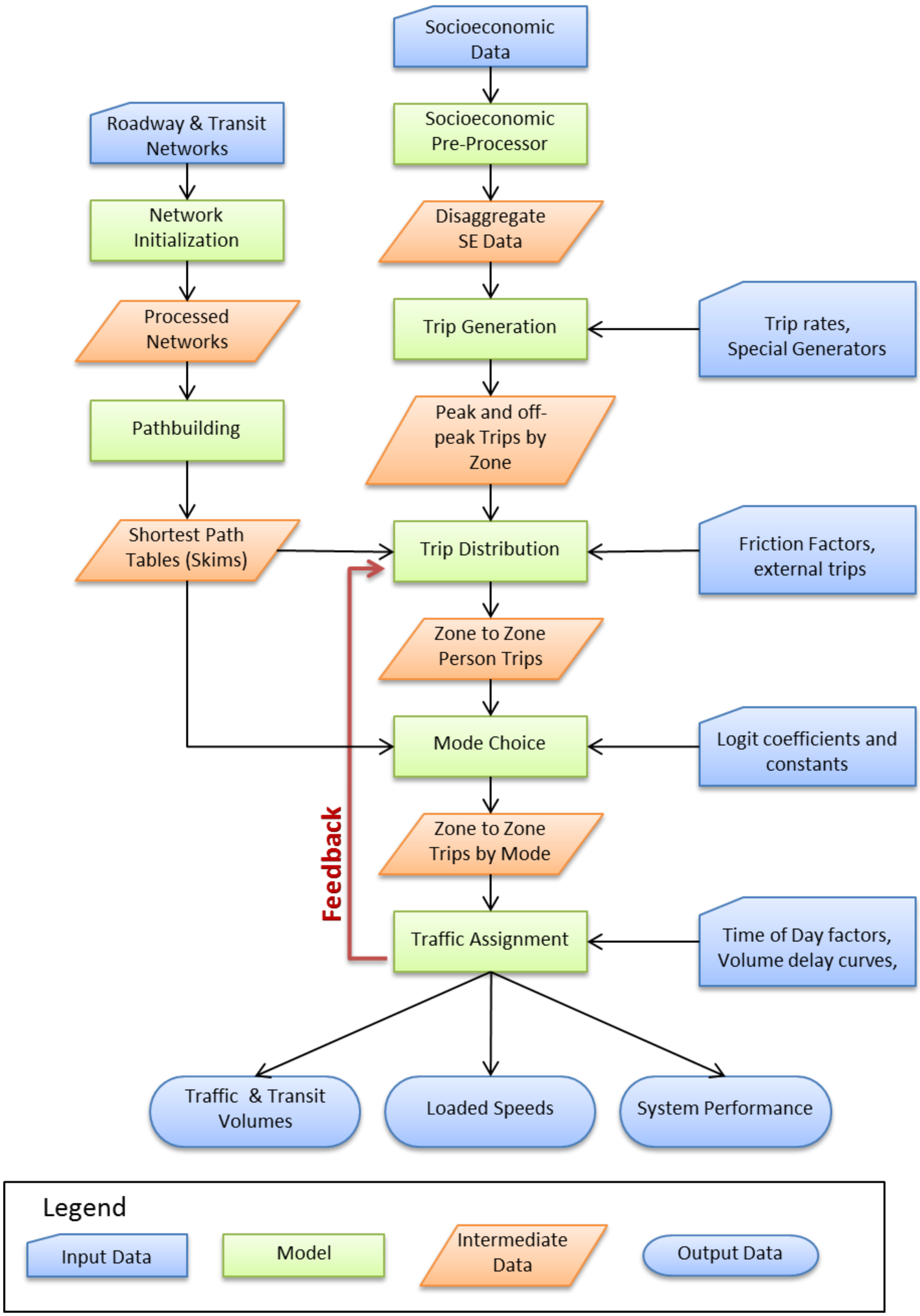
The North Front Range Metropolitan Planning Organization (NFRMPO) and member jurisdictions use the NFR Regional Travel Model (NFR Model) as a tool to forecast traffic and travel in communities throughout the region. The primary purposes of the travel model are to support the Regional Transportation Plan (RTP) and air quality conformity analysis. Additionally, the model can support evaluation of proposed roadway 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 2012 and contains future year data reflecting forecast 2040 conditions. Interim year data representing several intermediate timeframes is also maintained in the travel model dataset.

The previous version of the model featured a 2009 base year and 2035 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, improvements to the mode choice model, and incorporation of toll and HOV modeling functions. Data sources include a household travel survey, an external station survey, a travel time survey, and a transit on-board survey. All of these data sources were accounted for in the 2009 base year version of the travel model.

Throughout the course of model development, the NFRMPO enlisted a *Model Development Team* (MDT) to review land use and travel model inputs, procedures, and results. This group included representatives from NFRMPO member jurisdictions, the Colorado Department of Transportation (CDOT), and NFRMPO staff. The group held four meetings over the course of the model development process.

The NFRMPO 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 communities in the U.S. for several decades.

Figure 1.1: Example Model Run Directory Structure



2.0 ROADWAY NETWORK

2.1 Context and Background

The roadway network contains basic input information for use in the travel demand model and represents real-world conditions for the 2012 base year. The roadway networks are used in the model to distribute trips and route automobile 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 criteria. This chapter 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 2012 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 MPO region as well as the expanded Ozone modeling region. It operates both as an input database containing roadway characteristics (such as facility type, number of lanes, area type, etc.) and as 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 MPO Model contains the 2012 base year network and can also store forecast year improvements or alternatives. It is designed to accommodate future horizon year networks, including 2040 and other interim years as desired. The model includes the capability to represent the 2012 base year, existing plus committed networks, plan forecast networks, interim horizon year networks, and any other network scenarios desired within a single network database. In addition, the network is structured so localized alternatives can be represented within the same file. These alternatives can be activated and deactivated based on the year of analysis and infrastructure scenario desired using the scenario management system that forms the basis of the travel model user interface.

2.2 Roadway Network Structure

The NFRMPO 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 chapters.

Input network attributes used by the travel model include facility type, area type, number of lanes, speed limit, and direction of flow. Each of these variables is addressed in the sections that follow. Values for these attributes have been populated on the roadway network file for the year 2012 and for a 2040 fiscally constrained scenario. In addition, all projects included in the 2040 fiscally constrained network include a year of completion (stored in a separate spreadsheet) which allows a separate roadway network to be created for interim years between 2012 and 2040.

The roadway network is structured to consolidate data from multiple years and scenarios in a single TransCAD geographic file. Year-specific input data is 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. This information is placed on a copy of the network rather than the original input file. Creation of a routable network required by several TransCAD processes is also discussed.

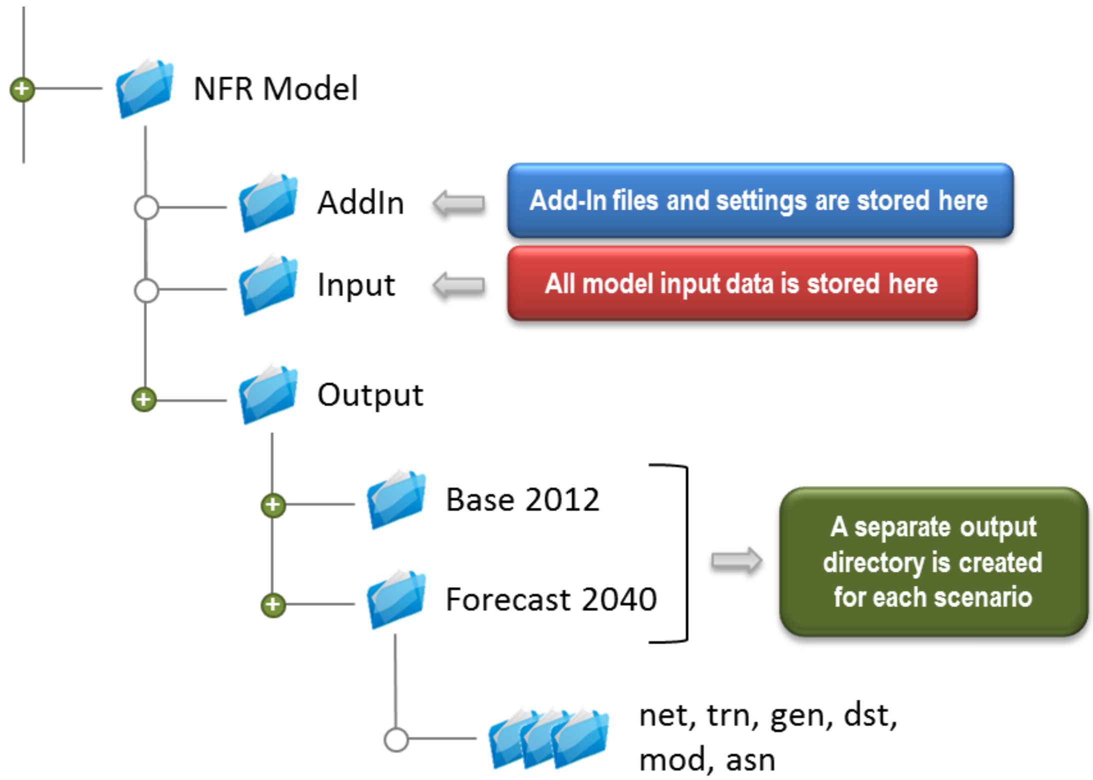
Input and Output Networks

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

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

- All input files are located in one standardized location, making identification of files easy when edits are required;
- Because input files are not modified by the travel model macros, it is unlikely important data present within input files will be inadvertently overwritten by travel model macros; and
- Since all output files related to a particular model run will be maintained in a single directory, there will be no confusion about which model scenario is represented by each file.

Figure 2.1: Example Model Run Directory Structure



Multi-Year and Alternative Network Structure

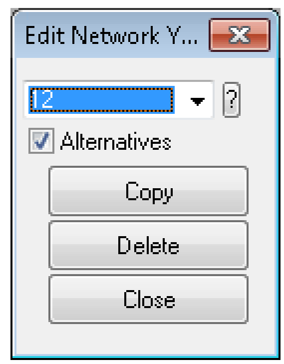
The NFRMPO roadway network is designed to store roadway data representing different years in one consolidated network layer. To accomplish this, selected network attribute names are appended with a two- through four-digit suffix representing a particular year. By representing multiple networks in one network file, consistency between baseline and forecast networks is enforced. Furthermore, this approach eliminates the need to edit multiple network files when making a change in a baseline or interim year network.

In addition, the network structure allows for the representation of alternative roadway projects such as roadway widening, realignments, and new facilities not tied to a specific network year. Hypothetical roadway projects that are not funded can be included in the network for testing without specifying a year of completion. These alternatives can be activated or deactivated individually or in groups, regardless of the network year that has been selected. While there are some limitations with respect to alternatives sharing the same link, this capability can be a valuable tool when performing alternatives with the travel model. These limitations and strategies to overcome them are described in the next section.

Representation of Networks by Year

Each attribute which can vary from year to year (e.g., facility type, area type, number of lanes, direction of flow, etc.) is represented in the roadway network by an attribute containing a two- through four-digit numerical suffix. When a particular network is selected for use in the travel model, only attributes with a suffix matching the selected year are used by the travel model. Of utmost importance is the facility type attribute. If this attribute is blank on a link for a particular year, that link is "closed" to traffic (i.e., will not exist) in the network when that year is selected. If a valid facility type value is found, then the remaining attributes specified for that year are referenced by the travel model.

The roadway network initially contains data for the years 2102 and 2040, with individual projects entered by expected year of completion. The roadway projects in these network scenarios are consistent with the current state of the MPO's fiscally constrained Regional Transportation Plan (RTP). The 2040 fiscally constrained roadway network has been thoroughly reviewed by the MPO's Model Development Team (MDT),. MPO staff has obtained feedback and approval of the 2040 fiscally constrained roadway network from all member jurisdictions.



Additional network years can be added as needed. Because this is a commonly performed task, the model interface includes a utility which aids in management of network data. The utility can add an additional network year to the roadway network geographic file by copying a pre-existing scenario. If alternatives are present in the network file, the utility allows the user to select alternatives to be included in a newly created network year. Once a new network year has been created, the user can adjust the network attributes as necessary. The utility can delete all attributes associated with a particular year. When run, the edit network utility performs the following steps:

- Add new columns to network link and node tables that represent the additional network year (e.g., FT_25, AT_25, etc.);
- Move new columns to a convenient location (e.g., between the 2012 and 2040 data columns);
- Fill new columns with data from corresponding attributes from the identified model year; and
- Update network values based on roadway alternatives (if selected).

Representation of New Facilities

The NFRMPO roadway network structure can represent roadway facilities which do not exist in the current network, but are planned for future construction. For example, if a new roadway is planned to be built by 2040, it could represent the 2040 roadway network, but not the base year roadway network. To implement this, the roadway is included in the network layer, but not assigned a facility type for the base year. Instead, a valid facility type is included for the 2040 scenario only. When the travel model is run, only links with a valid facility type are considered by model components which reference the roadway network.

Representation of Network Alternatives

Roadway network alternatives provide a mechanism for testing localized network changes individually or in combination without the need to create an additional network. Roadway network alternatives are specified by a set of attributes with suffix AL (e.g., FT_AL, AT_AL, etc.) and attributes named ALT and ALT2, as follows:

- The fields with an AL suffix represent the network attributes used when an alternative is activated, and
- The "ALT" and "ALT2" fields identify the alternative number associated with each link.

If a particular alternative has been activated prior to a model run, the values in fields containing the AL suffix override other network attributes on links where ALT or ALT2 match a selected alternative. The network structure example shown in this section further illustrates application of network alternatives. The Network Attribute Selection section describes the procedure used to process network attributes.

Network alternatives can represent scenarios in which roadway attributes differ or scenarios in which roadways are constructed or removed. For example, an alternative might represent a proposed roadway widening project not included in the 2040 roadway network. If the model network includes the example alternative as a project, model scenarios can then be created which:

- Represent the base-year network without the roadway widening;
- Represent the base-year network plus the roadway widening;
- Represent the 2040 network without the roadway widening; or
- Represent the 2040 network plus the roadway widening.

As with network attributes which vary by year, absence of facility type data results in a link being omitted from consideration in the travel model. It is possible to represent the closure of a roadway by activating an alternative with a null value for FT_AL on a particular roadway link. This is also useful when simulating a roadway realignment.

Network Structure Example

To illustrate the concept behind the network structure, a simplified example link data table is shown below. This table only shows facility type information. Lane, speed override, and area type information follow a similar theme. In this example network:

- Link 100 exists as a principal arterial (FT = 3) in 2012 and all subsequent years.
- Link 200 is programmed as a principal arterial (exists in 2020 and later).
- Link 300 is planned to be built as a minor arterial (FT = 4) by 2040.
- Link 300 is instead built as a collector (FT = 5) if Alternative 1 is activated.
- Link 400 is a new facility to be built as a minor arterial if Alternative 2 is activated.
- Link 500 exists in 2009 and all future years as a minor arterial, but is closed if Alternative 3 is activated.

Example Link Dataset

ID	FT_12	FT_20	FT_40	FT_AL	ALT
100	3	3	3	--	--
200	--	3	3	--	--
300	--	--	4	5	1
400	--	--	--	4	2
500	4	4	4	--	3

This structure has limitations. Only two alternatives can occupy the same link as limited by two fields, "ALT" and "ALT2." Also, only one set of alternative attributes can occupy the same link, limited by the one set of attributes with an "AL" suffix.

These limitations are of particular concern in a scenario where a road exists as a 2-lane facility and consideration is being given to whether it should be widened to 4- or 6-lanes. While this scenario cannot be readily represented in the network alternative structure, it can be represented through use of either of two options:

- The network can include a separate year (e.g., "12W4" or "40W4") that represents the road as a 4-lane facility, along with an alternative that represents the road as a 6-lane facility; or

- Users can manually revise the number of lanes when running the model. The network could include an alternative that represents the facility as a 4-lane facility, but the alternative can be revised to show 6 lanes as needed.

Network alternatives can represent scenarios in which roadway attributes differ or scenarios in which roadways are constructed or removed. For example, an alternative might represent a proposed roadway widening project not included in the 2040 roadway network. This improvement could be included as an alternative for testing purposes. After adding this alternative, model scenarios could then be created that:

- Represent the base-year network without the roadway widening;
- Represent the base-year network plus the roadway widening;
- Represent the 2040 network without the roadway widening; or
- Represent the 2040 network plus the roadway widening.

As with network attributes that vary by year, absence of facility type data will result in a link being omitted from consideration in the travel model. It is possible to represent the closure of a roadway by activating an alternative with a null value for FT_AL on a particular roadway link. This is useful when simulating a realigned roadway .

This structure has limitations. Only two alternatives can occupy the same link, limited by fields "ALT" and "ALT2." Only one set of alternative attributes can occupy the same link, limited by one set of attributes with an "AL" suffix.

These limitations are of particular concern in a scenario where a road exists as a 2-lane facility and consideration is being given as to whether it should be widened to 4 lanes or 6 lanes. While this scenario cannot be readily represented in the network alternative structure, this scenario can be represented through use of either of two options:

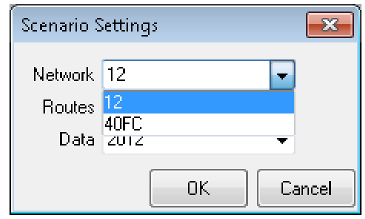
- Create a separate network year (e.g., "09W4" or "40W4") that represents the road as a 4-lane facility. Create an alternative that represents the road as a 6-lane facility; or

Create an alternative that represents the facility as a 4-lane facility. To run the alternative as a 6-lane facility, make a copy of the network and change the number of lanes (in the "AL" attributes) to six before running the model.

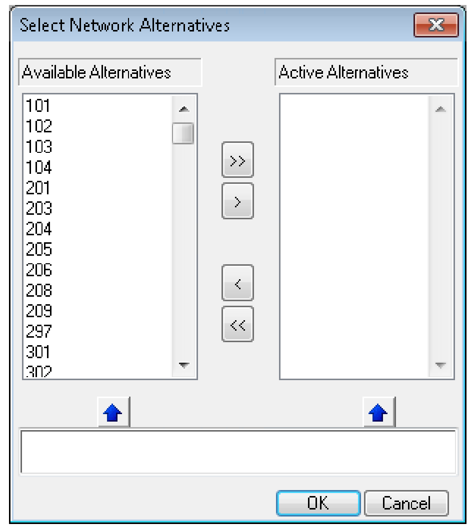
Network Attribute Selection

Year and alternative specific network attributes are identified by the travel model macros based on user selections. The scenario manager drives the travel model interface and maintains user selections regarding network year and alternative settings. Once these selections have been made, the automated network initialization step applies the selected network attributes. The process descried below is used to assign attribute values to the network for use in the travel model.

- When running the travel model, the user must select a network year. The scenario manager allows selection of any year where a complete set of data is present in the roadway network. User selections are saved with a model scenario accessible from the model interface.



- The user may optionally select to activate specific numbered alternatives present in the roadway network. A list of available alternatives is generated by identifying unique values present in the ALT and ALT2 fields. Each unique value is initially identified as an inactive alternative, but may be set to active by the user. Alternative selections made by the user are saved with a model scenario accessible from the model interface.



The network initialization step makes a copy of the input network file and places it in an output directory specified by the user. One new field is created for each year-specific attribute, but without the year-specific suffix (e.g., FT, AT, etc.). The field Dir is already present in the network, so the preexisting field is modified in subsequent steps.

Each new field is populated with data from the corresponding year-specific field matching the network year selected by the user. For example, if the network year is set to 40FC, the field FT will be filled with data in the field FT_40FC. Remaining fields will be populated in a similar manner.

If any alternatives have been activated, a selection set consisting only of links where either ALT or ALT2 matches an active alternative is created. Attributes for links in the selection set are filled with data from the corresponding field ending in _AL. This overwrites any data previously populated from the year-specific fields. For example, if Alternative 101 is selected, all links where ALT = 101 or ALT2 = 101 will be selected. For these links only, data in the FT field is replaced with data in the FT_AL attribute. This overwrites data previously read from the FT_40FC attribute. Remaining fields are populated in a similar manner.

Data fields that do not include a suffix (e.g., FT, AT, etc.) are referenced for all subsequent model steps, including speed, capacity, and volume-delay lookup procedures.

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_09).
- The Dir field and year-specific Dir fields should be populated with a 1, -1, or 0 – even for network years for which links are not active (i.e., year-specific FT is null). The Dir_AL field can be null, but only if FT_AL is also null.
- When editing route system files, it is vital the Dir field is set to the appropriate year 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.

Network Attribute List

By virtue of the discussions above, 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	

Field Name	Description	Comments
Dir_yyyy	Scenario-specific Direction Field	yyyy represents a two through four-digit year code (e.g., 12, 40FC) or the string AL
FT_yyyy	Scenario-specific facility type (see table 1.3 for definition)	
AT_yyyy	Scenario-specific area type (see Table 1.4 for definition)	
AB/BA_LN_yyyy	Scenario-specific directional number of through lanes *(lanes that are used for parking in the off-peak periods are included in this value)*	
PK/OPTOLL_yyyy	Scenario-specific toll in dollars. Null or zero indicates no toll.	
BIKE_PROHIB	A value of "1" indicates that bicycle travel is prohibited on the link	
WALK_PROHIB	A value of "1" indicates that walk travel is prohibited on the link, including both direct walk trips and walk access to transit.	
TRUCK_PROHIB	A value of "1" Indicates that large and small trucks are prohibited on the link.	
TIMEPEN_yyyy	Link time penalty in minutes	This field should be left empty in most cases.
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.
USE_yyyy	A value of "1" indicates that the link is an HOV lane; all drive alone trips are prohibited. A value of "2" indicates that the link is an HOT lane; a coded toll value will be charged to drive alone trips, but not shared ride trips.	
AB/BA_FBAM_yyyy AB/BA_FBAM_yyyy	Scenario-specific fields used to hold speed feedback results. These fields are managed by the travel model interface.	Fields ending in "AL" are not present for these fields.
ALT	Primary Alternative Number	
ALT2	Secondary Alternative Number	
NFR_SCRL	Indicates whether the link is on a screenline, and if so, which screenline	
NONATTAIN	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 Ozone boundary and links that overlap with the DRCOG model are omitted. (See note 1)	
SUB_REGION	Value – Subregion 1 – Rural / Other 2 – Greeley	

Field Name	Description	Comments
	3 Fort Collins	
	4 Loveland / Berthoud	
	5 Larimer County (expanded area)	
	6 Weld County (expanded area)	
	7 Central I-25	
COUNTY	County name	
NFRMPO	Identifies links within the MPO boundary	
Expand	Identifies links that are in the expanded ozone attainment region 1 = Links in the unexpanded area (inside MPO area) 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	Currently using SUB_REGION=1
CUSTOM2	User specified subarea where CUSTOM2 = 1	Currently using SUB_REGION=2
JJJ_YYYYCNT	Traffic count value (daily vehicles)	*Multiple fields are present:* JJJ – jurisdiction that provided the data YYYY – Year in which the traffic count was taken
JJJ_YYYYDATE	Date traffic count was taken (field format varies by source)	
JJJ_YYYYSEA	Season in which traffic count was taken – (V)acation season or (S)chool season	
CountLinkID CountCollect CountSchool	Information used to process traffic counts collected specifically to support travel model validation.	
SUM_EST_Count SUMEST_changed SUM_Count SUM_Year Adj_Factor	Fields used to process summer counts for Estes park validation. These counts are retained from the 2008 model, when a more complete seasonal analysis of count data was conducted.	
DO_NCHRP	A value of 1 indicates that NCHRP adjustment will be performed if all required data is available.	
BASEVOL	Base year model volume on regionally significant corridors used to perform an NCHRP adjustment	
VAL_Count	Traffic count selected for use in validation	
VAL_Year	Year validation count was taken	

Field Name	Description	Comments
VAL_Source	Traffic count source: LAR: Counts provided by Larimer County LOV: Counts provided by City of Loveland GRE: Counts provided by City of Greeley Evans: Counts provided by City of Evans FC: Counts provided by City of Fort Collins WELD: Counts provided by Weld County CDOT: Counts provided by CDOT NFR: Counts provided by MPO	
EST_Count	Estimated count data used to perform an NCHRP adjustment if a validation count is not available	
STruck_VAL	Classified counts: small truck	
LTruck_VAL	Classified counts: large truck	

Notes: 1. Geographic fields such as OZONE, NONATTAIN, and SUBREGION 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.
PNR_yyyy	Scenario specific Park and Ride nodes . A value of 1 indicates that a node is a park and 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	

Why Such Short Field Names?

Many of the recommended field names (e.g., FT_yy and AT_yy) are very short. This is to facilitate efficient use of the travel model network and ensures compatibility with GIS software.

- TransCAD data is often exported to an ESRI shapefile for use in ArcMAP and other software packages. This file type is limited to 10-digit attribute names. Longer attribute names are truncated and can lead to confusion.
- When working with the roadway network, a common task is to select all links with a particular facility type or area type (e.g., all centroid connectors). It is much more efficient to type "FT=99" than to type "FAC_TYPE=99", as shown by the keystroke examples below.
  - <shift> F T <end shift> = 99 → 6 keystrokes
  - <CAPS> F A C <shift> _ <end shift> T Y P E <CAPS> = 99 → 15 keystrokes

While this may seem trivial, the increase in efficiency and convenience allowed by short attribute names improves usability of the travel model.

Expanded Model Area

The NFR Travel Model includes the capability to model expanded portions of Larimer and Weld County 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 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.

2.3 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 Table 2.6**.

Figure 2.6 demonstrates the relationship between freeway, 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

Figure 2.2: 2012 Facility Type Designations (MPO region)

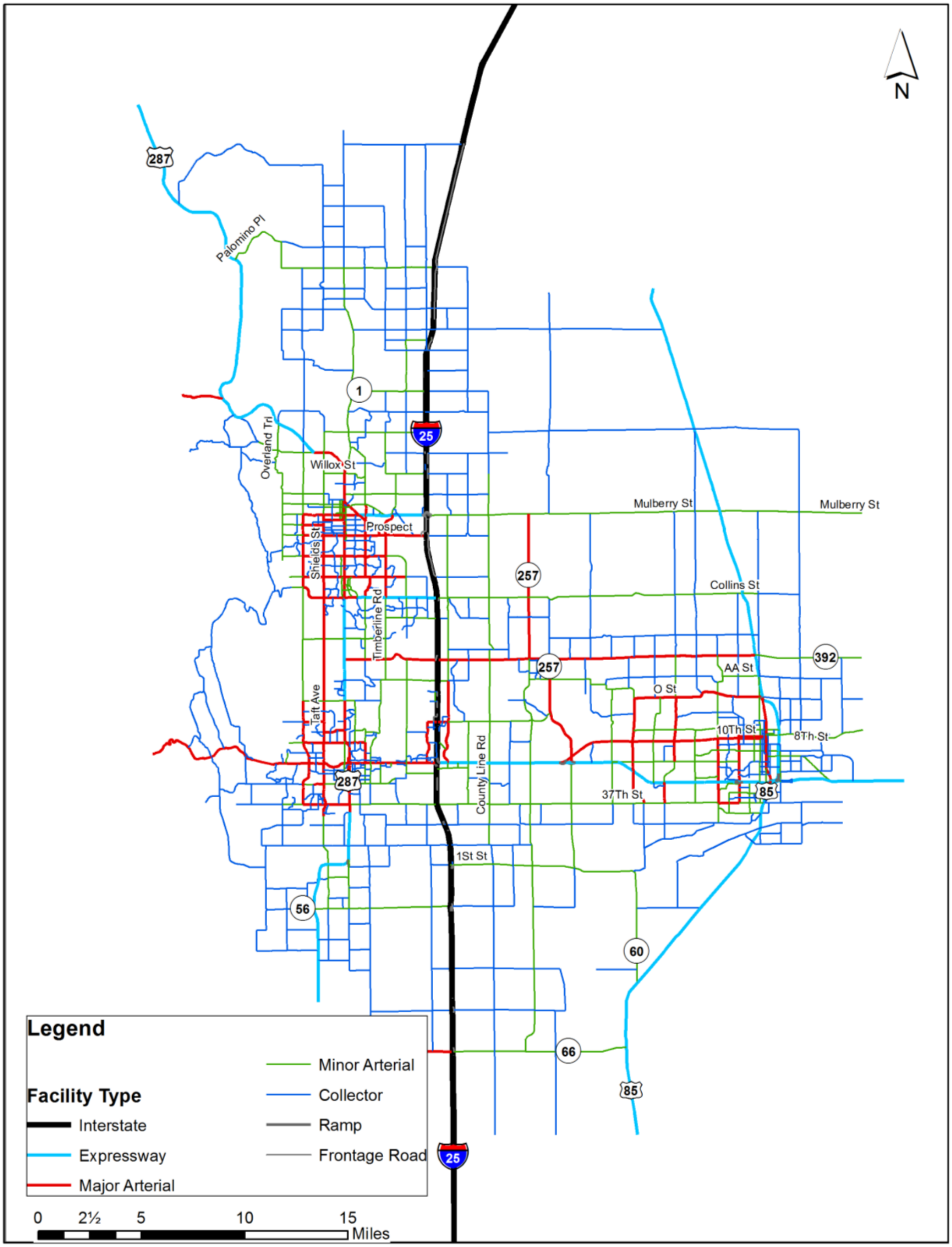


Figure 2.3: Facility Type Designations (Fort Collins)

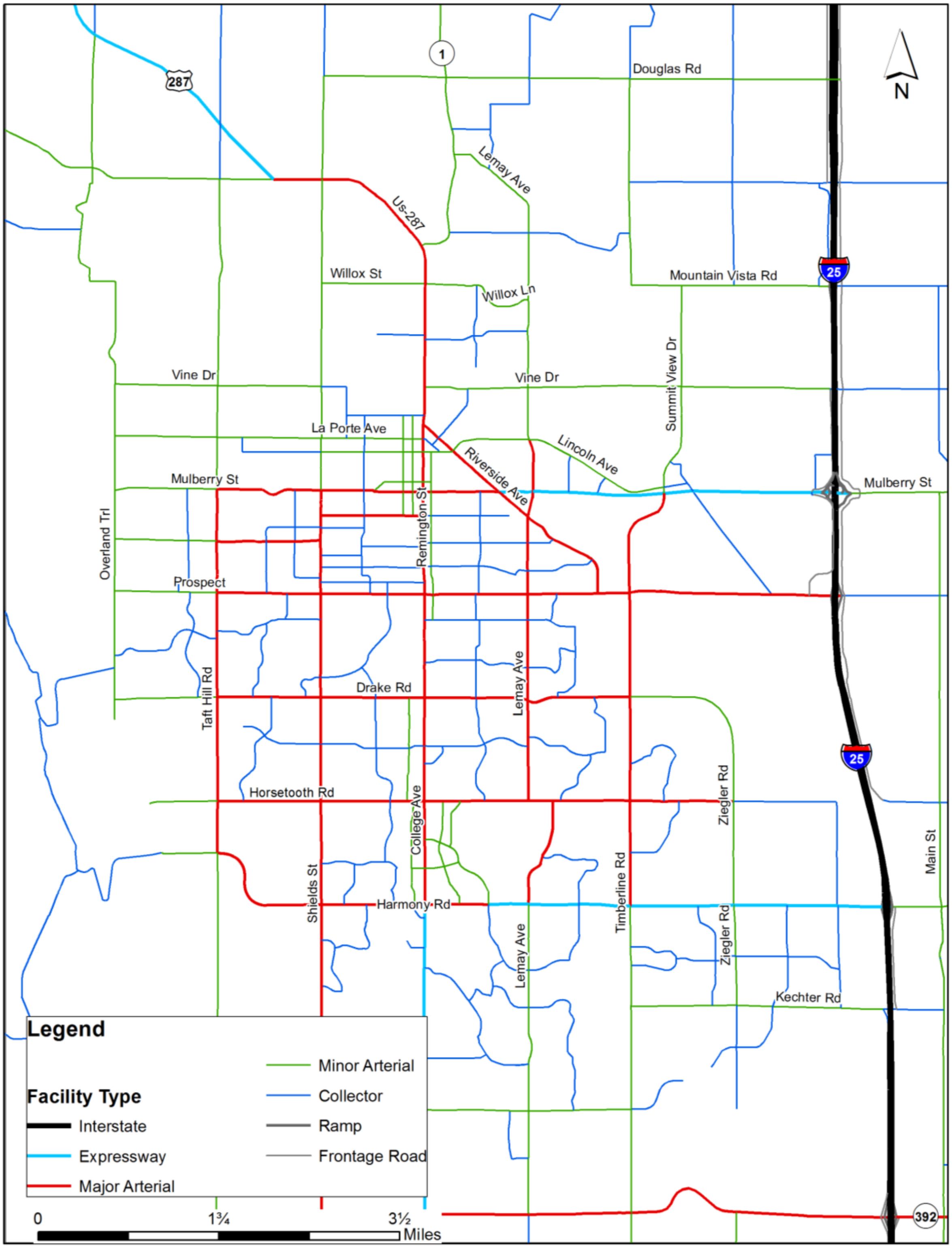


Figure 2.4: Facility Type Designations (Greeley)

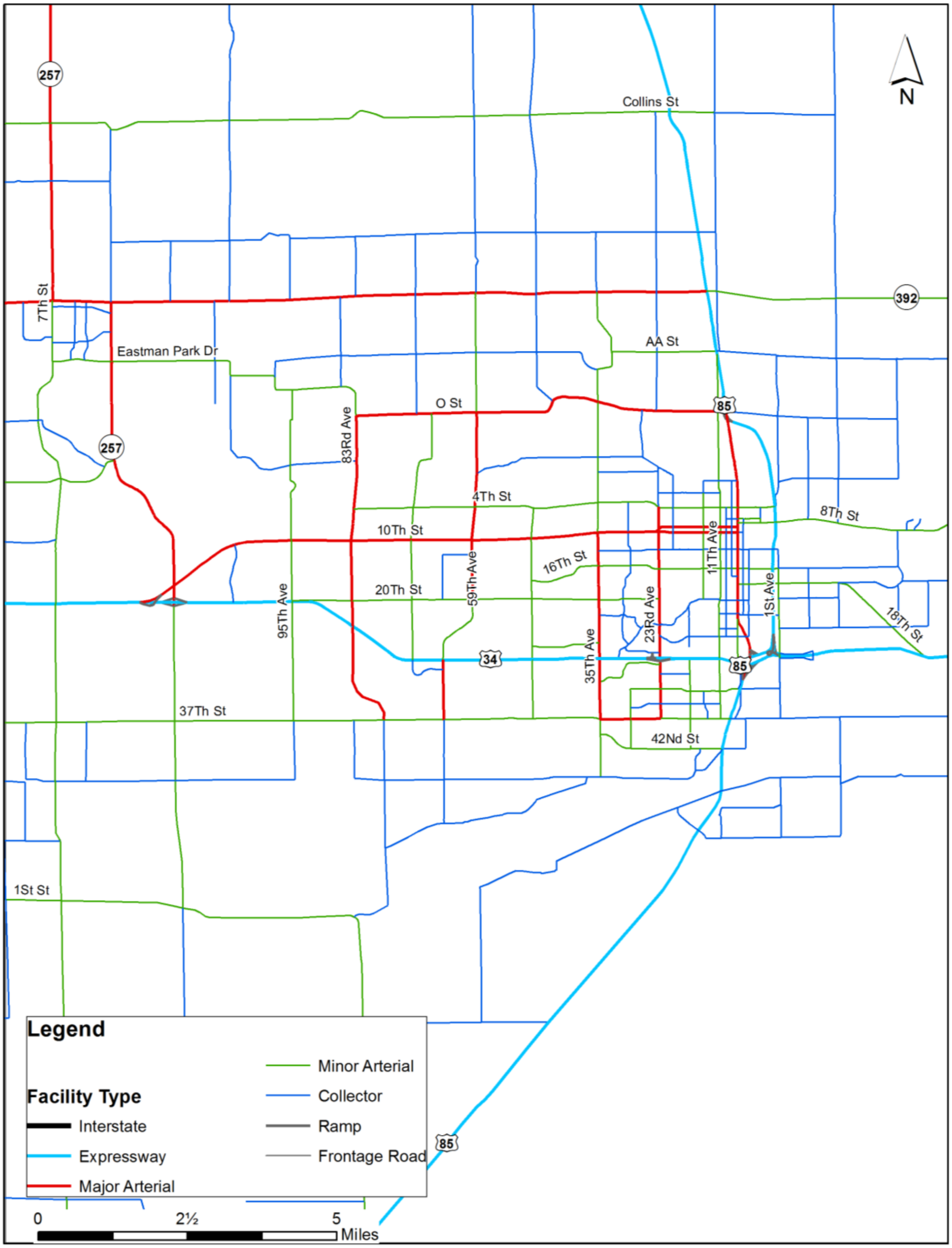


Figure 2.5: Facility Type Designations (Expanded Area)

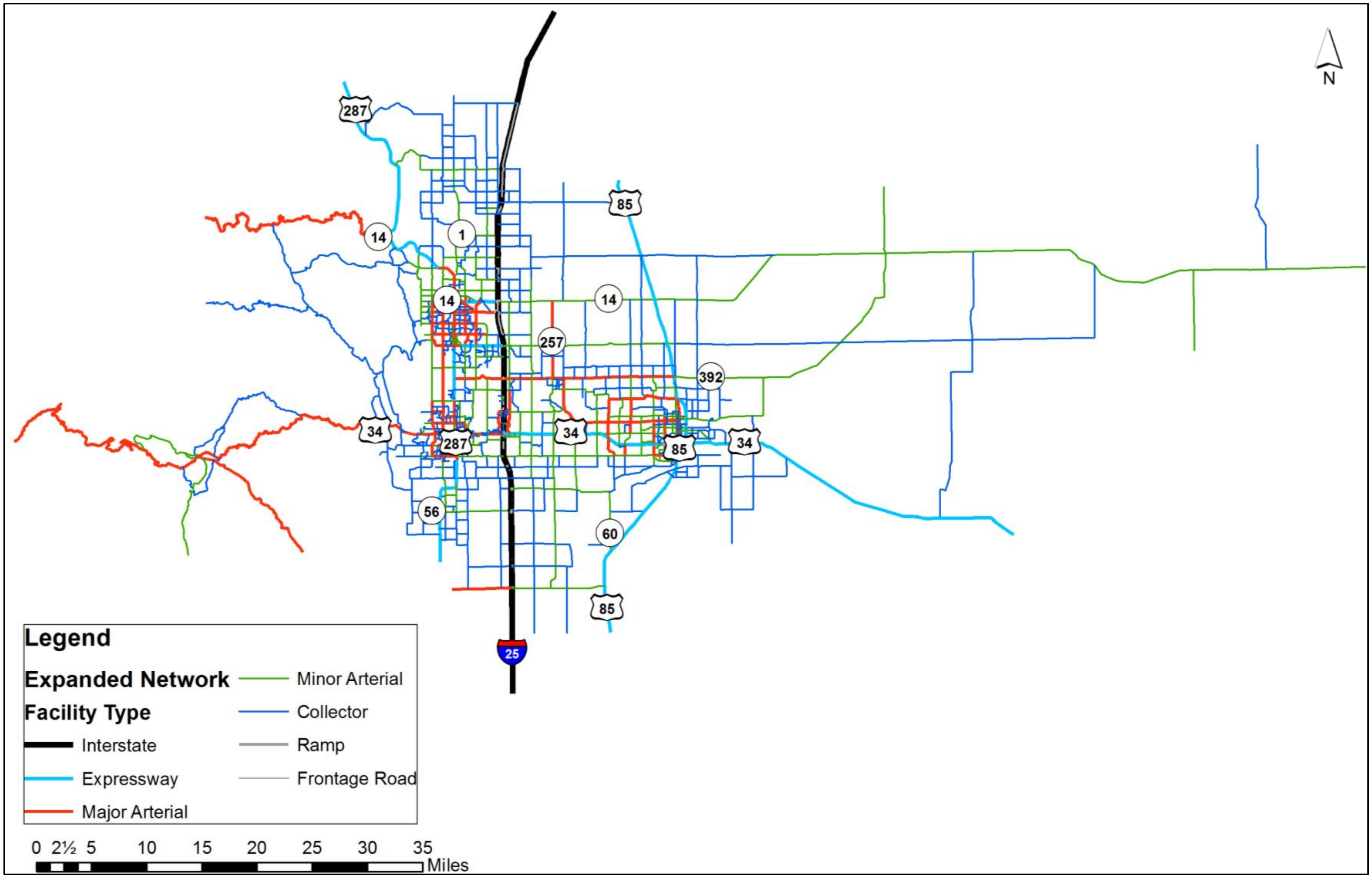


Figure 2.6: Roadway Facility Type Hierarchy

	Freeway	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		

- **<u>Freeway</u>** – 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 MPO model is I-25.

- **<u>Expressway</u>** – Expressway facilities are sometimes classified as divided major arterials, but include many features common to freeways. Expressways use a higher level of access control than other arterials and may include grade-separated intersections. Expressways have higher speed limits than other principal arterials (e.g., 55 or 65 MPH), provide little or no direct access to local businesses, may have frontage roads or access roads, and limit signal spacing to at least ½ mile. Examples include sections of US 34 and US 85.

- **<u>Ramp</u>** – 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.

- **<u>Principal Arterial</u>** – 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. Major 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 major 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 major 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 major arterials are not disrupted and receive shorter green times than major 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.

2.4 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. While socioeconomic data is initially generated at a parcel scale, information is aggregated to TAZs for use in the travel model. This allows the travel model to run in a reasonable amount of time, streamlines data maintenance, and makes it possible to manually inspect model inputs and outputs.

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 Fort Collins central business district and other central business district (CBD), urban, suburban, and rural as shown in **Table 2.4**.

Zones identified as CBD areas were retained from the previous version of the model, and initially identified using aerial photography and through discussions with MPO Staff. Initial identification of non-CBD area types was done at the TAZ level by applying the area type criteria shown in **Table 2.4** to non-CBD zones based on the 2012 socioeconomic dataset.

Table 2.4: Area Type Categories and Model Criteria

Area Type		Population/ Sq. Mile	Employment/ Sq. Mile
1	Rural	0 - 299	0 – 299
2	Suburban	300 – 3,999	300 – 3,999
3	Urban	4,000 +	4,000 – 19,999
4	Fort Collins CBD	n/a	n/a
5	Other CBD		

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

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:

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

Once area type values were assigned to each TAZ for the 2012 base year, roadway area type was assigned to the roadway network. This process started by applying a "Tag" operation to assign area type to each link based on the closest TAZ. For roadways bordered by different area types on either side, the denser (e.g., urban rather than suburban) area type was assigned. The denser area type was assigned for both sides of divided highways bordered by different area type values and for all ramps within interchanges located on or directly adjacent to area type borders. For links crossing an area type boundary, the most appropriate area type was selected based on visual evaluation. **Figure 2.7** through **Figure 2.11** show the resulting base year area type designations.

Figure 2.7: Base Year 2012 Area Type Designations (NFRMPO Region)

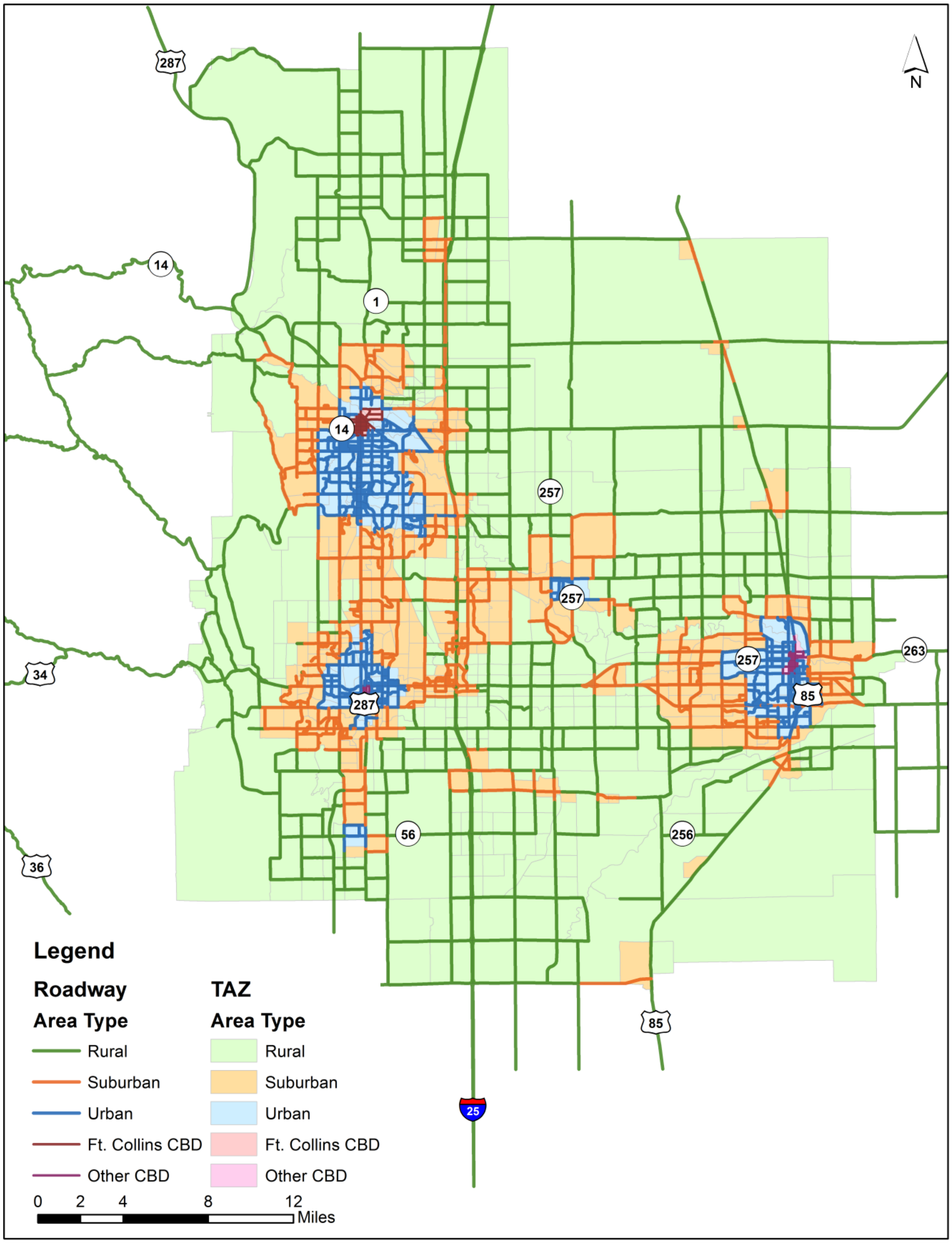


Figure 2.8: Base Year 2012 Area Type Designations (Fort Collins)

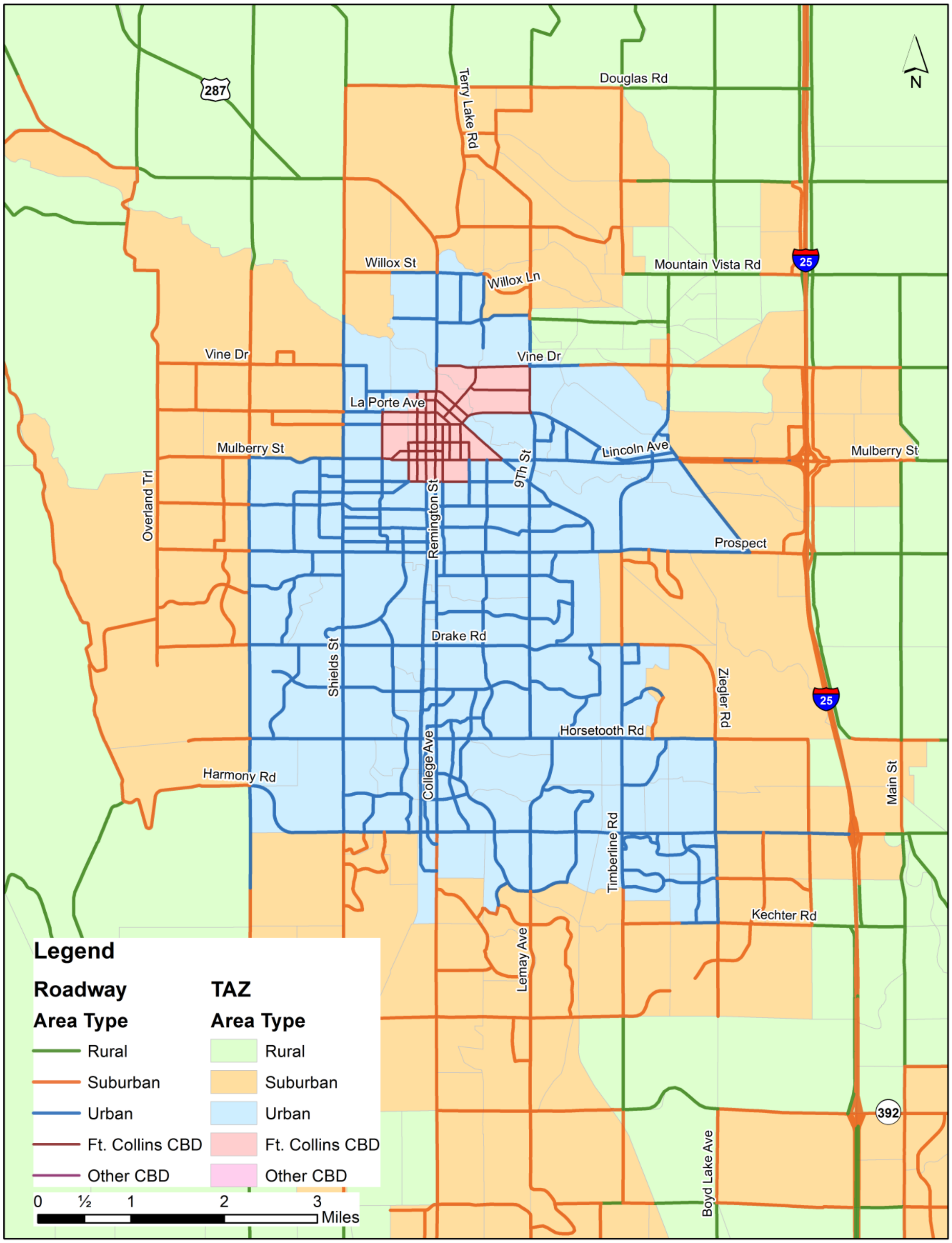


Figure 2.9: Base Year 2012 Area Type Designations (Greeley)

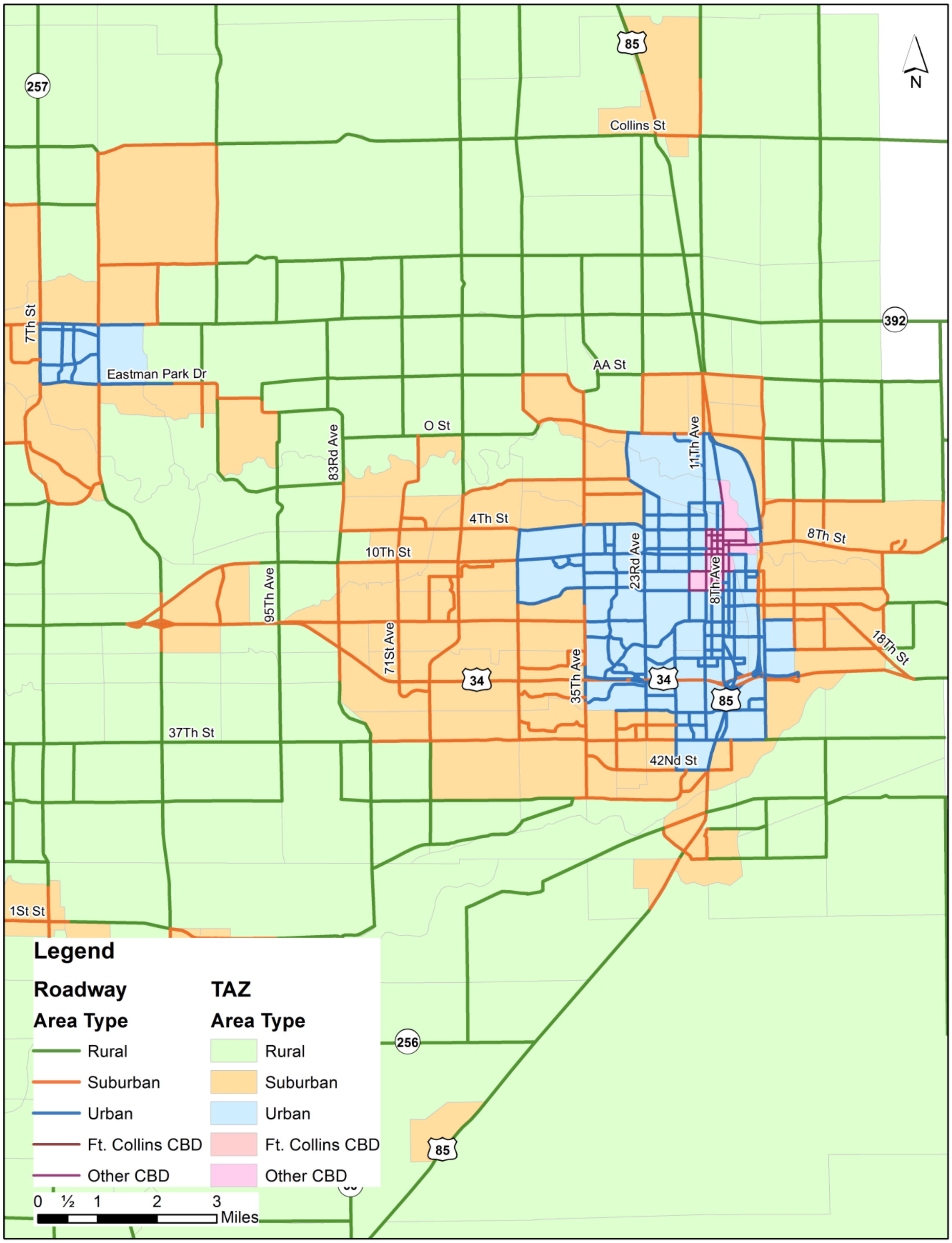


Figure 2.10: Base Year 2012 Area Type Designations (Loveland)

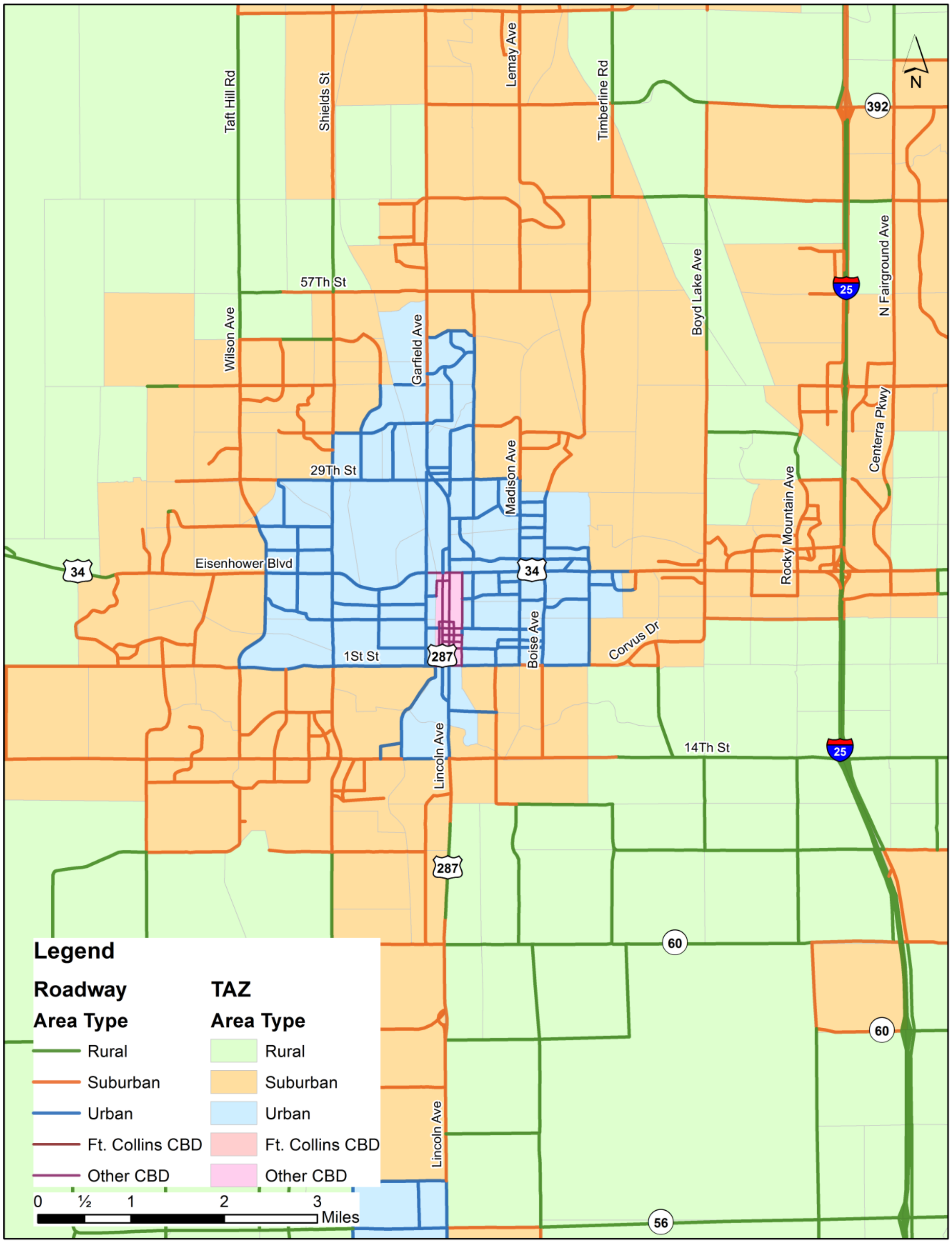
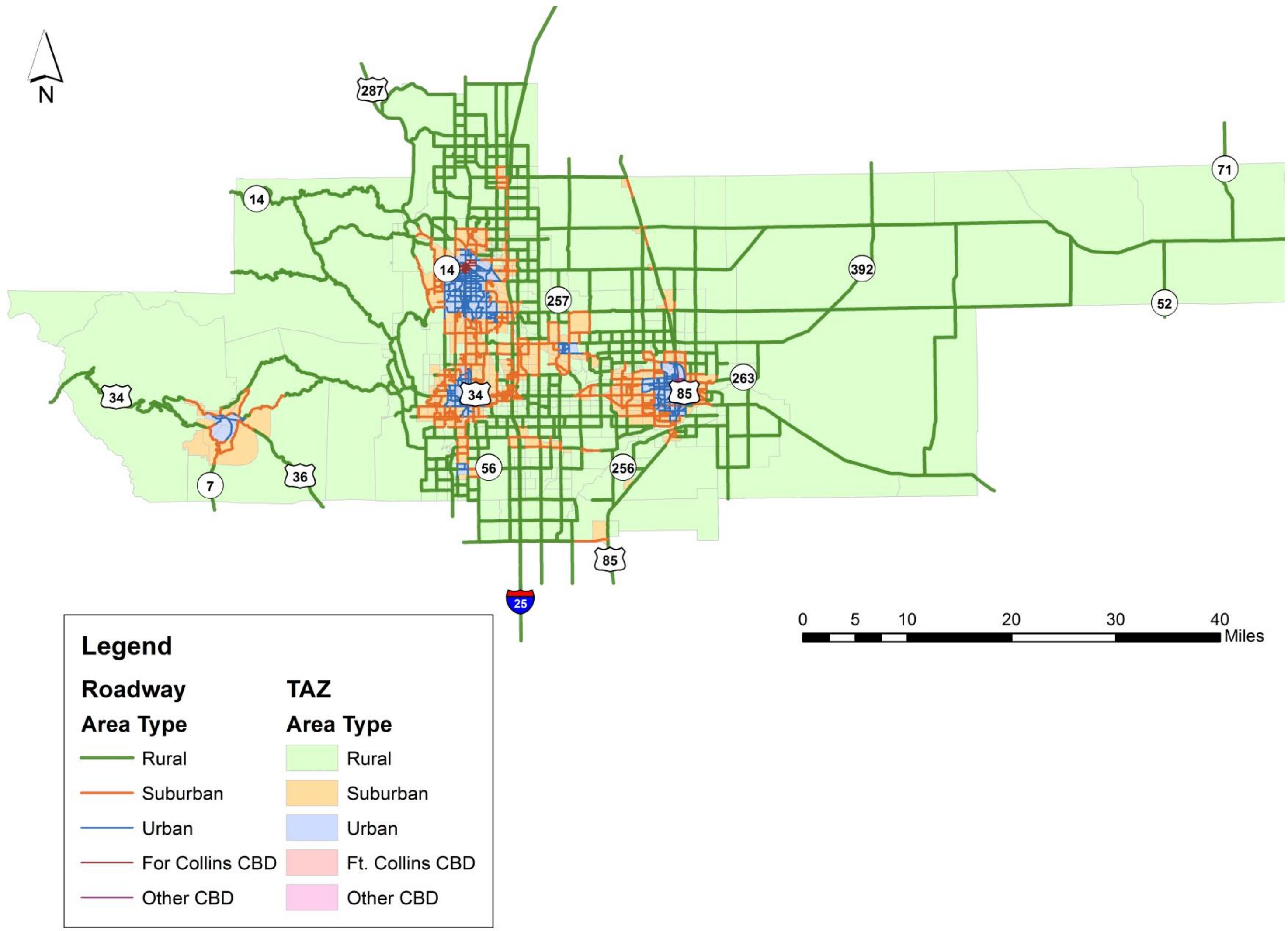


Figure 2.11: 2012 Base Year 2012 Type Designations (Expanded Model Area)



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 as a function of link facility type, and area type. Freeflow speeds are typically lower than the speed limit to account for intersection delay on arterials, collectors, and ramps. On freeways and expressways, the speed limit and freeflow speed may be the same.

The model's speeds are based on data collected in the travel time and speed study conducted by the MPO in 2005 (**2005 North Front Range Regional Speed Study**). The model's freeflow speeds are shown in **Table 2.5**. When speed feedback is run, congested speeds are computed and used in the trip distribution model. If the model is set to initialize speeds, then the congested speeds used in trip distribution are set to the freeflow speeds on the first speed feedback iteration. If the option to initialize speeds is not selected, congested speeds saved in the input roadway network's speed feedback fields are used for trip distribution.

Freeflow and congested speeds in the roadway network are used to compute travel time for each link. Travel time is computed in minutes and is saved in the output roadway network file.

Table 2.5: Freeflow Speed Lookup Table (mph)

Facility Type		Rural (1)	Suburban (2)	Urban (3)	CBD (4,5)
1	Freeway	75 / 75	75	75	75
2	Expressway	60 / 60	50	45	40
3	Principal Arterial	50 / 50	45	40	30
4	Minor Arterial	45 / 45	40	35	25
5	Collector	40 / 40	35	30	25
6	Ramp	30 / 30	30	30	30
7	Frontage Road	55 / 55	40	35	35
8	Centroid Connector	35 / 35	20	20	15
9	Walk Access	3 / 3	3	3	3
51	Transit Local	25 / 25	25	25	25

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 further documented in the *Trip Assignment* chapter.

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

Freeways

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

- **Heavy Vehicle Adjustment Factor** – The heavy vehicle adjustment factor accounts for passenger car equivalents 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 passenger car equivalent (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.

[1] Highway Capacity Manual. Transportation Research Board, 2000.

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).

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

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.

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

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[3] according to selected freeflow speed values are shown in **Table 2.6**, along with adjusted capacities computed using Equation (2). Adjusted capacities have been rounded to 100 vehicles per hour. These calculations result in a lower capacity on rural freeways than on suburban and urban freeways due to the difference in peaking factors associated with

[2] HCM 2000, p. 13-11

[3] HCM 2000, p. 23-5

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 2.6: 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.

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*

[4] HCM 2000, p. 30-5

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 2.7**, along with resulting capacity values.

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

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
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_w = adjustment factor for intersection widening

Table 2.7: Link Capacity Adjustment Factors and Resulting Capacity

FT	AT	f_a	g/C	f_w	Capacity
Major 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
Local Street	CBD	0.74	0.45	1.00	550
	Urban	0.95	0.40	1.00	630
	Suburban / Rural	0.99	0.40	1.00	660

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

Resulting Capacity Model

The calculations in **Table 2.7** 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 2.8**. 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 2.8: Roadway Capacities (vehicles per hour per lane, upper-limit LOS E)

Facility Type		Rural (1)	Suburban (2)	Urban (3)	CBD (4,5)
1	Freeway	2,200	2,100	2,100	2,100
2	Expressway	1,200	1,200	1,200	1,100
3	Major Arterial	1,162	960	920	740
4	Minor Arterial	956	790	760	650
5	Collector	850	710	680	590
6	Ramp	800	800	750	650
7	Frontage Road	850	710	680	590
8	Centroid Connector	10,000	10,000	10,000	10,000
9	Walk Access Connector	10,000	10,000	10,000	10,000
10	Transit Local	10,000	10,000	10,000	10,000

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 off-peak capacity. Off-peak capacity is computed using Equation (4) and stored on the roadway network for traffic assignment.

$$CAP_{op} = \frac{CAP_{hr}}{F_{pk}} \cdot \frac{HR_{op}}{24} \qquad (4)$$

Where:

CAP_{op} = Off-peak capacity

CAP_{hr} = Hourly capacity

F_{pk} = Hourly traffic as a percentage of daily traffic (set to 0.091)

HR_{op} = Number of hours in the off-peak period

2.7 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 and. 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.

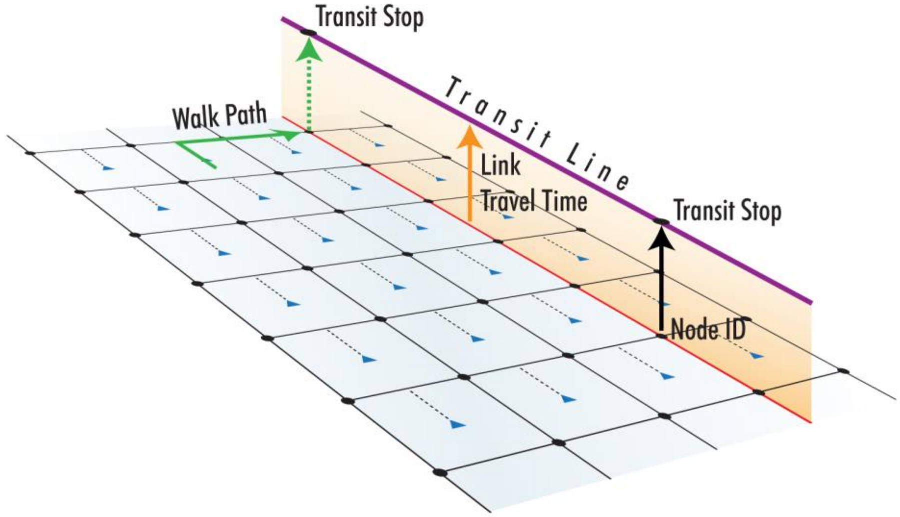
3.0 TRANSIT ROUTE SYSTEMS AND NETWORKS

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

3.1 Transit / Roadway Linkage

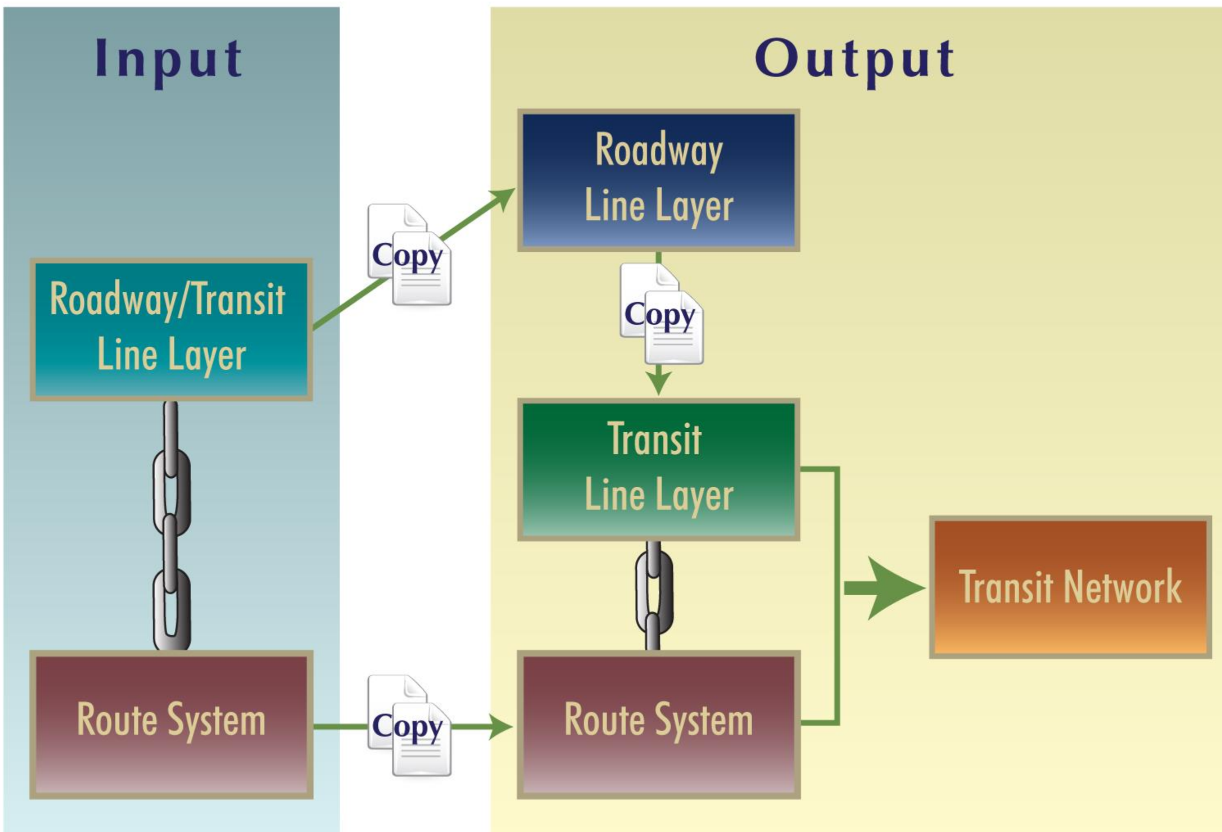
Transit networks in TransCAD are made up of two separate, but connected layers: the transit route system and the transit line layer. Information from these two layers is combined as shown in **Figure 3.1** to allow representation of walk, drive, and in-vehicle components of a transit trip. Because these 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 *Roadway Network* chapter. 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.

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
Fare	Indicates the fare used in pathbuilding and mode choice	This value represents the average fare paid by non-university students and may has been modified during model validation
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., 12, EC)
OP_Headway_yyyy	Scenario-specific off-peak route headway	
Agency	Name of operating agency	
Mode	Transit Mode	1 =Local Bus 10 = Local Bus (Coordinated with Premium transit) 20 = Express Bus 30 = Premium Transit *Note: Not all modes are present in all model scenarios.*
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 Stops

The transit route system includes transit stop locations coded at all locations where transit access may be possible. Transit stops were not coded based on actual stop locations, rather they are designed to represent good access to all routes since all existing routes are local. In future applications where express or premium transit is included, transit stop coding should represent access limitations where planned. For the existing FLEX service between Fort Collins, Loveland, and Longmont, stops are not included on sections where this route does not stop.

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 3.2**.

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 3.2: 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	This field is not used in the current version of the model, but is provided for potential future use.
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.

3.3 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. In particular, 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.

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. The model uses a transit time factor of 0.50 to convert vehicle travel speed to bus travel speed.

During roadway and transit network processing, the fields listed in **Table 3.3** 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 3.3: Key fields in the Transit Line Layer

Field Name	Description	Comments
AB_OPTRTIM BA_OPTRTIM	Off-peak period transit time	Based on the AM congested link time resulting from speed feedback
AB_PKTRTIM BA_PKTRTIM	Peak period transit time	Based on the off-peak link time resulting from speed feedback
AB_OPTRSPD BA_OPTRSPD	Off-peak period transit speed	Calculated based on link time and length (for reference only)
AB_PKTRSPD 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

Walk Access and Egress

The transit line layer also represents the connection between TAZ centroids and transit route stops. With the exception of park-n-ride trips, all transit trips must start and end on foot[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.

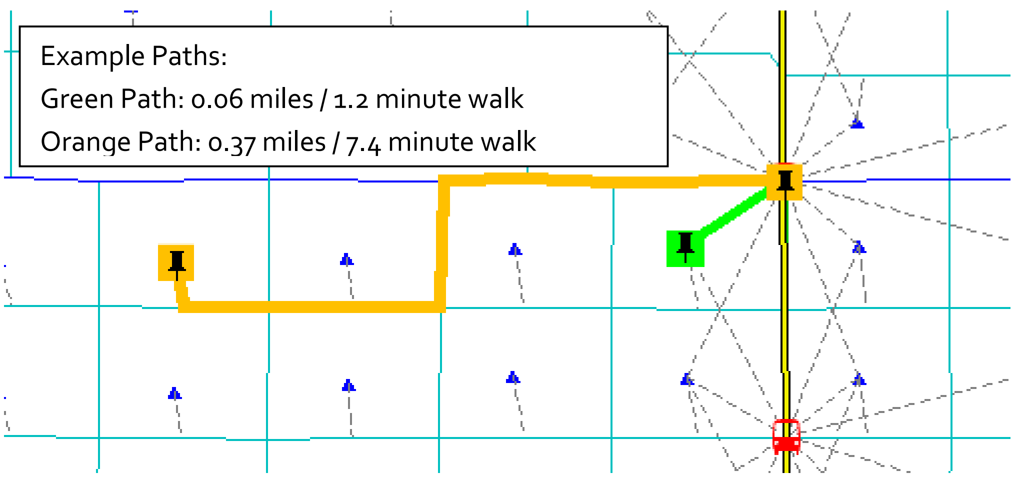
[5] Bicycle access and egress to transit is not modeled explicitly, but is instead modeled as walk access and egress.

- ***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.

- ***Combined Walk Links and Roadway Network:*** Walk access links are created between transit stops and immediately adjacent TAZs. Centroid connectors and the local street layer 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. A conceptual example of walk paths from two different zones to a specified transit stop is shown in **Figure 3.3**.

Figure 3.3: Example Walk Access Paths



The TransCAD model implements this methodology by automatically drawing walk links from each stop to TAZ centroids within a 1/4 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.

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 walk segments, the following procedure is used:
  - The minimum walk times specified for each market segment in **Table 3.4** are used; and
  - 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.

Table 3.4: Minimum Walk Access/Egress Times by Market Segment

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

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 transit node layer. Positive values specified in the node field PULSE_yyyy will override the default transfer time for all transfers occurring at a node.

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 and ride, but not from a park and 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 3.5.**

Table 3.5: 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)	2.0
Drive Access Time	Time spent driving from the production TAZ centroid to a park and 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)	2.0
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	2.0**
Initial Wait Time (Long)	Initial wait time exceeding 7.5 minutes	1**
In-Vehicle Travel Time	Time spent riding or waiting in a transit vehicle	1
Transfer Wait Time	Time spent walking between stops for a transfer (if applicable)	2.0
Transfer Walk Time	Time spent walking between stops for a transfer (if applicable)	2.0
Transfer Penalty Time	Additional transfer penalty (calibration parameter)	2.0
Egress Walk Time	Time spent walking from the transit stop to the attraction TAZ centroid	2.0
Fare	Transit fare paid for the trip	1*

** Travel time variables are converted for consistency with cost variables using the value of time documented in the mode choice model specification.*
*** Weighted initial wait time is computed for each route based on the combined short and long wait times. The transit network weight is set to 1 for initial wait time. Transit shortest path matrices are post-processed to represent unweighted short and long initial wait time.*

4.0 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.

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

Prior to application of trip production and attraction rates, it is necessary to process input household data at the TAZ level. Model input data includes information about the number of households in each TAZ, along with average household size, number of workers, and median household income. The model uses household disaggregation models to estimate the univariate distribution of households by size, number of workers, and income group for each TAZ. Once these distributions have been estimated, the model uses an iterative proportional factoring process to develop bivariate distributions of households by income and size as well as by income and number of workers for each TAZ.

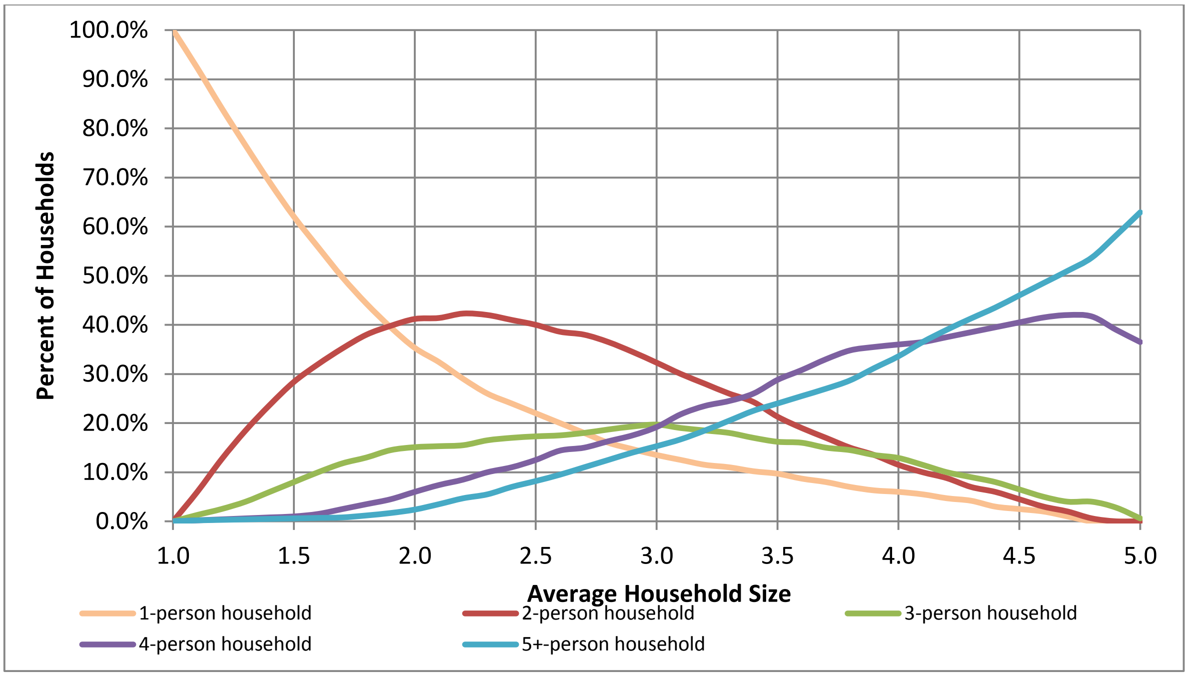
Household disaggregation models use known variables to establish a distribution of households by classification. For example, a zone with an average household size of one person would be comprised entirely of one-person households. Conversely, a zone with an average household size of four people would be modeled as a combination of one, two, three, four, and five+ person households.

Disaggregation models are defined by a set of curves that identify the distribution of households based on input average or median value. These curves always sum up to 100 percent and for the household size and worker models, the results must be consistent with the input value when applied. Hand-fitted curves have been adjusted to fit observed data points, sum to 100%, and produce the appropriate results when applied.

Household Size Disaggregation Model

Model trip rates are classified by five household size groups. The portion of households in each group can be approximated for any given TAZ based on the average household size using the disaggregation curves shown in **Figure 4.1**. The resulting model is defined as a lookup table provided with the travel model input dataset.

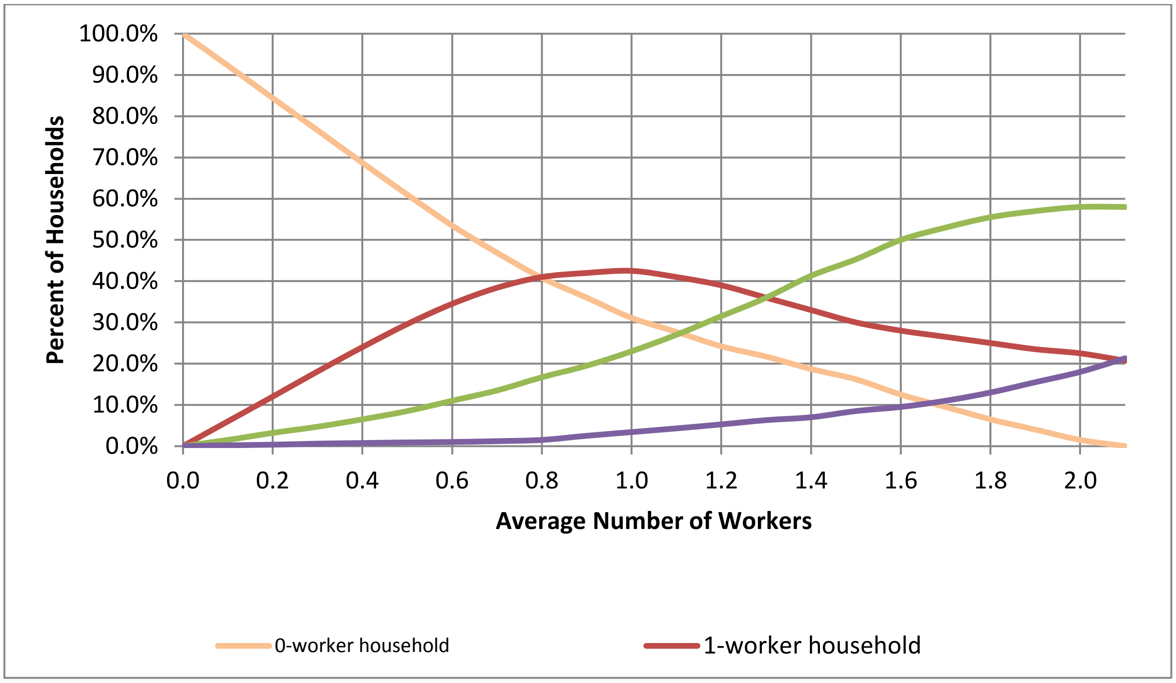
Figure 4.1: Household Size Disaggregation Model



Household Worker Disaggregation Model

For work-based trips, the NFR Model is based on number of household workers rather than total household size. Household worker disaggregation curves are shown in **Figure 4.2**

Figure 4.2: Household Workers Disaggregation Model



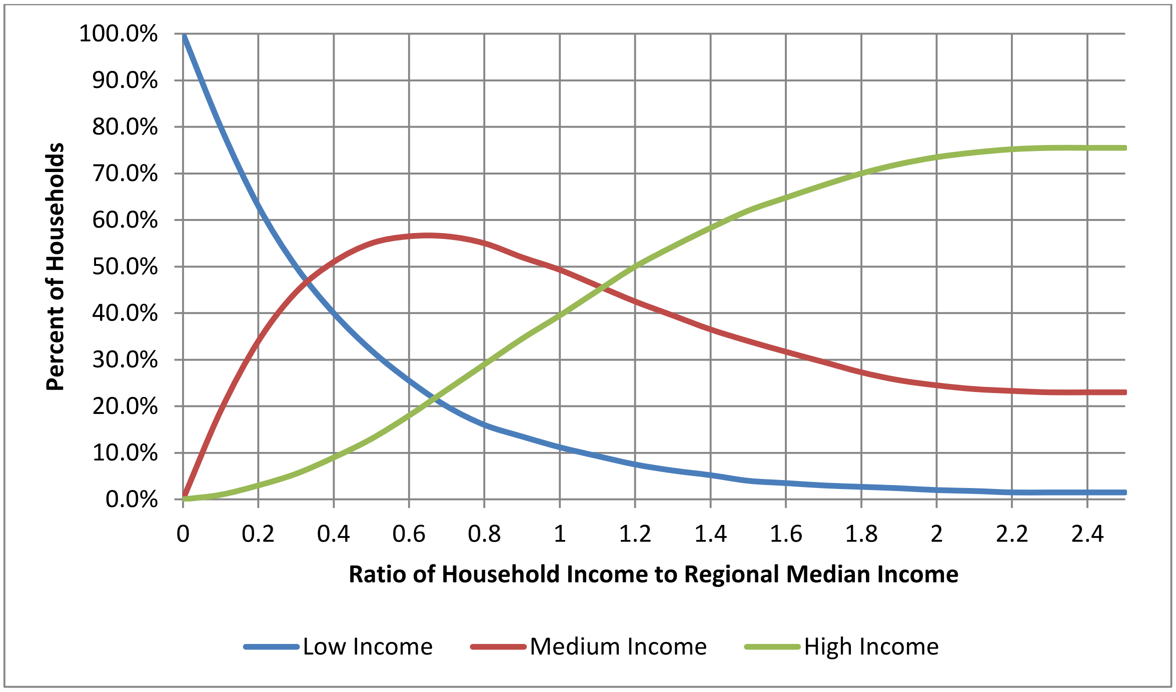
Household Income Disaggregation Model

The household income group model is similar to the household size and worker disaggregation models. Low, medium, and high income groups are defined in **Table 4.1** and disaggregation curves are shown in **Figure 4.3**.

Table 4.1: Income Group Definitions

Income Group	Income Range
Low	$19,999 and lower
Medium	$20,000 - $74,999
High	$75,000 and higher

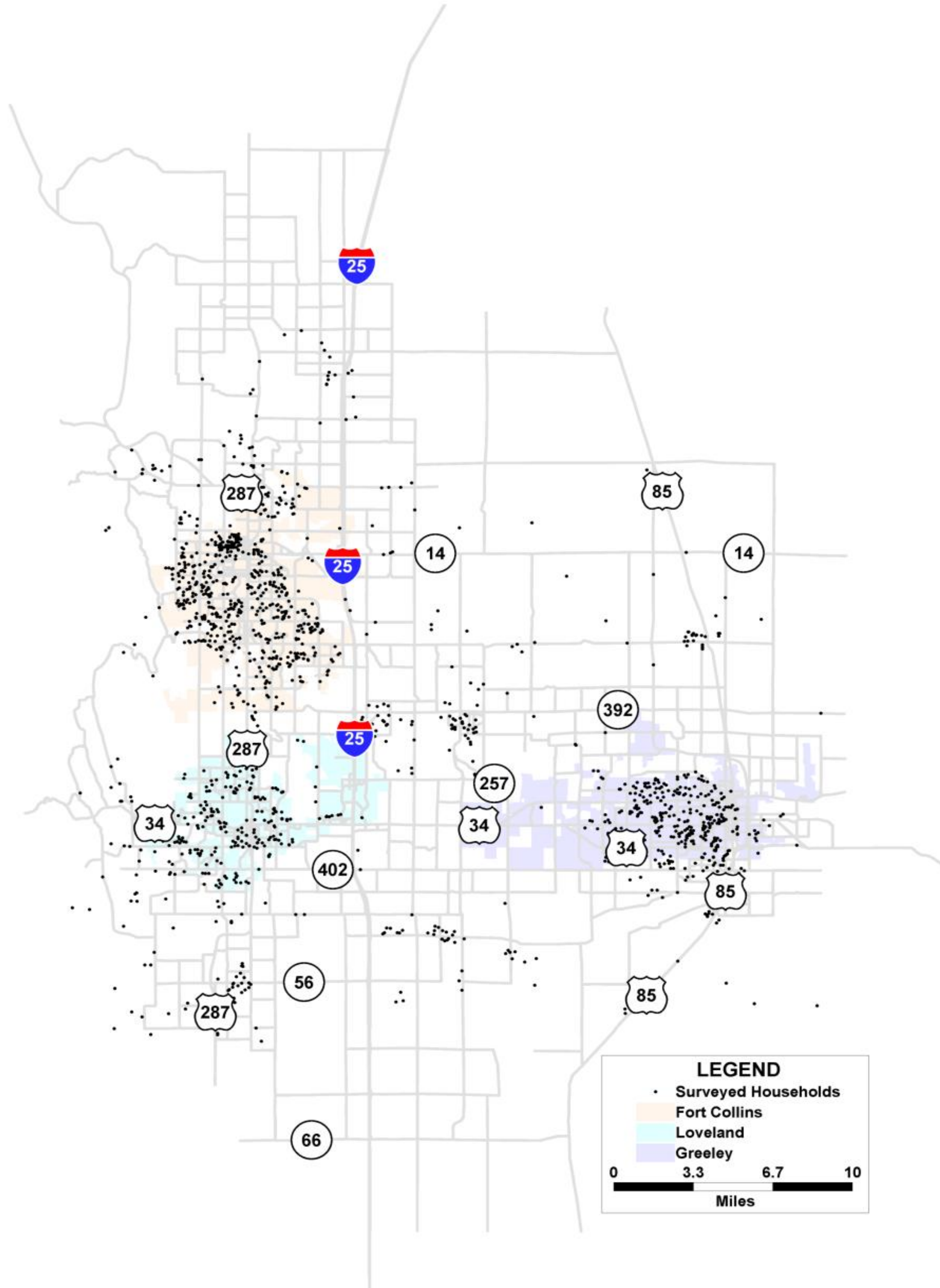
Figure 4.3: Household Income Disaggregation Model



4.2 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. Household socioeconomic data gathered in this survey includes information on household size, income, vehicle ownership, employment status of each household member, and housing unit type. The survey also collected information about each trip made by members of all participating household, 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 dairy information. Households surveyed are shown in **Figure 4.4**.

Figure 4.4: Front Range Travel Counts– Participating Household Locations



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.

The NFR region can be divided into five major sub-regions: Fort Collins, Greeley, Loveland, Central I-25, and the remaining areas (Other). The Front Range portion of the survey collected statistically significant household samples from the five sub-regions within the MPO planning area as shown in **Table 4.2**. When classified by variables such as household income and size, trip generation rates for the NFR region as a whole are expected to be representative of trip generation rates within the sub-regions. This assumption allows use of the region wide dataset to develop trip rates for each sub-region.

Table 4.2: Household Samples by Sub-Region

Sub-Region	Household Records	Weighted Households	Weighted & Expanded Households
Fort Collins	628	668	68,862
Greeley	351	286	44,793
Loveland	279	253	35,780
Central I-25	115	115	18,074
Rest of Region	132	182	15,404
TOTAL	1,505	1,505	182,913

Note: Households are weighed top 2010 totals, the year the survey was conducted.

Survey Weighting and Expansion

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

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

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

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

Following the factoring process, household weights were normalized so the sum of weighted households is equal to the number of participating households. The resulting average household weighting factors by subregion are shown in **Table 4.3**.

Table 4.3: Average Household Weighting Factors by Sub-region

Sub-Region	Household Records
Fort Collins	1.06
Greeley	0.81
Loveland	0.91
Central I-25	1.00
Rest of Region	1.38
Overall Average	1.00

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 expansion factors are shown in **Table 4.4**.

Table 4.4: Household Expansion Factor by Sub-region

Sub-Region	Expansion Factor
Fort Collins	103
Greeley	157
Loveland	141
Central I-25	158
Rest of Region	84
Average Expansion Factor	122

4.3 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 retained for this model update, as they reasonably capture activity within the region and are consistent with common travel modeling practice. 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 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).
- ***Small Truck (STRK):*** Small truck trips (FHWA Vehicle classes 5-7)
- ***Large Truck (LTRK):*** Large 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 4.5**, with trips by day of travel shown in **Table 4.6**. Trip purposes were identified based on the origin and destination activity for each trip using the relationship shown in **Table 4.7**. 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 4.5: Weighted and Expanded Trips by Trip Purpose

Trip Purpose	Weekday Trip Records	Weighted & Expanded Trips	Percent of Total
HBW	2,460	259,380	14.87%
HBS	1,850	230,190	13.20%
HBO	5,682	725,738	41.60%
WBO	1,331	125,887	7.22%
OBO	3,278	400,929	22.98%
N/A	30	2,337	0.13%
Total	14,631	1,744,461	100.00%

Source: Analysis of Front Range Travel Counts survey data for the NFR

Table 4.6: 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: Analysis of Front Range Travel Counts survey data for the NFR

Table 4.7: 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	All Other
Working at home/Other home activities	N/A	HBW	HBW	HBS	HBO
Work/Other work activities	HBW	N/A	WBO	WBO	WBO
Business related	HBW	WBO	WBO	WBO	WBO
Shopping/ Drive Thru/Dining Outside Home	HBS	WBO	WBO	OBO	OBO
All Other	HBO	OBO	WBO	OBO	OBO

4.4 Production Rates

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

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

Income Groups

The survey places each household into one of seven income groups. Although useful, there are not sufficient records in the dataset to retain all seven groupings as income categories. Furthermore, analysis of person trip rates for each of the categories suggests aggregation to three income groups: low, medium, and high, as shown in **Table 4.8**.

Table 4.8: Household Person Trip Production Rates by Income Category

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

Cross Classified Production Rates

Cross classified trip rates are computed as the mean number of trips per household for each combination of household income and size/worker category. However, a sufficient number of samples are not available for each combination. A review of mean trip rates, trip rate standard deviations, and trip rate confidence intervals resulted in the grouping of some income and household combinations with small sample sizes and similar trip rates. These grouped production rate are applied to each combination within the group for use in the model. The resulting person trip rates by purpose are shown in **Table 4.9** through **Table 4.13**.

Table 4.9: Trip Production Rates – HBW

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

Table 4.10: Trip Production Rates – HBS

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

Table 4.11: Trip Production Rates – HBO

	1-person	2-person	3-person	4-person	5-person	All Sizes
Low	1.15	2.16	4.04	5.39	8.82	**2.27**
Medium	1.15	2.22	4.34	7.20	9.97	**3.57**
High	1.40	2.22	4.34	7.20	14.85	**4.56**
All Incomes	1.22	2.22	4.31	7.04	12.09	3.73

Table 4.12: Trip Production Rates – WBO

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

Table 4.13: Trip Production Rates – OBO

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

The possibility that trip rates vary by area type or by sub-region was also investigated. During model validation, traffic volumes appeared to be overestimated in rural areas and underestimated in urban areas. As a result, both subregion and area type factors were implemented to improve the ability of the model to matched roadway counts. Home-based trip productions were reduced for rural areas and increased for urban and CBD areas, as shown in **Table 4.14.** Non home based trip production rates were increased in rural areas, along with a corresponding increase to non-home based trip attraction and production allocation rates in suburban and urban areas. This effectively increased the model's representation of trip chaining by rural residents.

Separately, trip production rates were increased for all subregions as shown in **Table 4.15**. Subregional trip rate factors are all greater than one to compensate for the tendency of survey respondents to under-report the amount of travel made in one day.

Table 4.14: Trip Production Rate Factors by Area Type

Area Type		HBW	HBS	HBO	HBU	WBO	OBO
1	Rural	0.7	0.7	0.7	1	1.1	1.1
2	Suburban	1	1	1	1	1	1
3	Urban	1.2	1.2	1.2	1	1	1
4	Fort Collins CBD	1.3	1.3	1.3	1.3	1	1
5	Other CBD	1.3	1.3	1.3	1.3	1	1

Table 4.15: Trip Production Rate Factors by Subregion

Sub-Region	HBW	HBS	HBO	WBO	OBO
Fort Collins	1.3	1.7	1.7	1.6	1.8
Greeley	1.3	1.7	1.7	1.6	1.8
Loveland	1.3	1.7	1.7	1.6	1.8
Central I-25	1.2	1.5	1.5	1.5	2
Extended Larimer	1.2	1.5	1.5	1.5	2
Extended Weld	1.2	1.5	1.5	1.5	2
Rest of Region	1.2	1.5	1.5	1.5	2

4.5 Attraction Rates

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

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

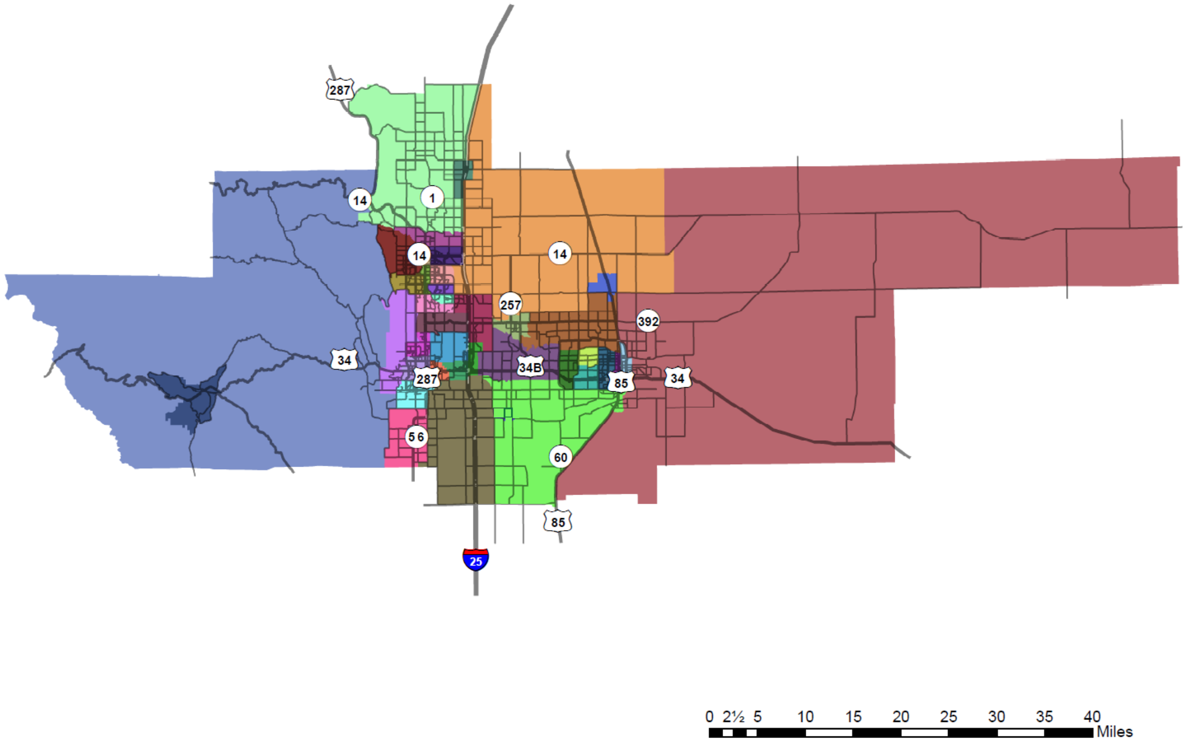
Due to the household survey capturing only 14,631 trips, it was not possible to run a regression model at the TAZ level. Instead, TAZs were aggregated into regression districts, shown in **Figure 4.5**. For each trip purpose, the number of trip attractions in each district was input to a regression model 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. Trip rates resulting from the regression analysis are shown in **Table 4.16**.

Table 4.16: Trip Attraction Rates

Trip Purpose	Retail Employment	Service Employment	Medical Employment	Basic Employment	Total Households
HBW	0.88	0.88	0.88	0.88	n/a
HBS	5.24	n/a	n/a	n/a	n/a
HBO	2.93	0.93	n/a	n/a	2.60
WBO	0.77	0.35	0.35	n/a	0.15
OBO	5.72	0.075	0.075	n/a	0.91

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

Figure 4.5: Trip Attraction Regression Districts



After the estimation was complete, trip attraction rates were investigated by area type and subregion. For most trip purposes, trip attraction factors were set to be identical to trip production rate factors. A notable exception is non-home-based attraction rates, which were decreased in rural areas and increased in non-rural areas, while non-home-based production rates were increased in rural areas. Trip attraction rate factors are shown in **Table 4.17**.

Table 4.17: Trip Attraction Rate Factors by Area Type

Area Type		HBW	HBS	HBO	HBU	WBO	OBO
1	Rural	0.7	0.7	0.7	1	0.7	0.7
2	Suburban	1	1	1	1	1	1
3	Urban	1.2	1.2	1.2	1	1.2	1.2
4	Fort Collins CBD	1.3	1.3	1.3	1.3	1.3	1.3
5	Other CBD	1.3	1.3	1.3	1.3	1.3	1.3

Table 4.18: Trip Attraction Rate Factors by Subregion

Sub-Region	HBW	HBS	HBO	WBO	OBO
Fort Collins	1.3	1.6	1.7	1.5	1.5
Greeley	1.3	1.6	1.7	1.5	1.5
Loveland	1.3	1.6	1.7	1.5	1.5
Central I-25	1.2	1.5	1.5	1	1
Extended Larimer	1.2	1.5	1.5	1	1
Extended Weld	1.2	1.5	1.5	1	1
Rest of Region	1.2	1.4	1.4	1	1

4.6 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 4.19**. 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. 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 4.19: WBO Production Allocation Rates

Employment Category	WBO PA
Retail Employment	0.44
Service Employment	0.62
Basic Employment	0.44
Medical Employment	0.62
Average (per employee)	**0.53**

4.7 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.

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, summer traffic volumes can be reasonably estimated by adjusting school-season traffic volumes outside of the Estes Park area. In Estes Park, summer traffic patterns and volumes are significantly different than non-summer conditions. 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 a special lodging-based trip purpose and a national park special generator.

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 4.20**.

Table 4.20: LBO Production Allocation Rates

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

Rocky Mountain National Park collects traffic count data at entrance stations throughout the year. Although events in 2013, including a government shutdown followed by severe flooding, resulted in unusual visitation patterns, a representative from the park indicated 2012 visitation was indicative of a typical year. Therefore, entrance station count data provided by the park has been used to specify special generator values shown in **Table 4.21**

Table 4.21: Rocky Mountain National Park Special Generator Values

Trip Purpose	Production / Attraction	Wild Basin (TAZ 1016)	Beaver Meadows (TAZ 1017)	Fall River (TAZ 1018)	Fall River (TAZ 1019)
HBW	Productions	0	0	0	0
	Attractions	15	172	48	48
HBS	Productions	0	0	0	0
	Attractions	0	0	0	0
HBO	Productions	0	0	0	0
	Attractions	507	5873	1657	1657
WBO	Productions	0	0	0	0
	Attractions	0	0	0	0
OBO	Productions	34	395	111	111
	Attractions	34	395	111	111
LBO	Productions	14	158	44	44
	Attractions	103	1186	334	334

Source: 2012 traffic count data provided by Rocky Mountain National Park.

4.8 Truck Trip Generation

The North Front Range travel demand model generates, distributes, and assigns small and large trucks to the roadway network. Since no recent truck survey data is available, truck generation rates are based on vehicle classification traffic count data along with an origin destination matrix estimation (ODME) procedure.

The ODME process aims to estimate an origin-destination trip matrix that, when assigned, would yield flows corresponding to observed count data. The ODME process starts with a seed origin-destination trip matrix assigned to the roadway network. The resulting assigned trips are compared to the observed counts. If the difference between the observed and estimated trips exceeds a specified threshold, the seed matrix is adjusted to produce trips that better match observed counts. The process is repeated until the difference between the estimated and observed trips is below the specified threshold, or a specified number of iterations is met.

To estimate truck trip generation rates, an ODME procedure was implemented. The resulting trip table was converted to a table of origins and destinations by TAZ, allowing for estimation of truck trip generation rates.

Truck ODME Process

The first step in performing the ODME procedure involved collecting the most recent count data from CDOT and MPO member jurisdictions. All available vehicle classification count data was added to the roadway network layer and inventoried. Additional data was collected to provide additional coverage in areas where sufficient vehicle classification data was not available. Once all data had been collected and inventoried, vehicle classification counts were available for 262 links in the network.

An initial attempt was made to run the ODME procedure representing a 24-hour period. However, it soon became evident it would be necessary to run ODME by time of day. The ODME process relies on travel time to estimate the demand between given origin-destination pairs. It was therefore necessary to account for peak period congestion occurring on the roadway network. Neglecting to account for peak period congestion could result in estimation of too many long trips due to the low level of congestion observable on a daily basis.

To perform ODME by time of day, it was necessary to process truck counts to reflect volumes by time of day. Since hourly truck counts were unavailable for the majority of counted links, the percentage of daily truck trips that occur within each time period were estimated from four high volume locations where time of day data was available:

- I-25 north of Buckeye Rd;
- US-34 east of I-25;
- US-34 west of I-25; and
- US-85.

To be consistent with the time periods used in the rest of the model, the truck ODME process was performed for the same eight time periods. The time periods as well as the shares of small and large trucks during each period are shown in **Table 4.22**

Table 4.22: Truck Share by Time of Day

Period	Time Period	% Small Trucks	% Large Trucks
AM	7:00-8:00	7%	6%
AM2	8:00-9:00	6%	7%
PM	16:30-17:30	6%	5%
PM2	15:30-16:30	7%	6%
PM3	17:30-18:30	4%	4%
PM4	14:30-15:30	7%	7%
Mid Day	12:30-13:30	7%	6%
Off Peak	All other	55%	59%
Total		**100%**	**100%**

Once the counts were split by time period, the ODME process in TransCAD was run for each of the eight time periods. For each period, the truck matrices from the previous version of the travel demand model were used as seed matrices. The multi-class ODME process included autos, small trucks, and large trucks so congestion effects due to auto traffic would also be considered in the process. Traffic assignment resulting from the eight-period ODME process were added up to produce daily volumes, which were compared to daily counts to evaluate the effectiveness of the ODME process. The percentage root mean square error[6] (RMSE), a metric to evaluate how well model estimates match observed data, was calculated to be 20 percent for small trucks and 16 percent for large trucks. These values were determined to be reasonable given the tendency of traffic volumes to vary from day to day, along with generally low truck volumes.

Trip Generation Rates

The daily origin-destination matrices for small and large trucks, estimated through the ODME process, were used to develop trip generation rates. The total numbers of small and large truck trips generated in each zone were regressed against land use variables including retail employment, service/medical employment, basic employment, and number of households. All four variables were determined to be significant at the 95 percent confidence level for small trucks. For large trucks, the three employment variables were found to be significant at the 95 percent confidence level, but total households was not found to be significant at the 95 percent confidence level. The resulting coefficients and the model fits as described by R^2 are shown in **Table 4.23**.

[6] See the traffic assignment validation section for an explanation of the % RMSE validation metric.

Table 4.23: Small Truck Trip Generation Rates

Variable	Small Truck Values	Large Truck Values
Basic Employees	0.295	0.404
Retail Employees	0.407	0.329
Service and Medical Employees	0.067	0.020
Total Households	0.023	n/a
R Squared	**0.71**	**0.88**

While the zonal employment and household numbers explain most of the variation in the truck trip generation rates, other factors including presence of active oil wells may also affect the number of truck trips generated in a zone. As part of this analysis, the location of oil wells in the NFR region was obtained and the total number of active wells was considered in the estimation of truck trip rates. The coefficient for the number of oil wells proved to be insignificant and was not included as an explanatory variable. The reason for its insignificance likely stems from basic employment numbers already capturing additional jobs associated with an oil well and the corresponding truck trips.

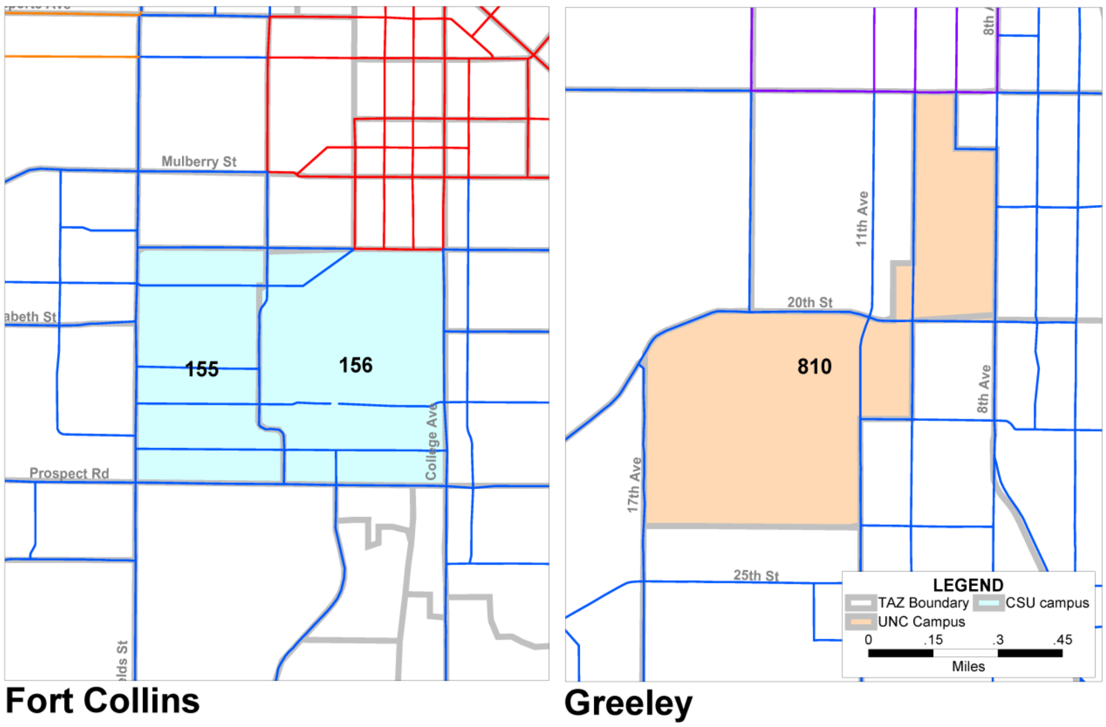
4.9 University Trip Generation and Production Allocation

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.

University Definition

CSU is separated into two TAZs for accurate representation of trips. The west zone includes on-campus residence halls while the east zone includes offices and classrooms. UNC is represented in the model by a single zone. **Figure 4.6** shows the definition of the university zones.

Figure 4.6: University Locations



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 can occur only for students living on campus.
- **HBW Attractions and WBO Productions**: These trip ends can occur only for University faculty and staff.
- **WBO Attractions and all OBO Trips**: These trip ends 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.

Employment and Enrollment Data

University trip generation is based on 2012 employment and enrollment totals obtained from each university's website. Employment data is summarized **Table 4.24** in units of full time equivalent (FT) and does not include third-party vendors or contractors. Enrollment data for each university is summarized in **Table 4.25**.

Table 4.24: Employment Data at CSU and UNC

Type	FTE Employment CSU	FTE Employment UNC
Faculty	1,517	705
Staff	2,256	953
Total Employment	**3,773**	**1,658**

Table 4.25: University Enrollment Summary

Student Type	CSU Students	% CSU Students	UNC Students	% UNC Students
On-Campus	6,149	24%	3,016	24%
Off-Campus	19,264	76%	9,695	76%
Total Enrollment	**25,413**	**100%**	**12,711**	**100%**

Special Generator Values

Trips for the CSU and UNC special generators are based on special generator studies conducted for CSU in 1999 and UNC in 2004. Trip rates based on the survey are defined in units of trips per on-campus student, trips per off-campus student, or trips per employee. Where data is 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 4.26 and Table 4.27**.

Table 4.26: CSU Special Generator Values

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

Table 4.27: UNC Special Generator Values

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

2040 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. Based on limited information regarding future university enrollment it was assumed the number of students attending CSU will grow by 30 percent while the number of students attending UNC will not change through 2040. The resulting special generator values are shown in **Table 4.28**.

Table 4.28: 2040 University Special Generator Values

Trip Purpose	Production / Attraction	CSU Special Generator Value	UNC Special Generator Value
HBW	Productions	1,759	844
	Attractions	7,848	2,437
HBS	Productions	1,600	2,413
	Attractions	0	0
HBU	Productions	0	0
	Attractions	95,164	33,933
HBO	Productions	3,998	3,921
	Attractions	0	0
WBO	Productions	1,815	613
	Attractions	4,758	1,842
OBO	Productions	6,261	2,424
	Attractions	6,261	2,424

4.10 External Trips

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. The 18 external stations are shown in **Figure 4.7**.

When running the model for the lager 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 4.8**. As is evident in these figures, external stations for the MPO modeling area are numbered in the 2000 range, with external stations present only in the expanded model being numbered in the 3000 range.

Figure 4.7: External Station Locations (MPO Modeling Area)

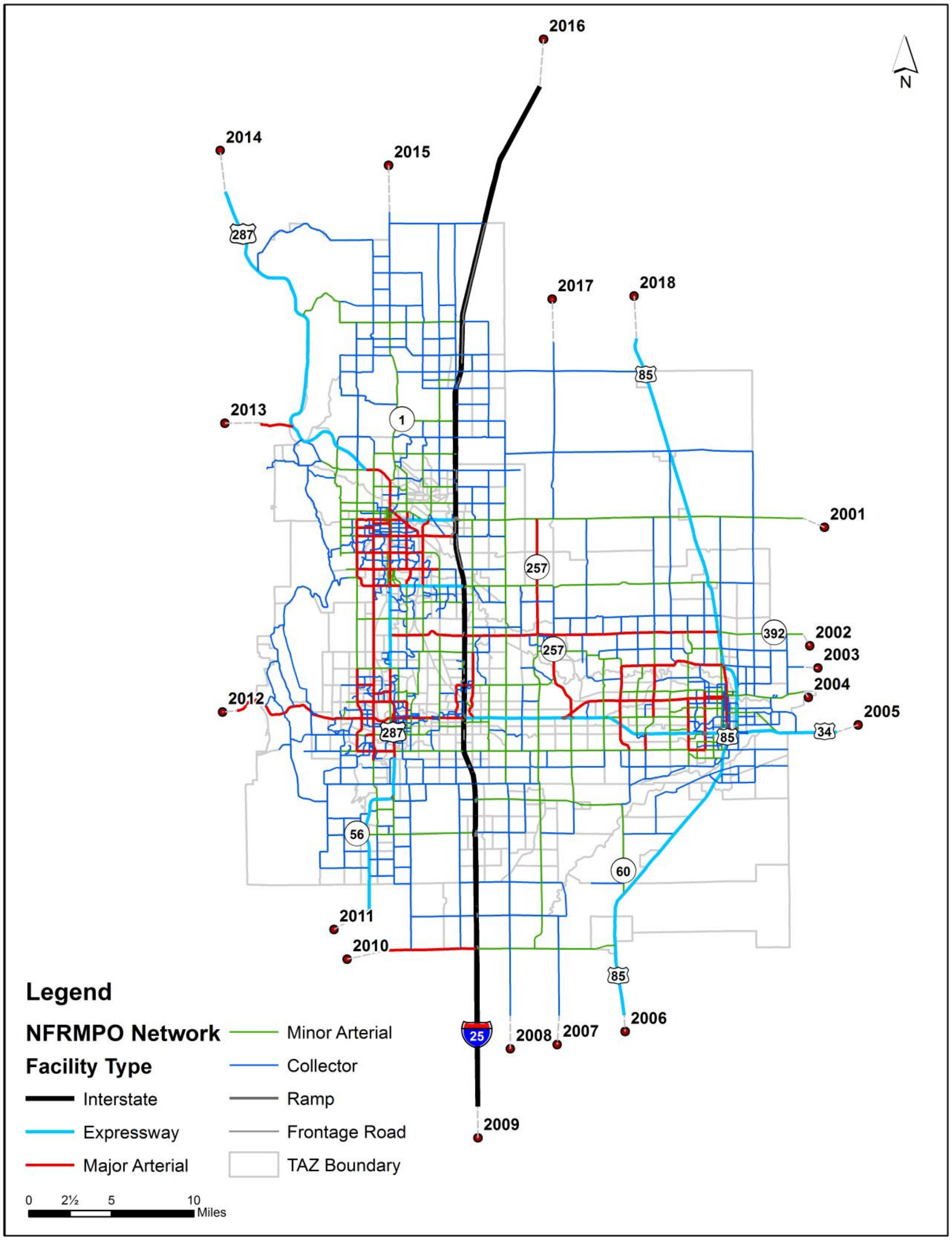
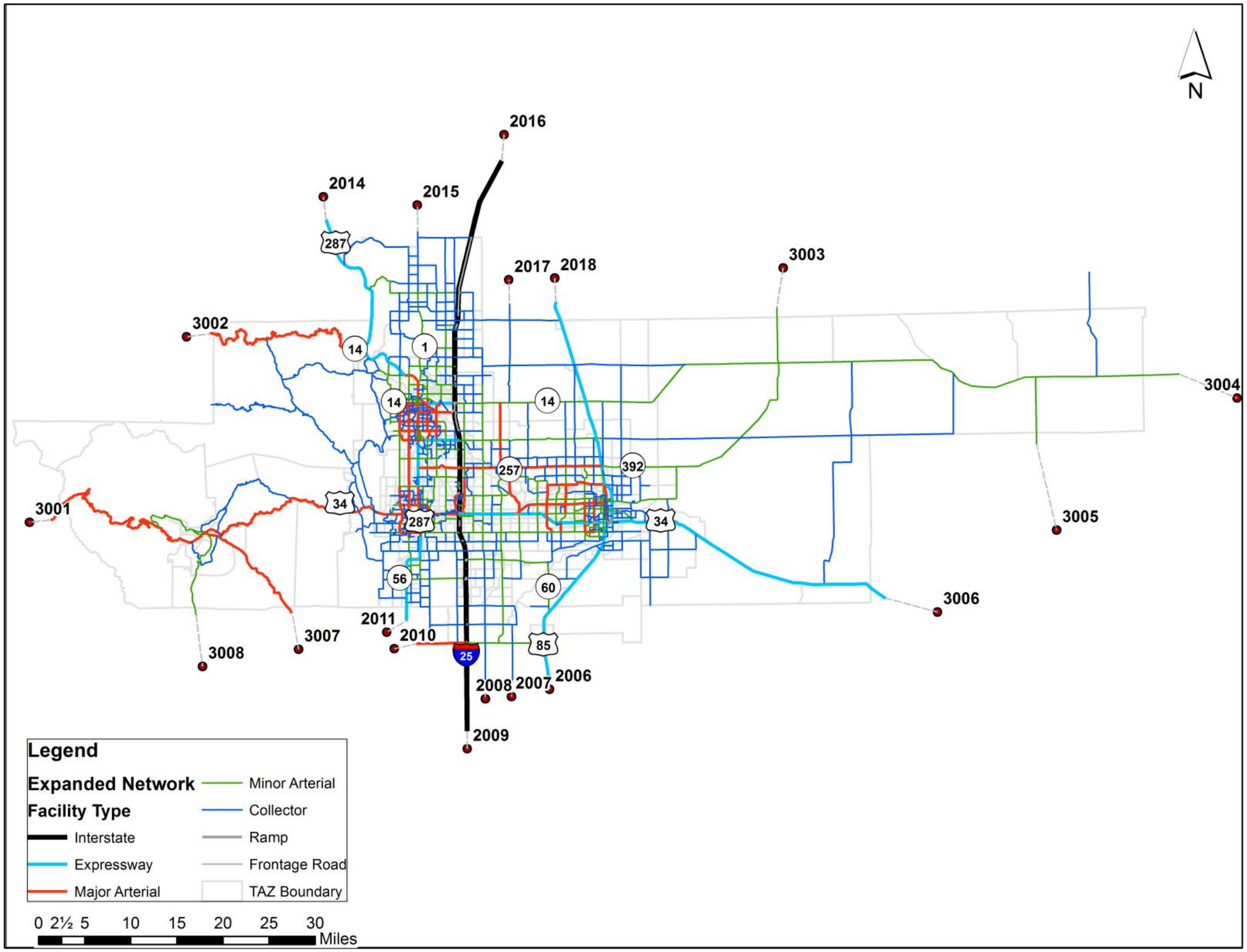


Figure 4.8: External Station Locations (Expanded Modeling Area)



4.11 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 average annual 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. Truck trips were split into through and IE/EI trips separately from auto trips. The splits were calculated using the *2006 North Front Range External Travel Study* and are shown in **Table 4.29**. 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 large truck trips. For the MPO modeling area, external stations have been numbered as zones 2001 through 2018. For the expanded area, several internal stations were removed and new external stations numbered 3001 through 3008 were added. This numbering approach simplifies identification of external stations and allows for easier zone splits as necessary for focused internal area modeling.

Table 4.29: External Travel Assumptions

External Station ID	Location	Total Volume	Auto EE %	Small Truck EE %	Large Truck EE %
2001	SH-14 East*	1,700	0.0%	0.0%	48.6%
2002	SH-392 East*	1,985	0.0%	0.0%	46.7%
2003	CR-64 East*	64	0.0%	0.0%	0.00%
2004	SH-263 East*	2,984	0.0%	0.0%	0.00%
2005	US-34 East*	12,223	1.8%	2.0%	50.3%
2006	US-85 South	16,881	1.6%	1.4%	50.2%
2007	CR-19 South	1,418	0.0%	0.0%	0.00%
2008	CR-13 South	3,278	0.0%	0.0%	0.00%
2009	I-25 South	84,698	6.6%	6.3%	53.7%
2010	SH-66 West	16,820	9.6%	10.3%	56.0%
2011	US-287 South	21,153	0.6%	0.7%	50.0%
2012	US-34 West*	8,211	3.9%	4.5%	52.5%
2013	SH-14 West*	1,183	1.5%	0.0%	51.9%
2014	US-287 North	5,581	14.6%	14.5%	0.00%
2015	CR-15 North	150	0.0%	0.0%	0.00%
2016	I-25 North	20,200	17.5%	17.7%	61.6%
2017	CR-19 North	60	0.0%	0.0%	50.0%
2018	US-85 North	2,342	3.4%	3.6%	51.7%
3001	US-34 west expanded	3,294	3.90%	4.50%	52.50%
3002	SH-14 west expanded	1,450	1.50%	0.00%	51.90%
3003	SH-392 north expanded	1,091	0.00%	0.00%	0.00%
3004	SH-14 east expanded	1,338	0.00%	0.00%	48.60%
3005	SH-52 east expanded	700	0.00%	0.00%	0.00%
3006	US-34 east expanded	3,659	1.80%	2.00%	50.30%
3007	US-36 west expanded	8,159	3.90%	4.50%	0.00%
3008	SH-7 west expanded	3,000	3.90%	4.50%	0.00%

Note: * indicates external stations that are not external to the expanded model, and are therefore only included when running the model for the MPO area.

Internal-External and External-Internal Trips

IE/EI trips processed in the travel model use the internal trip purposes described previously. Trips with production at the external station are EI trips, while trips with attraction at the external station are IE trips. IE/EI are were separated into IE and EI trips based on an analysis of directional traffic counts in the AM and PM peak periods. The resulting allocation of trips into the IE and EI categories is shown in **Table 4.30**.

Table 4.30: IE/EI Trip Allocation

External Station Type	% IE (Attraction external to the NFR)	% EI (Production external to the NFR)
Denver Connections (2006, 2009, and 2011)	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 4.31**.

Table 4.31: Distribution of IE and EI Trips by Trip Purpose

Trip Purpose	IE/EI Trips
HBW	30.1%
HBS	8.4%
HBO	37.7%
WBO	7.3%
OBO	16.5%
TOTAL	**100.0%**

External-External Trips

Based on the *2006 North Front Range External Travel Study*, significant EE trips only occur at a subset of external stations. As previously discussed, external trip totals are derived from total traffic volumes and observed external trip percentages.

Over the course of a day, the total number of EE trips at each external station is assumed to be equal for both directions (inbound trips = outbound trips). This means the daily directional number of EE trips at each external station is equal to half the total EE trips at the station. These totals are used to adjust the observed distribution of EE trips in 2006 to represent 2012 conditions. The adjustment was performed using an iterative proportional factoring process. The resulting through trips for autos, small trucks, and large trucks are shown in **Table 4.32 through Table 4.34**.

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 4.35 through Table 4.37**.

Table 4.32: Daily EE Auto Trip Table (MPO Region)

		2005	2006	2009	2010	2011	2012	2013	2014	2016	2018	
		US-34 East	US-85 South	I-25 South	SH-66 West	US-287 South	US-34 West	SH-14 West	US-287 North	I-25 North	US-85 North	Total
2005	US-34 East	0	30	19	12	5	18	0	1	4	7	97
2006	US-85 South	30	0	26	36	0	3	1	1	2	11	112
2009	I-25 South	19	26	0	697	23	91	3	329	1,320	15	2,524
2010	SH-66 West	12	36	697	0	1	2	0	4	24	0	775
2011	US-287 South	5	0	23	1	0	28	1	2	1	0	61
2012	US-34 West	18	3	91	2	28	0	0	1	16	0	159
2013	SH-14 West	0	1	3	0	1	0	0	3	1	0	9
2014	US-287 North	1	1	329	4	2	1	3	0	1	0	342
2016	I-25 North	4	2	1,320	24	1	16	1	1	0	0	1,368
2018	US-85 North	7	11	15	0	0	0	0	0	0	0	34
Total		97	112	2,524	775	61	159	9	342	1,368	34	5,480

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

Table 4.33: Daily EE Small Truck Trip Table (MPO Region)

		2005	2006	2009	2010	2011	2012	2013	2014	2016	2018	
		US-34 East	US-85 South	I-25 South	SH-66 West	US-287 South	US-34 West	SH-14 West	US-287 North	I-25 North	US-85 North	Total
2005	US-34 East	0	2	0	0	0	0	0	0	1	0	4
2006	US-85 South	2	0	0	4	0	0	0	0	3	1	11
2009	I-25 South	0	0	0	3	0	0	0	3	53	0	59
2010	SH-66 West	0	4	3	0	0	0	0	0	10	0	17
2011	US-287 South	0	0	0	0	0	0	0	0	1	0	1
2012	US-34 West	0	0	0	0	0	0	0	0	1	0	2
2013	SH-14 West	0	0	0	0	0	0	0	0	0	0	0
2014	US-287 North	0	0	3	0	0	0	0	0	1	0	4
2016	I-25 North	1	3	53	10	1	1	0	1	0	0	69
2018	US-85 North	0	1	0	0	0	0	0	0	0	0	1
Total		4	11	59	17	1	2	0	4	69	1	168

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

Table 4.34: Daily EE Large Truck Trip Table (MPO Region)

		2001	2002	2005	2006	2009	2010	2011	2013	2016	2018	
		SH-14 east	SH-392 east	US-34 east	US-85 south	I-25 south	SH-66 west	US-287 south	SH-14 west	I-25 north	US-85 north	Total
2001	SH-14 east	0	0	0	13	38	0	6	1	0	3	62
2002	SH-392 east	0	0	0	26	74	0	12	3	1	5	120
2005	US-34 east	0	0	0	138	107	1	13	0	3	13	277
2006	US-85 south	13	26	138	0	136	4	0	0	2	20	339
2009	I-25 south	38	74	107	136	0	88	73	1	1,159	32	1,708
2010	SH-66 west	0	0	1	4	88	0	0	0	0	0	94
2011	US-287 south	6	12	13	0	73	0	0	0	0	0	106
2013	SH-14 west	1	3	0	0	1	0	0	0	0	0	6
2016	I-25 north	0	1	3	2	1,159	0	0	0	0	0	1,166
2018	US-85 north	3	5	13	20	32	0	0	0	0	0	73
Total		**62**	**120**	**277**	**339**	**1,708**	**94**	**106**	**6**	**1,166**	**73**	**3,951**

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

Table 4.35: Daily EE Auto Trip Table (Expanded Area)

		2006	2009	2011	2010	2014	2016	2018	3001	3002	3006	
		US-85 south	I-25 south	SH-66 west	US-287 south	US-287 north	I-25 north	US-85 north	US-34 west	SH-14 west	US-34 east	Total
2006	US-85 south	0	34	0	37	1	2	12	14	2	9	112
2009	I-25 south	34	0	49	711	329	1,340	16	36	4	6	2,524
2010	SH-66 west	37	711	1	0	3	20	0	0	0	3	775
2011	US-287 south	0	49	0	1	4	2	0	0	2	3	61
2014	US-287 north	1	329	4	3	0	1	0	2	2	0	342
2016	I-25 north	2	1,339	2	20	1	0	0	2	1	1	1,368
2018	US-85 north	12	16	0	0	0	0	0	5	0	2	34
3001	US-34 west	14	36	0	0	2	2	5	0	0	4	64
3002	SH-14 west	2	4	2	0	2	1	0	0	0	0	10
3006	US-34 east	9	6	3	3	0	1	2	4	0	0	28
Total		**112**	**2,523**	**61**	**775**	**342**	**1,368**	**34**	**64**	**10**	**28**	**5,318**

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

Table 4.36: Daily EE Small Truck Trip Table (Expanded Area)

		2006	2009	2011	2010	2014	2016	2018	3001	3002	3006	
		US-85 south	I-25 south	SH-66 west	US-287 south	US-287 north	I-25 north	US-85 north	US-34 west	SH-14 west	US-34 east	Total
2006	US-85 south	0	0	0	5	0	4	1	0	0	1	11
2009	I-25 south	0	0	0	2	2	53	0	0	0	0	59
2010	SH-66 west	5	2	0	0	0	10	0	0	0	0	17
2011	US-287 south	0	0	0	0	0	1	0	0	0	0	1
2014	US-287 north	0	2	0	0	0	1	0	0	0	0	4
2016	I-25 north	4	53	1	10	1	0	0	0	0	0	69
2018	US-85 north	1	0	0	0	0	0	0	0	0	0	1
3001	US-34 west	0	0	0	0	0	0	0	0	0	0	1
3002	SH-14 west	0	0	0	0	0	0	0	0	0	0	0
3006	US-34 east	1	0	0	0	0	0	0	0	0	0	1
Total		11	59	1	17	4	69	1	1	0	1	164

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

Table 4.37: Daily EE Large Truck Trip Table (Expanded Area)

		2006	2009	2010	2011	2016	2018	3002	3004	3006	
		US-85 south	I-25 south	SH-66 west	US-287 south	I-25 north	US-85 north	SH-14 west	SH-14 east	US-34 east	Total
2006	US-85 south	0	221	5	0	2	30	2	25	55	339
2009	I-25 south	221	0	89	95	1,162	39	4	63	36	1,708
2010	SH-66 west	5	89	0	0	0	0	0	0	0	94
2011	US-287 south	0	95	0	0	0	0	1	5	5	106
2016	I-25 north	2	1,162	0	0	0	0	0	1	1	1,166
2018	US-85 north	30	39	0	0	0	0	0	0	4	73
3002	SH-14 west	2	4	0	1	0	0	0	4	0	11
3004	SH-14 east	25	63	0	5	1	0	4	0	0	97
3006	US-34 east	55	36	0	5	1	4	0	0	0	101
Total		339	1,708	94	106	1,166	73	11	97	101	3,696

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

External Station Growth Rates

When running the travel model in a forecast year condition, external station volumes must be increased to account for future growth. Unlike internal growth, control totals and land use data is not directly applicable at external stations. Instead, external station volumes are grown using a compound annual growth rate applied to each external station. After total volumes are increased, remaining assumptions such as IE/EI/EE percentages and trip purposes are retained. Annual growth rates at each external station were calculated based on the 20-year growth factor obtained from the CDOT Traffic Data Explorer. Growth rates by station and resulting volumes are shown in **Table 4.38**.

Table 4.38: External Station Growth Rates (% growth per year)

Station	Station Name	Growth Rate (% per year)	2040 Volume
2001	SH-14 east	2.3%	3,197
2002	SH-392 east	2.2%	3,651
2003	CR-64 east	2.2%	118
2004	SH-263 east	1.6%	4,654
2005	US-34 east	2.4%	23,745
2006	US-85 south	2.1%	30,208
2007	CR-19 south	2.1%	2,537
2008	CR-13 south	2.1%	5,866
2009	I-25 south	2.0%	147,461
2010	SH-66 west	2.4%	32,676
2011	US-287 south	2.2%	38,904
2012	US-34 west	1.9%	13,908
2013	SH-14 west	2.8%	2,563
2014	US-287 north	2.3%	10,549
2015	CR-15 north	2.2%	276
2016	I-25 north	2.0%	35,169
2017	CR-19 north	2.2%	110
2018	US-85 north	2.3%	4,427
3001	US-34 west	2.1%	5,894
3002	SH-14 west	2.6%	2,975
3003	SH-392 north	2.2%	2,007
3004	SH-14 east	1.8%	2,208
3005	SH-52 east	3.3%	1,757
3006	US-34 east	2.3%	7,004
3007	US-36 west	2.4%	15,893
3008	SH-7 west	2.4%	5,828

4.12 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. One exception is the HBU trip purpose. 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, so HBU productions are balanced to attractions.

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

5.0 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 NFR Model uses a gravity model equation and 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. This relationship is similar to the standard gravity model which assumes the gravitational attraction between two bodies decreases as they become further apart. The gravity model also assumes the gravitational attraction between the two bodies is directly proportional to their masses. The trip distribution model makes a similar assumption in 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 used by trip distribution to estimate the number of trips between each zone pair is defined in Equation (5).

$$T_{ij} = P_i \cdot \frac{A_j \cdot F_{ij} \cdot K_{ij}}{\sum_{i=1}^{n}\left(A_j \cdot F_{ij} \cdot K_{ij}\right)} \qquad (5)$$

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)

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. In the NFR Model, K-factors were considered as a tool to improve trip distribution patterns between the different subregions, but were found to be unnecessary during themodel calibration and validation process.

Friction factors represent the impedance to travel between each zone pair. Friction factors have been calibrated for each trip purpose based on observed trip length (time) frequency distributions (TLFDs) and average travel times implied therein. Friction factors were calibrated using data from the 2010 Front Range Travel Counts household survey data.

5.1 Peak and Off-Peak Period Definitions

Trips occurring during the AM and PM peak hours were distributed based on peak congested speeds, while trips occurring during off-peak times are distributed based on 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 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 5.1**.

Table 5.1: Trip Distribution Time of Day Factors

	HBW	HBS	HBU	HBO	WBO	OBO
Off-Peak	53%	43%	43%	56%	53%	47%
Peak	47%	57%	57%	44%	47%	53%

5.2 Roadway Shortest Path

The impedance portion of the gravity model equation is based on the shortest path between each zone pair. 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.

Impedance Variable

The NFR Model finds the shortest paths between each zone pair based on the generalized cost function shown in equation (6). This function considers congested travel time along with any tolls that may be incurred along a path. The value of time parameter varies by time period, with values shown in **Table 5.2**. Travel time, distance, and toll costs are individually skimmed during the pathbuilding process. It is important to note there are not currently any toll facilities in the NFR region. Therefore, the toll and HOT aspects of the travel model are only applicable in forecast year scenarios that include toll and/or HOT facilities.

$$GC = Time \cdot VOT + Toll \qquad (6)$$

Where:

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

Table 5.2: Value of Time Parameters

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

Peak congested travel time is defined as the AM peak hour directional travel time, while off-peak travel time is defined as the off-peak period 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 high occupancy toll (HOT) lanes that are free to high occupancy vehicles (HOVs), but charge tolls to single occupant vehicles (SOVs), separate shortest path matrices are generated for HOVs and SOVs. The gravity model relies on SOV paths, but HOV paths are retained for use in the mode choice model.

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 5.3**, are added to both the production and attraction end of each zone pair based on the area type of each zone.

Table 5.3: Terminal Penalties by Area Type

Area Type		Terminal Time
1	Rural	0.75
2	Sub-urban	1
3	Urban	1
4	Fort Collins CBD	1.5
5	Other CBD	1.5

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.

5.3 Friction Factor Calibration

Friction factors represent the impedance to travel between each zone pair. The NFR Model applies friction factors in the form of gamma functions for each trip purpose. The gamma function is defined by Equation (7).

$$F_{ij} = \alpha t^{\beta} e^{\gamma t} \quad (7)$$

Where:

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

t = *travel time*

α, β, γ = *calibration parameters*

In addition to friction factor adjustments, other model variables and parameters including terminal penalties, intrazonal travel times, volume/delay equations, and K-factors can affect calibration of trip length distribution curves. It was not necessary to make further adjustments to these parameters during model validation.

Calibration Process

TLFD curves for each trip type were generated based on observed trip tables extracted from the 2010 Front Range Travel Counts household survey. Shortest path matrices used to develop these curves were consistent with the shortest path matrices applied by the travel model, and include both intrazonal travel time and terminal penalties. These curves were initially based on freeflow speed, but were updated using congested speeds resulting from speed feedback as model development progressed. These survey-based distribution curves served as trip distribution model calibration targets.

While shortest paths were identified using a generalized cost function, the gravity model is applied using congested travel time alone. Likewise, calibration targets are based on travel time rather than generalized cost. The resulting TLFD curves are shown in **Figure 5.1 and Figure 5.2**.

Figure 5.1: Regionwide Trip Time Distribution Curves by Purpose – Peak

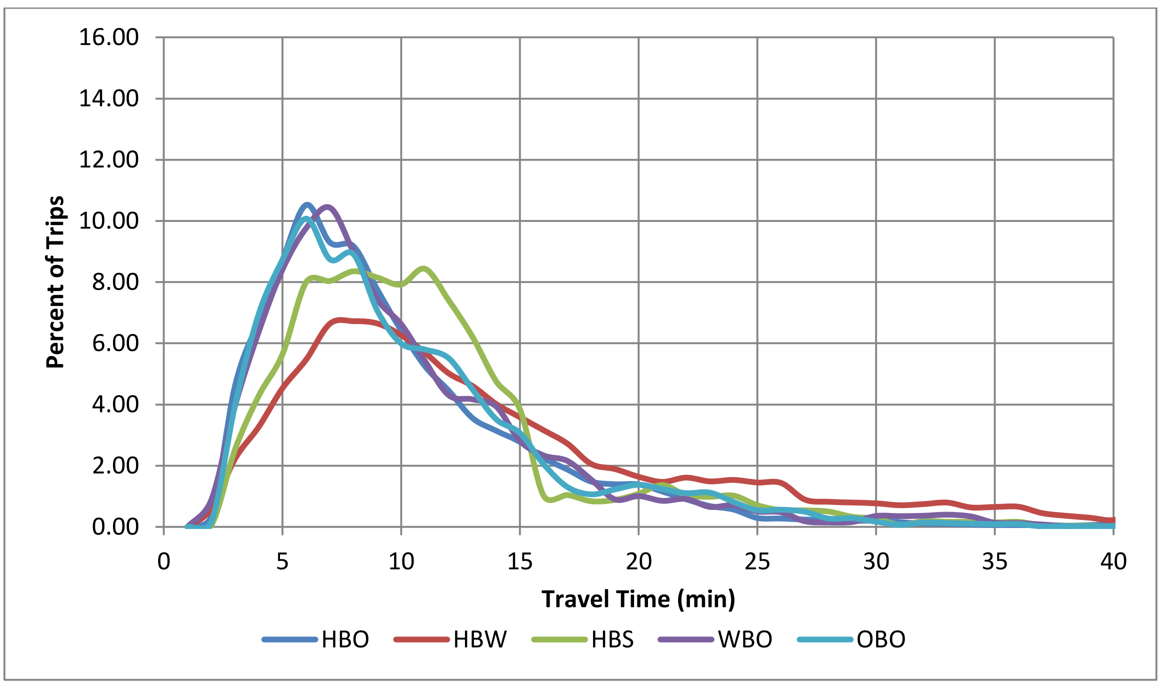
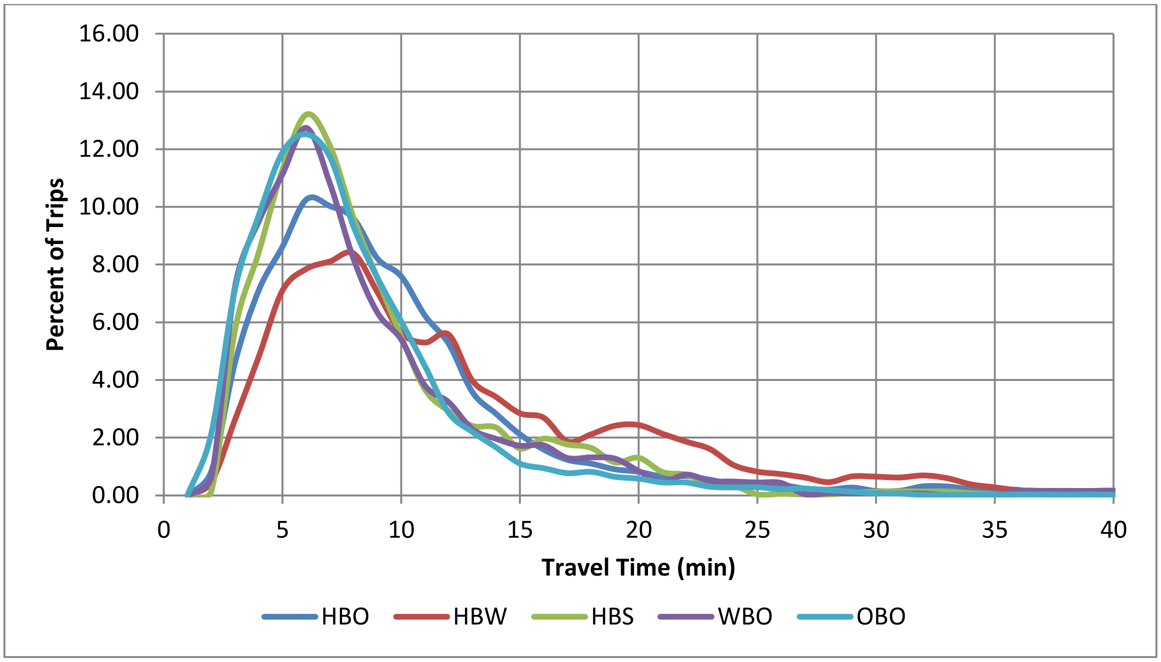


Figure 5.2: Regionwide Trip Time Distribution Curves by Purpose – Off-Peak



The trip distribution model was calibrated by applying the gravity model using results of the trip generation model and comparing the resulting trip length distributions to the observed targets. Friction factors were adjusted for each trip type. This iterative process was continued until no further improvement in replication of the calibration target could be achieved through friction factor adjustments.

For each iteration of the calibration process, parameters were adjusted in one of two ways.

- For initial iterations, Equation (8) was used to predict friction factor values at one minute increments. Gamma parameters were then adjusted to fit a curve to the predicted friction factors. Equation (8) compares the trip length distribution resulting from application of a set of friction factors to the calibration target and predicts new friction factor values that are more likely to replicate the calibration target.

$$F_i^r = F_{i-1}^r \left(\frac{SurveyTrips^r}{ModelTrips_{i-1}^r} \right) \qquad (8)$$

Where:

F_i^r = Predicted friction factor value for impedance range r and iteration i

F_{i-1}^r = Gamma function based friction factor value for impedance range r and iteration i-1

$SurveyTrips^r$ = The percentage of surveyed trips in impedance range r

$ModelTrips_{i-1}^r$ = The percentage of trips in impedance range r resulting from application of iteration i-1 of the gravity model

Once application of Equation (8) stopped producing improvements, the gamma parameters were manually adjusted for each iteration.

Trip length and trip distributions for the region as a whole, as well as trips in the Fort Collins, Greeley, and Loveland sub regions were monitored during the calibration process. Since the model's focus is region-wide, a higher amount of error was accepted at the subregional level to improve trip distribution region wide.

Calibration Results

Resulting trip time distribution curves for each trip purpose by period are shown in **Figure 5.3 through Figure 5.12**. Friction factors by trip type and by period are shown in **Table 5.4 and Table 5.5**.

A measure that can be used to quantify the relationship between observed and modeled trip length distribution curves is the coincidence ratio. The coincidence ratio is a number between zero and one that specifies the area under both the calibration target and model result trip length distribution curve. Coincidence ratios for each trip type and period are shown in **Table 5.6**.

Figure 5.3: HBW Trip Time Distribution Curve – Peak Period

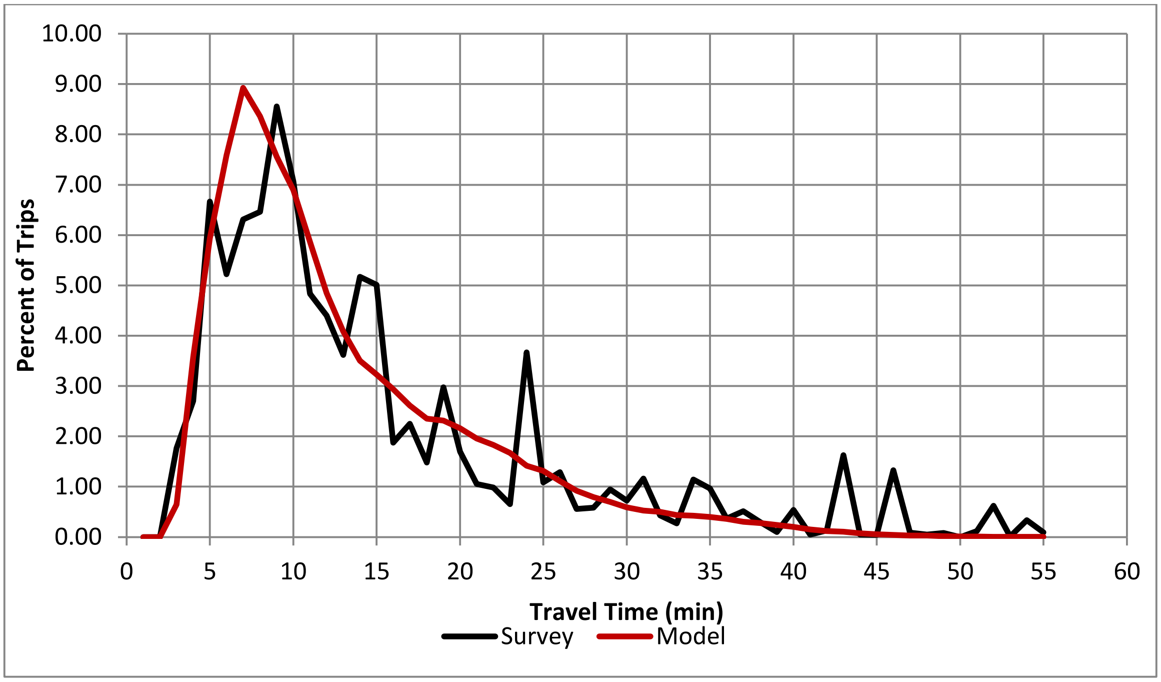


Figure 5.4: HBW Trip Time Distribution Curve – Off-Peak Period

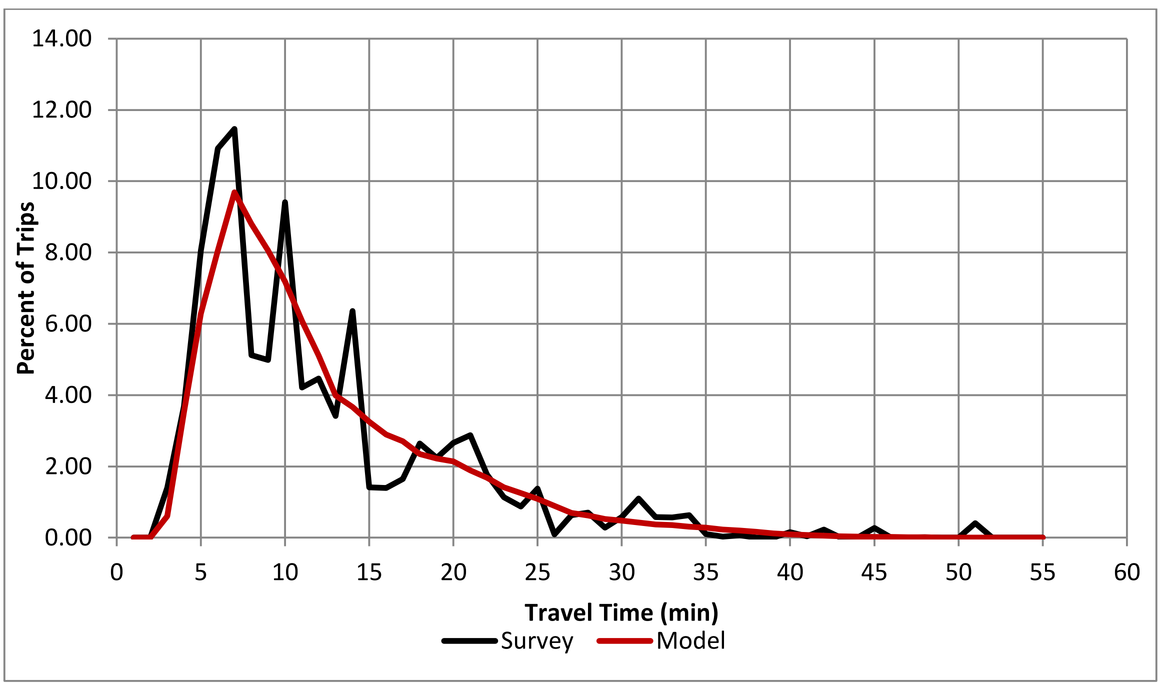


Figure 5.5: HBS Trip Time Distribution Curve – Peak Period

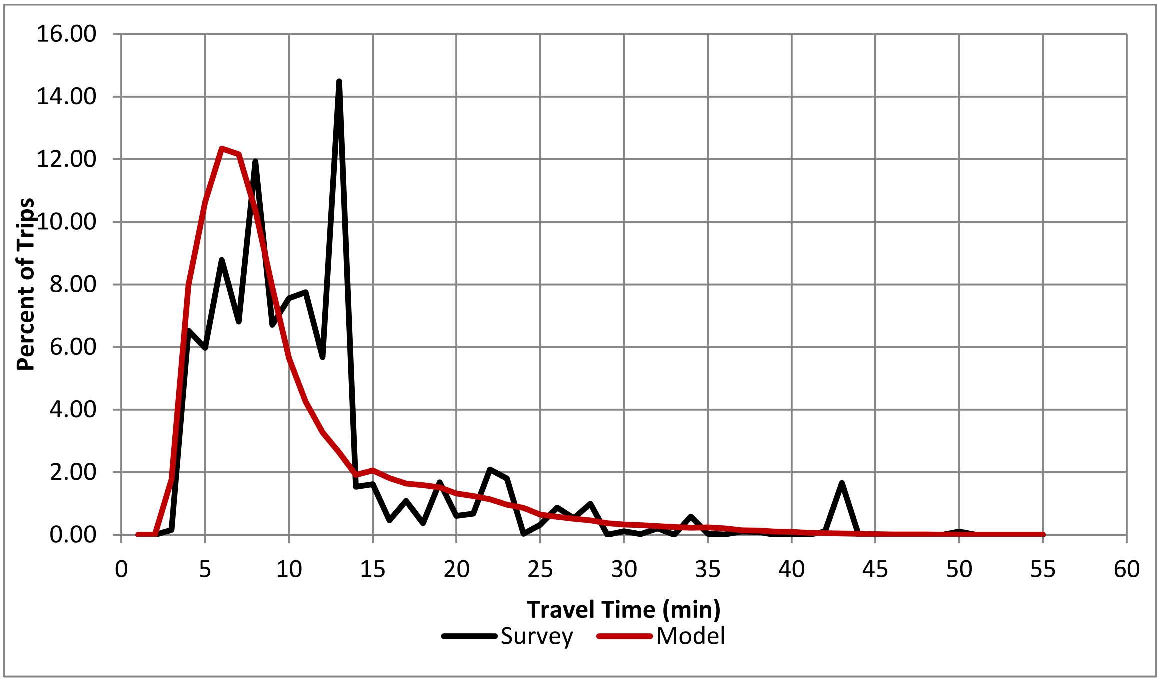


Figure 5.6: HBS Trip Time Distribution Curve – Off-Peak Period

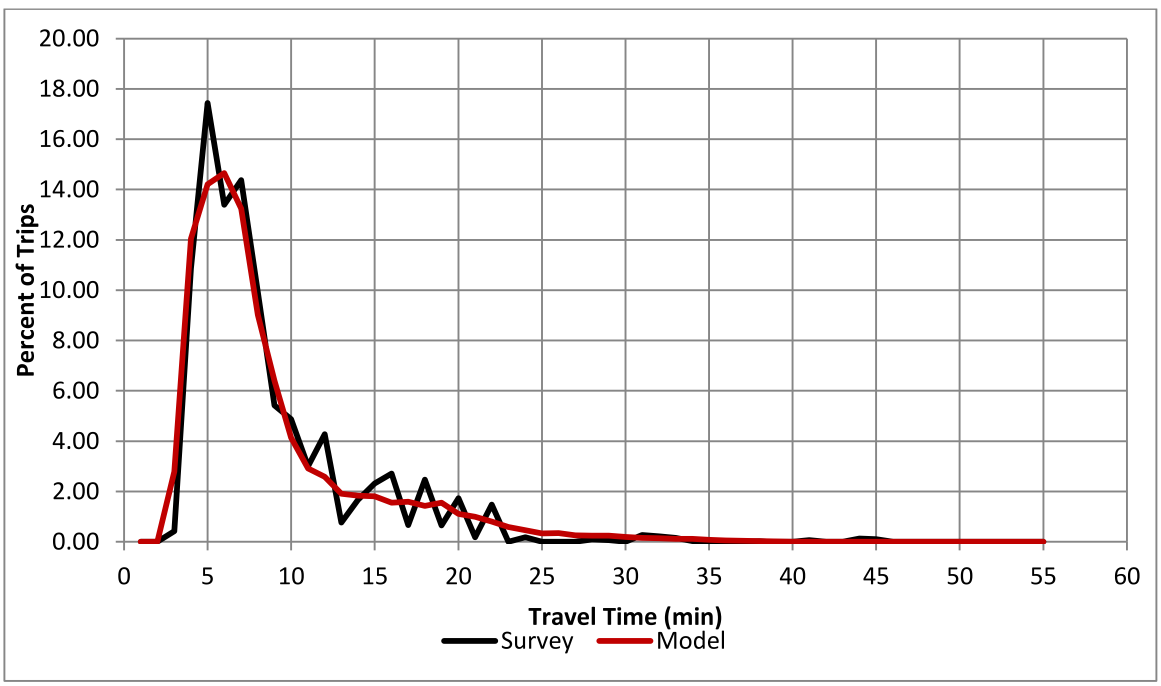


Figure 5.7: HBO Trip Time Distribution Curve – Peak Period

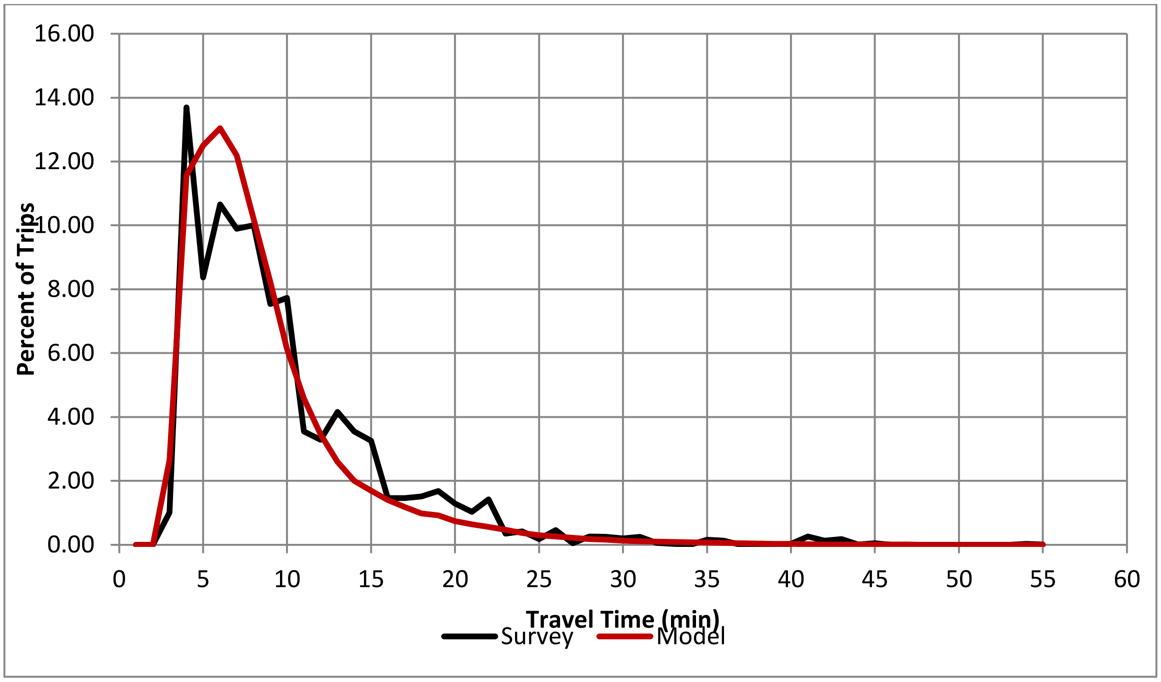


Figure 5.8: HBO Trip Time Distribution Curve – Off-Peak Period

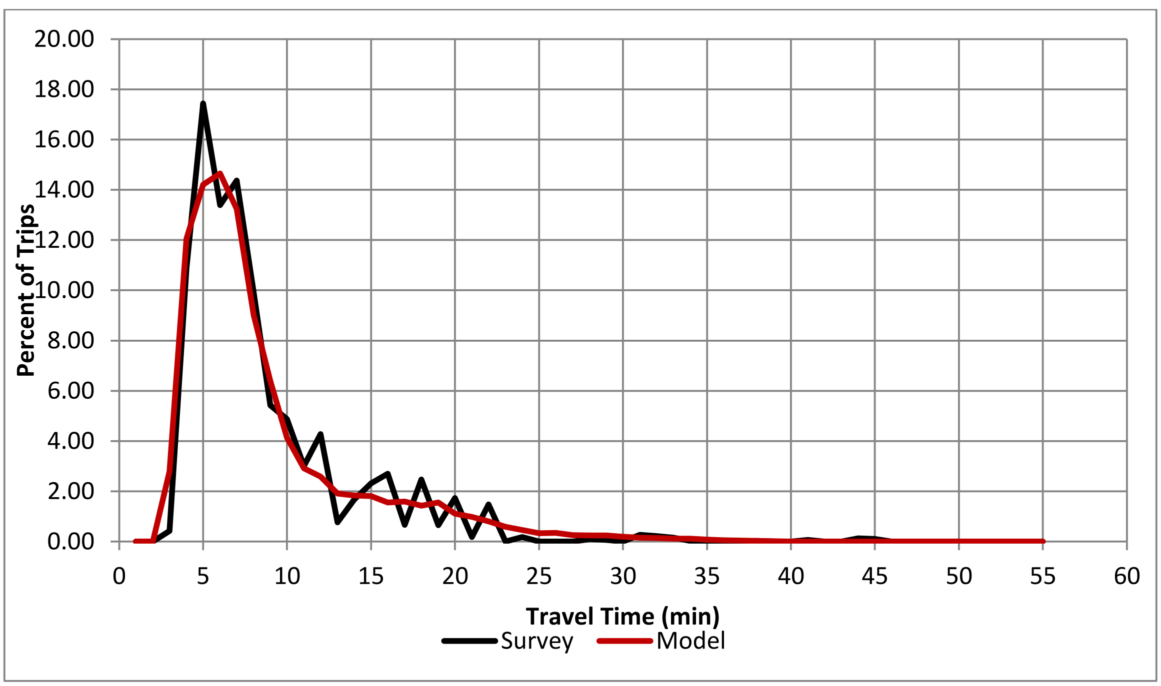


Figure 5.9: WBO Trip Time Distribution Curve – Peak Period

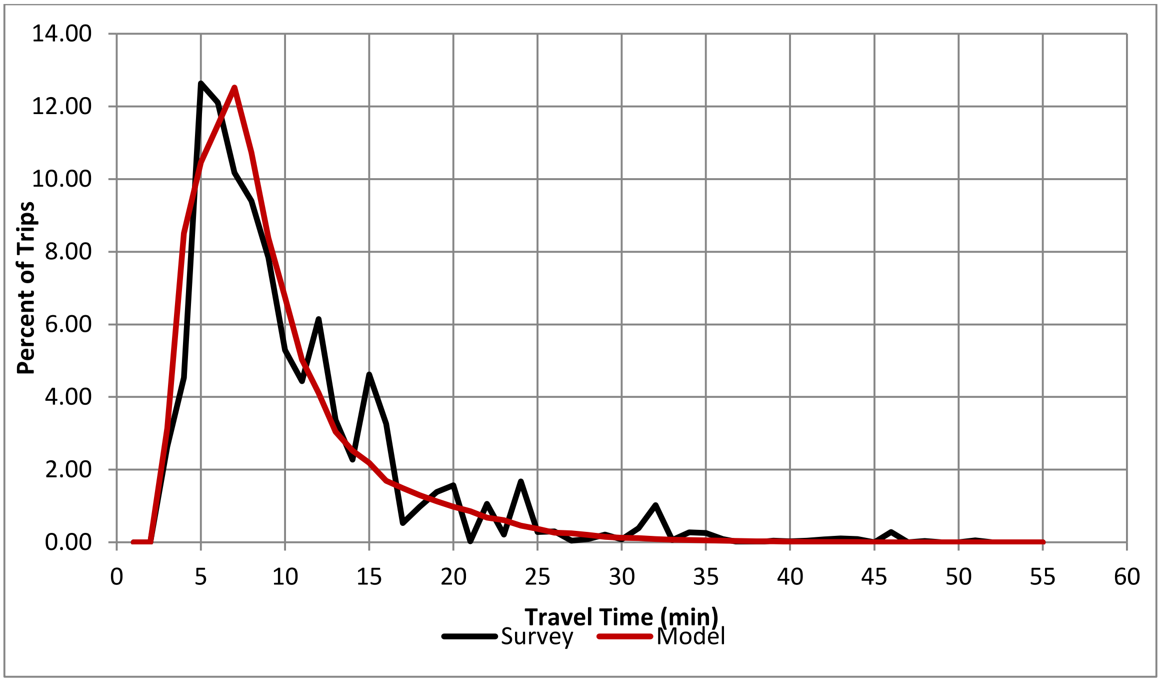


Figure 5.10: WBO Trip Time Distribution Curve – Off-Peak Period

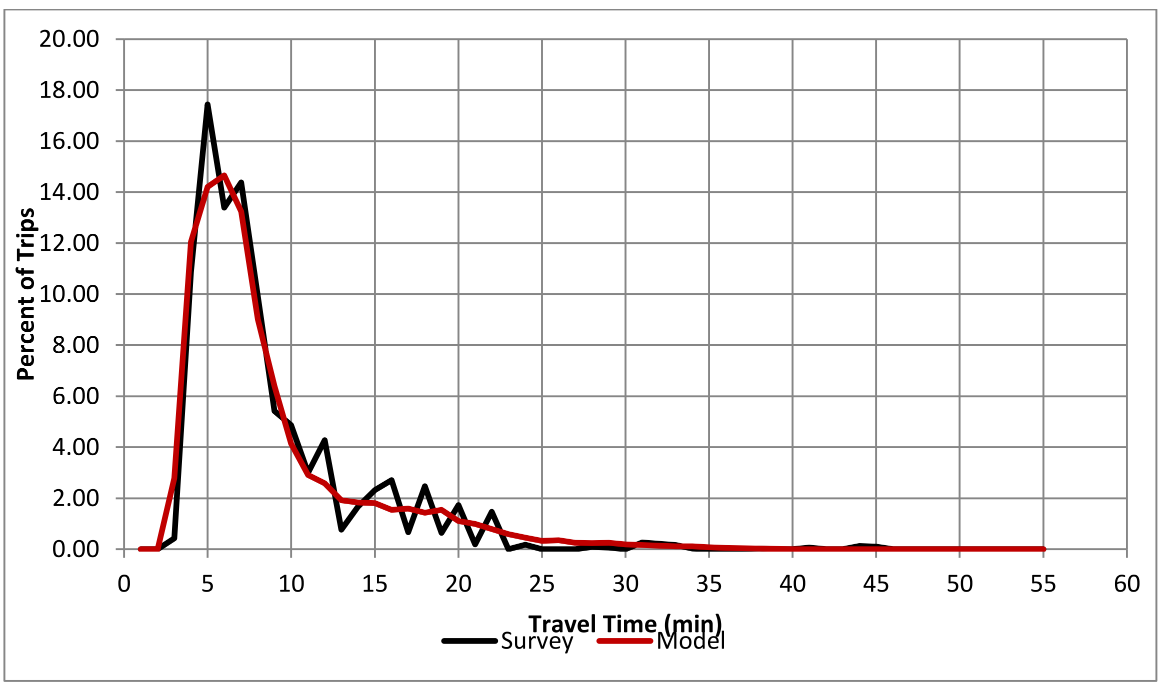


Figure 5.11: OBO Trip Time Distribution Curve – Peak Period

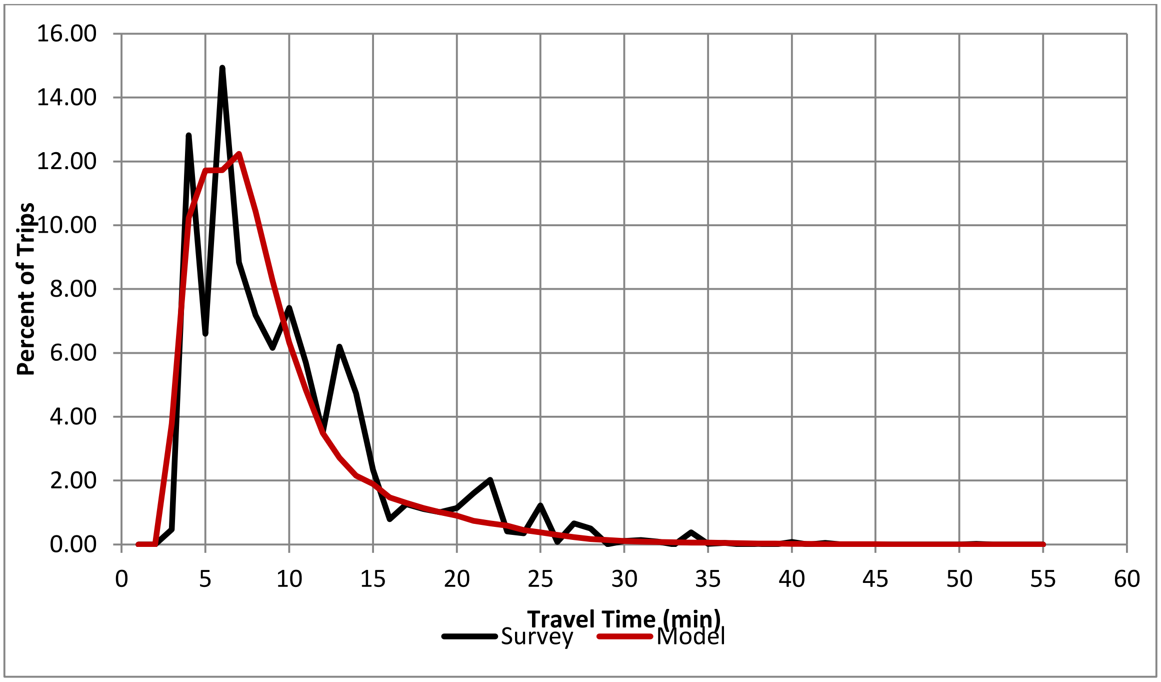


Figure 5.12: OBO Trip Time Distribution Curve – Off-Peak Period

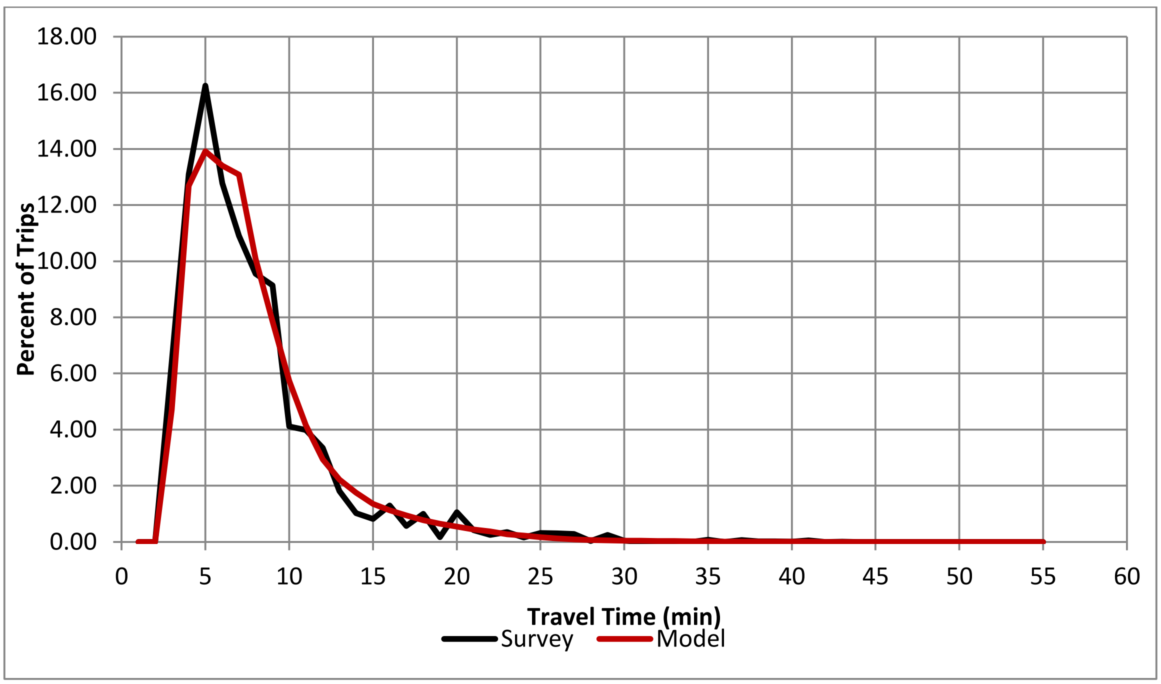


Figure 5.13: Friction Factor Curves – Peak Period

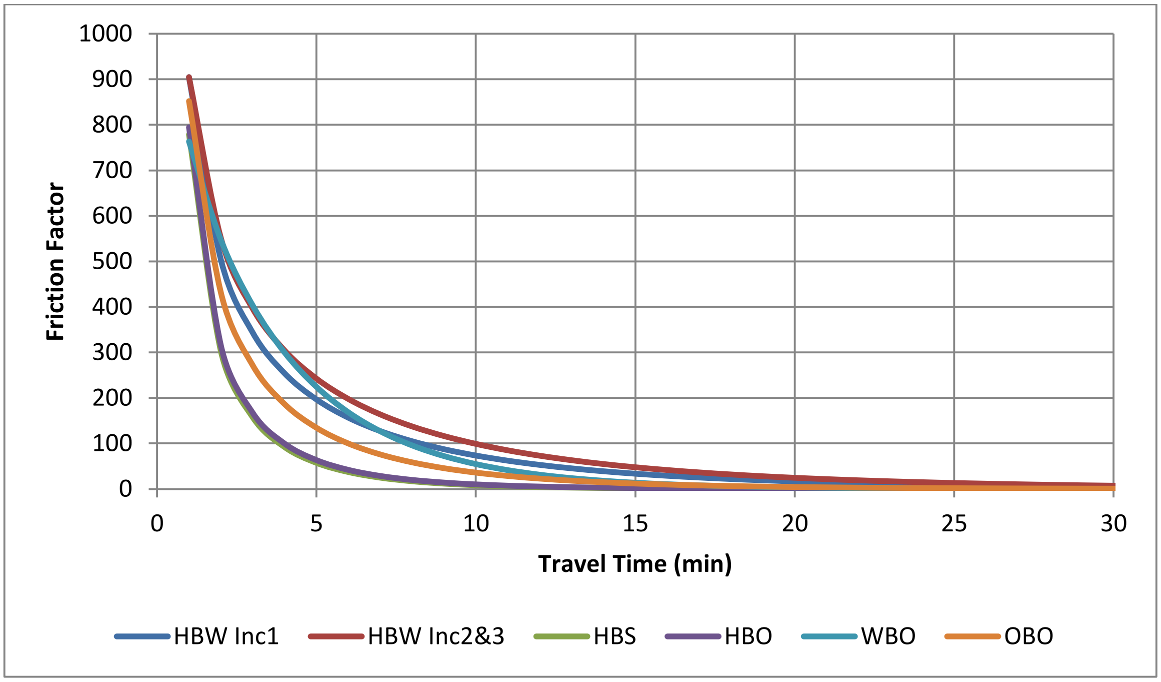


Figure 5.14: Friction Factor Curves – Off-Peak Period

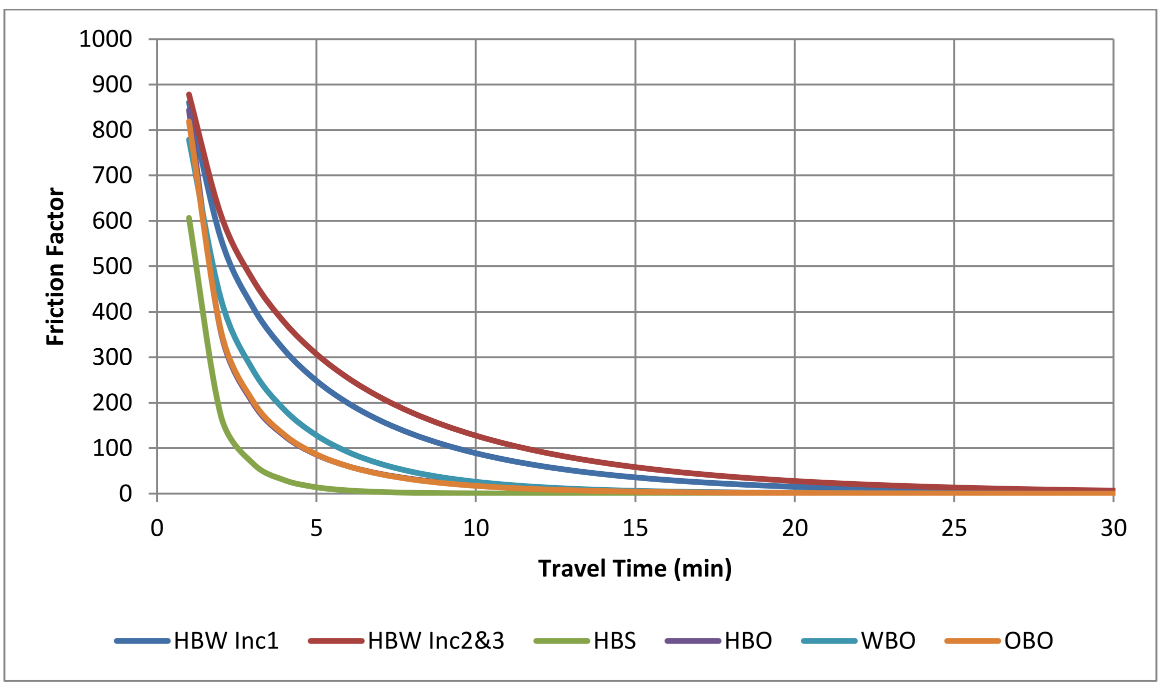


Table 5.4: Peak Friction Factors

	HBW Inc 1	HBW Inc 2	HBW Inc 3	HBS	HBO	WBO	OBO
A	1000	1000	1000	1000	1000	1000	1000
B	0.7	0.57	0.57	1	1	0.09	0.75
C	0.1	0.1	0.1	0.25	0.23	0.27	0.16

Table 5.5: Off-Peak Friction Factors

	HBW Inc 1	HBW Inc 2	HBW Inc 3	HBS	HBO	WBO	OBO
A	1000	1000	1000	1000	1000	1000	1000
B	0.4	0.33	0.33	1.1	1	0.5	0.9
C	0.15	0.13	0.13	0.5	0.17	0.25	0.2

Table 5.6: Coincidence Ratios

	HBW	HBS	HBO	WBO	OBO
Peak	72%	77%	59%	75%	68%
Off-peak	71%	81%	78%	68%	85%

6.0 MODE CHOICE

The NFR Model produces and distributes all person trips including non-motorized, auto, and transit trips. The mode models separate the resulting person trip tables into the drive alone, shared ride (i.e., carpool), 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. The mode choice model considers trip lengths produced by the gravity 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.

6.1 Observed 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 Front Range Travel Counts household travel survey data shown in **Table 6.1**.

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 in Greeley. These surveys included a complete cordon count paired with student/visitor and faculty/staff surveys. This dataset also contains information about university trip mode share. University mode shares from the special generator surveys have been combined into a weighted average, shown in **Table 6.1**.

Table 6.1: Observed Mode Shares

Purpose	DA	SR	Walk	Bike
HBW Low Income	86.4%	8.0%	5.1%	0.5%
HBW Medium Income	83.3%	9.4%	2.4%	4.9%
HBW High Income	80.2%	8.7%	1.7%	9.5%
HBS	43.3%	50.3%	4.7%	1.8%
HBU	46.0%	18.7%	23.3%	12.1%
HBO	33.7%	52.5%	10.8%	3.0%
WBO	77.6%	11.9%	8.3%	2.1%
OBO	36.8%	52.7%	9.5%	1.0%

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

For transit trips, total transit boardings were obtained from Transfort, Greeley-Evans Transit (GET), and City of Loveland Transit (COLT) as shown in **Table 6.2**, The boardings cannot be directly used as transit targets because they include transfers and need to be linked first. The NFRMPO conducted a transit on-board survey in 2008, which identifies the distribution of transit trips by purpose and the average number of boardings per transit trip. This allowed estimation of the total number of linked transit trips (i.e., origin to destination including any transfers) by purpose for each transit operator and for the region as a whole. **Table 6.3** shows a summary of weighted and expanded on board survey data, along with information about trip purposes and average transfer rates. This information was used to generate updated 2012 mode choice transit calibration targets, discussed later in this chapter.

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 and ride. While some transit riders in the North Front Range do indeed use an informal park and ride or drop-off location, this was observed to be a very small portion of total transit usage. Furthermore, the region did not have any formal park-n-ride locations served by fixed route transit in 2012. Therefore, the base year 2012 model calibration targets do not include any drive access transit trips.

Table 6.2: 2012 Fixed Route Boardings

Operator	Average Weekday Boardings
Transfort	9,235
Greeley Evans Transit (GET)	1,119
City of Loveland Transit (COLT)	448
Regional Total	**10,802**

Source: Data provided by NFR area transit agencies

Table 6.3: 2008 On-Board Survey Summary Data

Trip Purpose	Linked Trips	Transfers	Total Boardings	Total Boardings per Linked Trip	% Transfers per Boarding
			Transfort		
Home-based Work	800	418	1,214	1.52	34%
Home-based Shopping	129	73	201	1.56	36%
Home-based University	1,919	241	2,224	1.16	11%
Home-based Other	907	467	1,403	1.55	33%
Work-based Other	354	207	525	1.48	39%
Other-based Other	491	274	715	1.46	38%
System Total	**4,601**	**1,681**	**6,282**	**1.37**	**21%**
			Greeley – Evans Transit (GET)		
Home-based Work	168	69	242	1.44	28%
Home-based Shopping	127	85	177	1.39	48%
Home-based University	57	26	82	1.43	32%
Home-based Other	380	176	555	1.46	32%
Work-based Other	131	38	192	1.47	20%
Other-based Other	223	94	327	1.46	29%
System Total	**1,086**	**488**	**1,574**	**1.45**	**31%**
			City of Loveland Transit (COLT)		
Home-based Work	80	36	111	1.39	32%
Home-based Shopping	38	23	57	1.51	39%
Home-based University	14	10	19	1.36	52%
Home-based Other	119	42	175	1.47	24%
Work-based Other	38	26	56	1.48	46%
Other-based Other	37	14	58	1.56	25%
System Total	**326**	**150**	**476**	**1.46**	**32%**
			All Systems		
Home-based Work	1,048	523	1,568	1.50	33%
Home-based Shopping	294	180	436	1.48	41%
Home-based University	1,990	278	2,324	1.17	12%
Home-Based Other	1,407	686	2,133	1.52	32%
Work-Based Other	523	271	772	1.48	35%
Other-Based Other	751	382	1,099	1.46	35%
All Systems Total	**6,013**	**2,319**	**8,332**	**1.39**	**28%**

Source: 2008 NFRMPO On-board transit survey, expanded to 2008 ridership totals

Resulting Mode Targets

The analysis above relies on different datasets to produce mode share targets for non-motorized trips, trips in vehicles, and transit trips. While this information is all valid, the different data sources are not always compatible. The transit mode shares are expressed in total trips and need to be expanded to match 2012 boarding data, while the other targets are expressed as percentages. To account for these conditions, mode share targets shown in **Table 6.4** are expressed in different units for transit and non-transit trips.

Table 6.4: Resulting Mode Targets

Purpose	Drive Alone	Shared Ride	Walk	Bike	Transit
HBW Low Inc	86.4%	8.0%	5.1%	0.5%	474
HBW Med Inc	83.3%	9.4%	2.4%	4.9%	739
HBW High Inc	80.2%	8.7%	1.7%	9.5%	160
HBS	43.3%	50.3%	4.7%	1.8%	318
HBU	46.0%	18.7%	23.3%	12.1%	2873
HBO	33.7%	52.5%	10.8%	3.0%	1721
WBO	77.6%	11.9%	8.3%	2.1%	652
OBO	36.8%	52.7%	9.5%	1.0%	917

Note: Non-transit mode targets are shown as a percentage of person-trips not using transit. Transit targets are shown as total numbers of linked trips.

6.2 Mode Choice Model Structure

The NFR Model applies a logit-based mode choice model for all internal trip purposes except for truck trips and LBO trips. The general equation describing a multinomial mode choice is shown in Equation (9).

$$P_i = \frac{e^u}{\sum_m e^{U_m}} \quad (9)$$

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 standard utility equation is shown in Equation (10).

$$u_i = c_1 X_{1i} + c_2 x_{2i} + \; c_3 x_{3i} + \; \ldots + c_n x_{ni} \qquad (10)$$

Where:

u_i = Utility for mode i

$c_1, c_2, c_3, \ldots, c_n$ = Estimated coefficients for variables 1 through n

$x_{1i}, x_{2i}, x_{3i}, \ldots, x_{ni}$ = 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 nest). An example of a lower level mode is walk, while an 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 in Equation (11).

$$LS_i = \ln\left(\sum_{j=1}^{n} e^{u_j}\right) \quad (11)$$

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 a 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. Intermediate nodes are calculated as show in in Equation (12)

$$P_i = \frac{e^{\theta_i \cdot LS_i}}{\sum_{m=1}^{n} e^{\theta_m \cdot LS_m}} \quad (12)$$

Where:

P_i = The probability of selecting intermediate mode i

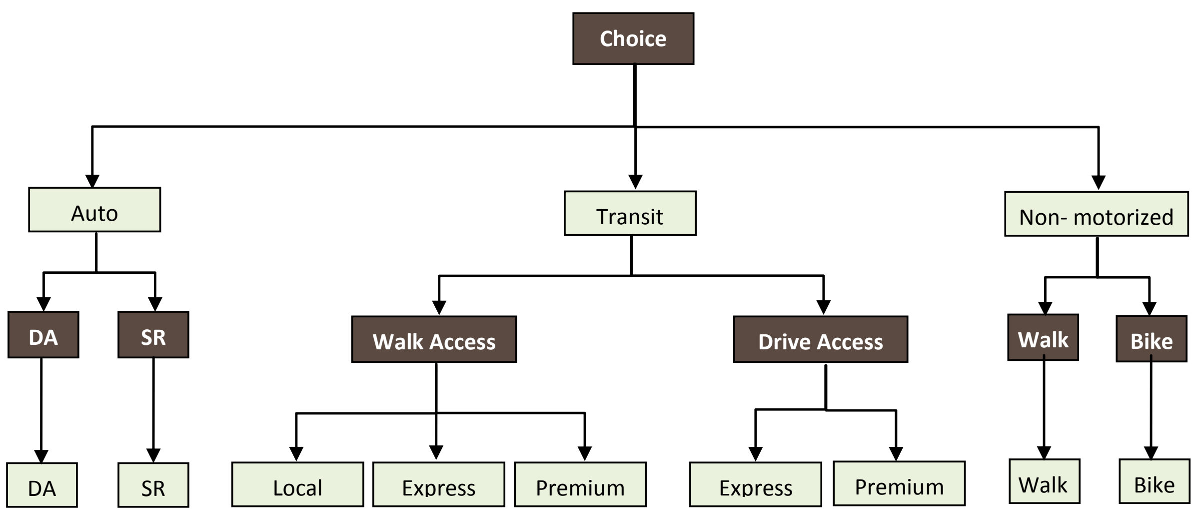
θ_i = The nesting coefficient for intermediate mode i

θ_m = The nesting coefficient for mode m

n = The number of modes at the same level as mode i

The structure for the NFR mode choice models, shown in **Figure 6.1**, assumes modes, sub-modes, and access modes are distinctly different types of alternatives that present distinct choices to travelers. Within each nest, the model operates on the modes included in the nest as a multinomial logit model. Likewise, the model operates on nests included at a specific nesting level as a multinomial logit model. However, the competition between modes included in different nests or nesting levels is not in proportion to initial estimates of the mode shares. As a result, an important departure from multinomial logit models is "lower level" choices are more elastic than they would be in a multinomial logit model.

Figure 6.1: Nested Logit Mode Choice Structure



The nested logit model employs several multinomial logit models. The first is choice among primary modes: auto, transit, and non-motorized. The second model provides a choice between drive alone and shared ride. The third model provides a choice between walk and drive access to transit. The fourth model provides a choice between walk access to local bus, walk access to express bus, or walk access to premium transit (BRT or rail). The fifth model provides a choice between drive access to express or premium transit. It is assumed that drive access to local transit is not frequent enough to be explicitly included in the travel model. 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 through the use of "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 transit. It would be calculated as shown in equation (13a). Likewise, the logsum of the composite drive access to transit mode would be calculated as shown in Equation (13b).

$$LS_{wacc} = -\ln(e^{u_{wl}} + e^{u_{we}} + e^{u_{wp}}) \qquad (13a)$$

$$LS_{dacc} = -\ln(e^{u_{de}} + e^{u_{dp}}) \qquad (13b)$$

The logsum terms for the walk access and drive access modes would then appear in the multinomial choice model for transit access as shown in Equation (14).

$$P_{wacc} = \frac{e^{B_1 \cdot LS_{wacc}}}{e^{B_1 \cdot LS_{wacc}} + e^{B_1 \cdot LS_{dacc}}} \qquad (14)$$

Where:

P_{walk} = 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

In 2010, the MPO conducted an on-board transit survey on all three transit systems in the region. The results from this survey were expanded by trip type, forming the basis for calibration of mode constants. This survey also provided information used in an attempt to re-estimate model coefficients. However, transit service in the region is not currently varied enough to allow estimation of all mode choice coefficients using local data. Therefore, mode choice coefficients from the previous version of the model were retained.

The mode choice model originally developed for the Mason Street Corridor Model and later adopted as part of the NFR Model was transferred from other areas. Several sources originally formed the basis for the donor models. For the 2009 base year model update the in-vehicle travel time coefficients were updated to fall mid-way between the Federal Transit Administration (FTA) minimum and maximum recommended coefficients identified in **Table 6.5**. The out of vehicle travel time coefficient was updated to be double the in-vehicle coefficient. These coefficients were retained in the 2012 model update.

Table 6.5: New Starts Coefficient Guidelines

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

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

Market Segmentation

The updated NFR Model utilizes market segmentation to more accurately model transit ridership. Market segmentation by walk access and egress distance is used to provide a finer level of detail in the walk to transit modes. Market segmentation by income is used to more accurately identify potential transit riders, as the on-board survey indicated members of low income households are more likely to use transit. Segmentation of markets into three walk access categories, three walk egress categories, and three income groups results in 27 different transit markets for the home-based work trip purpose. Additionally, the nine walk access/egress markets 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 1/2-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 parcel 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 parcel level. The model includes a GIS process which separates TAZ data into three access/egress market segments. This has the effect of more appropriately representing concentrated densities often associated with multi-family dwelling units (apartments or condos) or transit oriented development. For example, a large zone consisting of mainly low density housing with a transit oriented development on one end would be accurately represented by the walk access/egress market segmentation model due to use of parcel level data.

In preparation for addition of the mode choice model to the NFR Model, TAZ splits were made along existing and potential future transit corridors. In general, TAZs were modified so a single

TAZ did not extend for more than ½ mile beyond a transit corridor. This results in a maximum average walk distance of ¼ mile in most cases. To further increase model precision, walk access segments were defined at ¼ mile from transit (average walk distance of 1/8 mile), ¾ mile from transit (average walk distance of 3/8 mile), and greater than ¾ mile from transit. The nine possible combinations of walk access and egress markets are shown in **Table 6.6**.

Table 6.6: 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**

FTA guidelines suggest using an implied value of time between 1/4 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 1/4 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 6.7**.

Table 6.7: Income Market Segmentation

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

Note: The long term values of time utilized in mode choice are set separately from short-term values of time documented for roadway pathbuilding and traffic assignment.

Production and Attraction Density Variables

In an effort 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 in Equation (15). Test runs performed during model validation confirmed these density variables have a beneficial effect on transit mode choice validation.

$$Density_i = \frac{HH_i + EMP_i \cdot \frac{\sum_{Zones} HH_i}{\sum_{Zones} EMP_i}}{Area_i} \qquad (15)$$

Where:

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

Model Specification

The utility equations for the mode choice model follow. The coefficient designations (e.g., C_{ivtt} for Coefficient of in-vehicle travel time) rather than the actual model coefficients are shown to aid in the understanding of the model specification. The actual model coefficients are shown in **Table 6.8**. Model constants (K_m) calibrated to reproduce observed mode shares in the North Front Range are shown in **Table 6.9**. Express and premium transit mode constants have been set equal to local transit constants because these modes did not exist in the NFR region in the 2012 model validation year. The drive access constants have been adjusted based on experience in other regions. The initial constant is equivalent to a penalty of five minutes of IVTT, but can be further adjusted once better information about drive access to recently opened formal park-n-ride facilities is available.

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 Utility:

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

*Note: the cost term is divided by [average auto occupancy * 0.5] for the HBW trip purpose.*

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

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

Drive to Transit Utilities (PDE, PDP):

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

Walk Utility:

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

Bike Utility:

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

Where*:*

$IVTT_{transit}$	=Transit in-vehicle travel time
$IVTT_{drive}$	= Drive in-vehicle travel time
TTIME	= Terminal time in minutes
CPM	= Auto operating cost per mile in cents

Dist	= Distance traveled in miles
Park8	= Daily (8-hour) parking cost in cents
Form	= Carpool formation time
CBD_{mode}	= CBD Attraction dummy variable for the specified mode (1 if attraction TAZ has is in the CBD, 0 otherwise)
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
TT_{bike}	= Bike time
C_x	= Coefficient for variable "x"
K_{mode}	$=Constant\ for\ specified\ mode$

Table 6.8: Mode Choice Model Coefficients

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

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

Table 6.9: Mode Choice Model Constants

Mode	HBW Low Income	HBW Medium Income	HBW High Income	HBS	HBU	HBO	WBO	OBO
Drive Alone	0	0	0	0	0	0	0	0
Shared Ride	-2.4475	-1.7434	-1.6832	-1.5231	0.1055	0.3107	-1.3104	0.2515
Walk to Local Transit	-4.5398	-6.22	-8.005	-6.2464	-6.6983	-6.1642	-7.4177	-6.9405
Walk to Express/ Premium Transit	-4.5398	-6.22	-8.005	-6.2464	-6.6983	-6.1642	-7.4177	-6.9405
Drive to Express/ Premium Transit	-4.6648	-6.345	-8.13	-6.3714	-6.8233	-6.2892	-7.5427	-7.0655
Walk	-2.7147	-0.5459	0.5376	0.1754	-1.6265	-0.6364	-1.656	-1.6836
Bike	-0.6173	-0.6093	-0.1909	1.074	-0.6091	0.6424	-0.3446	0.2249

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. For shared ride trips, it is necessary to use an average auto occupancy rate to identify the number of vehicle trips. The average auto occupancy values are shown in **Table 6.10**.

Table 6.10: Average Auto Occupancy for Home-Based Trips

Purpose	Average SR Auto Occupancy
HBW	2.22
HBS	2.57
HBU	2.57
HBO	2.56
WBO	2.44
OBO	2.85

6.3 Mode Choice Model Calibration Results

Alternative specific constants have been calibrated so the regional total number of trips by mode are consistent with mode share targets presented in **Table 6.4**. As shown in **Table 6.11**, all resulting mode shares are within 2 percent of observed values.

Table 6.11: Percent Difference between targets and model results

	Targets				
	Walk	Bike	Drive Alone	Shared Ride	Transit
HBW Low Inc	0.0%	0.0%	0.0%	0.0%	-0.6%
HBW Med Inc	0.0%	0.0%	0.0%	0.0%	-0.6%
HBW High Inc	0.0%	0.0%	0.0%	0.0%	-1.1%
HBS	0.0%	0.0%	0.0%	0.0%	-0.6%
HBU	0.0%	0.0%	0.0%	0.0%	-0.6%
HBO	0.0%	0.0%	0.0%	0.0%	-0.6%
WBO	0.0%	0.0%	0.0%	0.0%	-0.6%
OBO	0.0%	0.0%	0.0%	0.0%	-0.6%

6.4 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 2012 base year, the FLEX route connecting Fort Collins, Loveland, and Longmont is included as an external transit connector. In the forecast year, transit service connecting the North Front Range to Denver via the I-25 corridor is included.

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 the areas 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 input database. 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.

7.0 TRIP ASSIGNMENT

Trip assignment is the final phase of the traditional 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, as well as identification of specific path 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. Because the travel model represents a typical school day, traffic volumes are representative of a typical weekday when school is in session.

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.

7.1 Time of Day

Based on the analysis of the household travel survey, the NFR Model includes a two-hour AM peak period, a one-hour mid-day peak , and a four-hour PM peak period as defined in **Table 7.1**. 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.

To define time of day for each trip in the household survey, reported trips were multiplied by zone to zone distance to produce an observed distribution of VMT for each half-hour period, with the resulting VMT distribution shown in **Figure 7.1**. The travel model assigns all off-peak trips in a single off-peak period. However, some model users may desire to separate off-peak model results into different times of day. This is particularly important in modeling ozone pollutants, as varying temperatures throughout the day impact ozone generation. **Table 7.2** provides further detail about off-peak VMT by time of day for use in such applications.

Table 7.1: Travel Model Periods and Sub-Periods

Period Name	Time Period	Description
MD	**12:30 PM – 1:30 PM**	**Mid-Day Peak**
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 Shoulder
PM	**2:30 PM – 6:30 PM**	**PM Peak Period**
PM1	4:30 PM – 5:30 PM	PM Peak Hour
PM2	3:30 PM – 4:30 PM	PM Shoulder
PM3	2:30 PM – 3:30 PM	PM Shoulder
PM4	5:30 PM – 6:30 PM	PM Shoulder
OP	**All other time periods**	**Off-Peak**

Note: For trip distribution and mode choice, AM and PM periods are included in the peak period and mid-day and off-peak are included in the off-peak period.

Figure 7.1: VMT by Time of Day from the Household Travel Survey

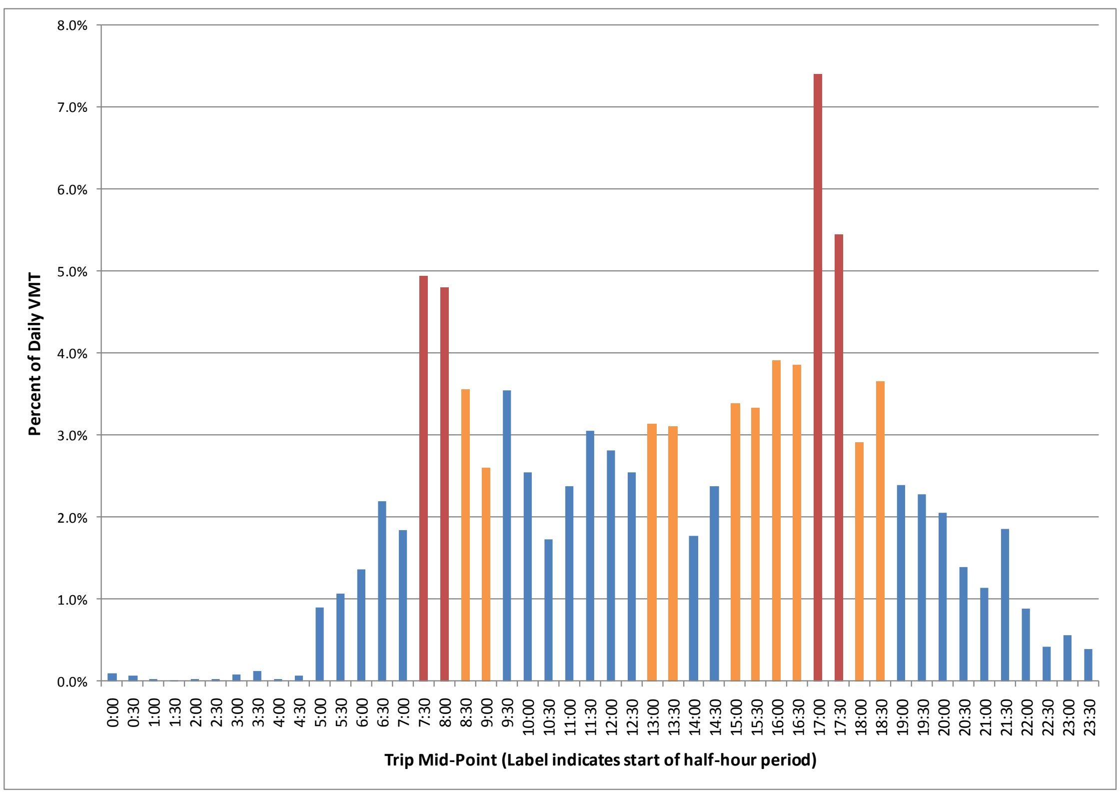


Table 7.2: Off-Peak VMT Distribution by Time of Day

Time Period	Description	Off-Peak VMT Percentage
12:00 AM – 7:00 AM	Early Morning Off-Peak	18%
9:00 AM – 12:30 PM	Mid-Morning Off-Peak	42%
1:30 PM – 2:30 PM	Mid-Afternoon Off-Peak	9%
6:30 PM – 12:00 AM	Night Off-Peak	30%

The NFR Model uses directional time of day factors to convert trips from PA format to OD format and into peak and off-peak time periods used in the model. This process is based on data from the household travel survey indicating t 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 *Trip Distribution* chapter, daily trip tables are separated into peak period (combined AM and PM peak periods) 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 7.3** identify the portion of trips by purpose and direction assigned to each time period. These detailed factors were created using the NFR MPO Household Travel Survey. The factors in **Table 7.3** 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 the *Trip Distribution* chapter and are repeated in **Table 7.4** for reference. The pre-assignment time of day parameters are shown in **Table 7.5**.

Pre-distribution time-of-day factors (**Table 7.4**) are computed from the 24-hour time of day factors shown in

Table 7.3. For the off-peak period, the distribution time of day factor is computed as the sum of the PA and AP factors for the MD and OP periods. For the peak period, the distribution time of day factor is the sum of PA and AP factors for the AM and PM periods. The pre-distribution time

of day factors shown in **Table 7.4** are applied by multiplying the factors by the vehicle trip tables from mode choice for each trip purpose.

Table 7.3: 24-Hour Time of Day Factors

Period	HBW		HBS		HBU		HBO		WBO		OBO	
	PA	AP	PA	AP	PA	AP	PA	AP	PA	AP	PA	AP
Off-Peak	0.248	0.176	0.196	0.279	0.244	0.255	0.188	0.214	0.249	0.143	0.228	0.228
Mid-Day	0.033	0.016	0.044	0.050	0.043	0.031	0.019	0.021	0.032	0.045	0.038	0.038
AM Peak	0.202	0.009	0.033	0.016	0.093	0.016	0.185	0.033	0.041	0.100	0.047	0.047
PM Peak	0.049	0.266	0.157	0.224	0.120	0.198	0.116	0.225	0.341	0.048	0.187	0.187

Table 7.4: Pre-Distribution Time of Day Factors

	HBW	HBS	HBU	HBO	WBO	OBO
Off-Peak	0.47	0.57	0.57	0.44	0.47	0.53
Peak	0.53	0.43	0.43	0.56	0.53	0.47

Table 7.5: Pre-Assignment PA to OD Time of Day Factors

Period	HBW		HBS		HBU		HBO		WBO		OBO		EE
	PA	AP	PA	AP	PA	AP	PA	AP	PA	AP	PA	AP	
Off-Peak	0.525	0.373	0.344	0.49	0.426	0.446	0.426	0.485	0.531	0.304	0.429	0.429	0.48
Mid-Day	0.069	0.033	0.078	0.088	0.075	0.054	0.043	0.047	0.069	0.096	0.071	0.071	0.05
AM Peak	0.383	0.018	0.076	0.037	0.218	0.036	0.331	0.059	0.078	0.189	0.101	0.101	0.14
PM Peak	0.094	0.505	0.365	0.522	0.282	0.464	0.208	0.402	0.643	0.09	0.399	0.399	0.33

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 Equation (16), which multiplies the "PA" factors by the person trip table the "AP" by the transposed person trip table. This converts trip tables from production/attraction format to origin/destination format, while also retaining directional peaking characteristics. Because EE trips are not processed through trip distribution or mode choice, EE time of day is applied prior to trip distribution. EE time of day is computed by simply multiplying time of day factors by the 24-hour EE trip tables.

$$T_{OD,subper} = \left(\frac{1}{2} \cdot T_{PA,per} \cdot F_{PA}\right) + \left(\frac{1}{2} \cdot T'_{PA,per} \cdot F_{AP}\right) \quad (16)$$

Where:

$T_{OD,subper}$ = OD trip-table for the AM or PM hour (or for the off-peak period)
$T_{PA,per}$ = PA trip-table for the peak or off-peak period
$T'_{PA,per}$ = Transposed PA trip-table for the peak or off-peak period
F_{PA} = Pre-assignment time of day factor for the PA direction
F_{AP} = Pre-assignment time of day factor for the AP 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 must be further broken down into peak hour and shoulder periods. This is accomplished using the peak period to peak hour loading factors shown in **Table 7.6.** No conversion is necessary for the mid-day period, as this period consists of a single hour. For the off-peak period, all trips are assigned simultaneously using off-peak capacities.

Table 7.6: Peak hour and shoulder hour loading factors

Period Name	Time Period	Loading Factor
AM1	7:00 AM – 8:00 AM	0.612
AM2	8:00 AM – 9:00 AM	0.388
PM1	4:30 PM – 5:30 PM	0.379
PM2	3:30 PM – 4:30 PM	0.229
PM3	2:30 PM – 3:30 PM	0.198
PM4	5:30 PM – 6:30 PM	0.194

7.2 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 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.

TransCAD has traditionally used the Frank-Wolfe user equilibrium traffic assignment algorithm. In TransCAD 6.0, the a modified algorithm referred to as bi-conjugate Frank-Wolfe has been made available. This assignment methodology converges more quickly than the traditional Frank-Wolfe method, but produces consistent results.

Volume-Delay Functions

A volume-delay function represents the effect of increasing traffic volume on link travel time in the assignment process. While several volume delay functions are available for consideration, the most commonly used function is the modified Bureau of Public Roads (BPR) function. The modified BPR function is based on the original BPR equation shown in Equation (17).

$$T_C = T_F\left(1 + \alpha\left(\frac{V}{C}\right)^{\beta}\right) \tag{17}$$

Where:

T_C	= Congested impedance
T_F	= Freeflow travel time
V	= Traffic volume
C	= Highway design (practical) capacity
α	= Coefficient alpha (0.15)
β	= Exponent beta (4.0)

The modified BPR equation uses the same form, but replaces design capacity (i.e., upper limit LOS C capacity) with ultimate roadway capacity (i.e., upper limit LOS E capacity). Ultimate roadway capacities for links in the NFR Model roadway network are defined in the *Roadway Network* chapter. The modified BPR function also replaces the coefficient alpha and the exponent beta with calibrated values which vary by facility type and area type. Alpha and beta for centroid connectors were selected to ensure congestion is not represented on centroid connectors. Alpha and beta values were modified slightly from the previous model during validation, resulting in the values shown in **Table 7.7**.

Table 7.7: Volume Delay Parameters Alpha and Beta

		Rural (1)		Suburban (2)		Urban (3)		CBD (4/5)	
Facility Type		Alpha (α)	Beta(β)	Alpha (α)	Beta(β)	Alpha (α)	Beta(β)	Alpha (α)	Beta(β)
1	Freeway	0.75	7	0.9	6	0.9	6	0.9	6
2	Expressway	0.9	3	0.9	3	0.9	3	0.9	3
3	Principal Arterial	0.9	3	0.9	3	0.9	3	0.9	3
4	Minor Arterial	0.9	3	0.9	3	0.9	3	0.9	3
5	Collector	0.6	2	0.6	2	0.6	2	0.6	2
6	Ramp	0.55	5	0.55	5	0.55	5	0.55	5
7	Frontage Road	0.45	2	0.45	2	0.45	2	0.45	2
8	Centroid Connector	0.15	7	0.15	7	0.15	7	0.15	7

Notes: Parameters are provided for all FT/AT combinations, even though some do not exist (e.g., CBD Freeway).CBD parameters are the same for the Fort Collins CBD and other CBD area types.

7.1 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 shown in Equation (17) with generalized cost values specified in equation (18).

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

Where:

GC = Generalized Cost

t = travel time

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.

7.2 Multi-Class Assignment

The NFR Model considers four different types of vehicles in the traffic assignment step: single occupant vehicles, high occupant vehicles (2+ occupants), small trucks, and large trucks. Large 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.

In the unconstrained large truck assignment, all large trucks are assigned to the roadway network based on freeflow speed. Large trucks are prohibited from using any links with a truck prohibition flag, and/or from using HOV or HOT lanes designated by a USE code of 1 or 2. In addition, travel time is increased on collectors by a factor of 5 to minimize use of collector streets by large trucks. If desired, large 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 three 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 7.8**. 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 are charged a toll on HOT lanes.

- High Occupant Vehicles: HOVs are allowed to use any roadway link in the network, and are only charged tolls on tolled general purpose lanes. Tolls coded on HOT lanes (USE = 2) are not applicable to HOVs.

- Small Trucks: Small trucks are excluded from HOV lanes, HOT lanes, and any link with a truck prohibition (TRUCK_PROHIB = 1). Value of time for small trucks is slightly higher than the value of time applied for passenger vehicles.

Table 7.8: 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)
Small Truck	$22.20 ($0.37 / min)	$22.20 ($0.37 / min)
Large Truck	$48.00 ($0.80 / min)	$48.00 ($0.80 / min)

Note: Values are input to the model in units of $/minute.

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

7.3 Speed Feedback

The gravity model used in the trip distribution process relies on congested zone to zone travel time information to distribute trips. 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 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 re-run 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. However, the speed feedback process only results in *longer* trips, not more trips.

Methodology

There are various approaches to solving the speed feedback problem. 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 Method of Successive Averages

The Method of Successive Averages uses a simple average of all flows resulting from previous assignment runs. Flows can be computed as in Equation (19), or simplified to Equation (19a).

$$\boldsymbol{MSAFlow_n = \left(MSAFlow_{n-1} - \frac{MSAFlow_{n-1}}{n}\right) + \frac{Flow_n}{n}} \quad (19)$$

$$MSAFlow_n = MSAFlow_{n-1} + \frac{1}{n}(Flow_n - MSAFlow_{n-1}) \quad (19a)$$

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.

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 different 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 runs. 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.

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, 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 Equation (20), 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 speed feedback convergence criterion is set at 0.01% RMSE and the iteration limit is set to 10.

$$\%RMSE = \frac{\dfrac{\sqrt{\sum_{jk}\left(t_{jk(i)} - t_{jk(i-1)}\right)^2}}{n-1}}{\dfrac{\sum_{jk} t_{jk(i)}}{n}} \qquad (20)$$

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

Application of Speed Feedback for Alternatives Analysis

Speed feedback ensures travel time consistency within the entire modeling structure. It was conceived as a model enhancement in the early 1990's largely in response to environmental lawsuits, although it is good practice and now considered a necessity. Generally, speed feedback is most sensitive to network changes that provide a significant travel time improvement, such as a new freeway into a relatively undeveloped area. 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 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.*

7.4 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.

Transit Assignment Validation

Transit assignment has been validated to observed route boardings by operator. As shown in **Table 7.9**, the overall number of boardings is within 1 percent of observed values. For Transfort the total number of system boardings is within 2 percent of observed boardings. The Greeley and Loveland systems have higher error on a percentage basis, but total boardings for each system is within 200 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 7.9: Transit Assignment Validation Results

	Observed	Modeled	Difference	% Difference
Transfort	9,235	9,355	120	1.3%
City of Loveland Transit (COLT)	479	526	47	9.8%
Greeley Evans Transit (GET)	1,119	931	-188	-16.8%
Regional Total	10,833	10,812	-21	-0.2%

7.5 Traffic Assignment Validation

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, screenline comparisons, and inspection of individual link values.

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 level, as shown in **Table 7.10**. In addition, regional daily VMT and VHT are shown in **Table 7.11**.

Table 7.10: Regional Activity Validation

Link Type	Number of Counts	Model Volume / Count Volume	Model VMT / Count VMT	Target
Freeway	46	92.5%	96.2%	+/- 10%
Expressway	63	96.7%	97.6%	+/- 10%
Principal Arterial	276	103.4%	101.9%	+/- 10%
Minor Arterial	348	105.2%	107.0%	+/- 15%
Collector	393	113.7%	113.2%	+/- 25%
Rural	323	99.8%	99.0%	n/a
Suburban	325	102.9%	101.7%	n/a
Urban	380	103.4%	102.1%	n/a
CBD	102	99.0%	97.1%	n/a
Total	**1,130**	**102.4%**	**100.4%**	**+/- 5%**

Note: Activity level targets are based on industry standard practice guidelines, not a rule or regulation. The targets apply to the model volume to count volume ratio.

Table 7.11: VMT and VHT Totals

Link Type	VMT	VHT
Freeway	3,021,006	48,569
Expressway	1,948,680	45,007
Principal Arterial	2,966,234	90,425
Minor Arterial	2,365,771	69,988
Collector	1,233,465	37,618
Frontage Road	63,899	2,590
Centroid Connector	133,786	2,796
Rural	5,723,086	117,764
Suburban	4,014,505	112,424
Urban	3,169,194	106,907
CBD	248,433	10,402
Total	**13,155,218**	**347,497**

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 on individual links. 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 7.2** demonstrates the ability of the NFR Model to match individual traffic count data points and notes the resulting R-squared value. **Table 7.12** lists % RMSE values and target values for each facility type. General guidelines suggest that % RMSE should be near 40 percent region-wide, with values below 30 percent for high volume facility types such as freeways. The % RMSE measure tends to over-represent errors on low volume facilities, so values on collectors are not particularly meaningful. **Table 7.13** shows % RMSE values by volume group.

Figure 7.2: Model Count/Volume Comparison

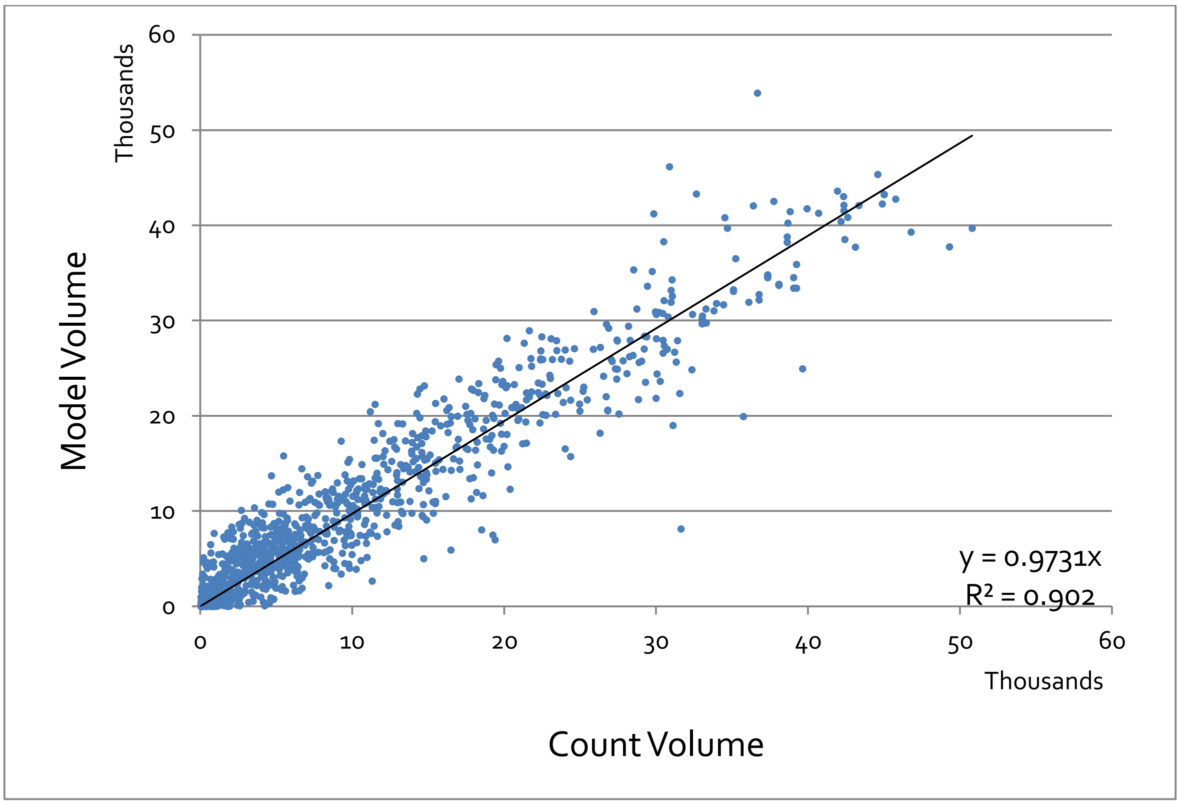


Table 7.12: Model % Root Mean Square Error

Link Type	Number of Counts	RMSE	% RMSE
Freeway	46	3,174	11%
Expressway	63	5,917	24%
Principal Arterial	276	3,884	21%
Minor Arterial	348	3,310	44%
Collector	393	1,941	93%
CBD	323	2,086	33%
Urban	325	3,729	39%
Suburban	380	3,471	24%
Rural	102	3,958	45%
Total	**1,130**	**3,266**	**32%**

Table 7.13: % Root Mean Square Error by Volume Group

Range	Number of Counts	RMSE	% RMSE
0 - 9,999	718	2,432	68%
10,000 - 19,999	220	3,786	26%
20,000 - 29,999	101	3,904	16%
30,000 and up	91	5,917	16%

The regional validation shows the model is appropriate for use in regional and subregional planning, as well as for use in air quality conformity analysis. For specific corridor studies or detailed subarea studies, review of localized traffic assignment validation is recommended. As is typical with regional models, traffic volumes on higher volume facilities are more reliable than traffic volumes on low volume facilities, such as collector streets and arterial streets. **Tables 7.12 and 7.13** demonstrate the NFR Model is reasonably able to represent 2012 traffic volumes.