May 2020

Dixie Travel Demand Model

Calibration & Validation Report

Unified Transportation Planning

DIXIE

METROPOLITAN

PLANNING ORGANIZATION

Table of Contents

List of Exhibits

1.0 INTRODUCTION

This documentation provides a technical description of the procedures and parameters used by the Dixie Metropolitan Planning Organization travel demand model to predict travel demand and transportation system performance. This document includes several parts:

- Part 1 – gives an introduction to the purpose and scope of the Dixie travel demand model and a brief history of the Dixie travel models (Section 1)
- Part 2 –summarizes the recommendations from a peer review of the Dixie travel demand model (Section 2)
- Part 3 – A user's guide to understanding the model structure and how to setup and initiate a model run in Cube (Section 3)
- Part 4 – describes the model and its inputs, processes, data sources and validation (sections 4 through 10)

1.1 Dixie Travel Demand Model Scope & Purpose

In support of the transportation planning activities in the region, the Dixie MPO maintains the travel demand model for the areas covered by the Dixie MPO and the balance of Washington County. The Dixie travel demand model is designed primarily for use in transportation planning at a regional scale, such as in the development of the long-range transportation plan or for regional air quality emissions analyses. Though the Dixie travel demand model's primary use is for regional planning, it is also available for use in more detailed analytical work, such as corridor-level environmental documents. As with other regional travel demand models, because the model is designed and calibrated for regional planning activities, forecasts produced at a more localized level may require more localized validation at this scale. It is the responsibility of the user to verify the reasonableness of the travel demand model for their intended application of the model.

The Dixie travel demand model was also built to be used more directly with the Utah Statewide Travel Model (USTM), which is maintained and developed by UDOT. USTM uses data from MPO travel models across the state as a direct input to the statewide model. The current version of the Dixie model uses a platform and data structure that allows for this data integration into USTM.

1.2 History of the Dixie Travel Demand Model

The first version of the Dixie travel demand model was developed in 1994 and was built by UDOT for the City of St. George. The model was built using QRS software. This model included just the city of St. George. In 1995 the City of St. George expanded the model and used it for city transportation plans and UDOT projects.

In 2002, the City of St. George commissioned a consultant to perform a model year 2000 calibration based on the release of the 2000 Census. The Dixie MPO was also formed in this year and became the keepers of the Dixie QRS model. In 2005, the model was again updated to include the Hurricane area and many of the smaller cities in Washington County. In 2007, the MPO commissioned a consultant to validate the 2005 expanded model.

In August 2008, the Dixie travel demand model underwent a peer review as part of FHWA's Travel Model Improvement Program (TMIP). The peer review panel offered that the MPO should consider adopting a software platform for the Dixie travel demand model similar to that used by other travel models in the state. Pursuant to this, in the summer of 2010 RSG was hired to develop the Dixie travel demand model in Citilabs' CUBE software. This first generation CUBE model was a major shift in the way travel forecasting was performed at the MPO. The first version of the Dixie Cube travel model was used in developing the MPO's 2011 Regional Transportation Plan and on UDOT's Bluff Street and I-15 Washington County Environmental Assessment studies.

In the summer of 2013, the Dixie MPO again commissioned RSG to update the travel demand model to incorporate the results of the 2012 Household Travel Survey and the 2010 Census, to make the model current with the updates being made to the other travel demand models in Utah, and to bring the model up to date with the evolving state of the practice. Improvements were also made to the user interface to make the model easier to use. In addition, the Dixie MPO commissioned Horrocks Engineers to refresh the socioeconomic forecasts based on the Kem C. Gardner Policy Institute (GPI) at the University of Utah forecasts and to update other travel model inputs needed for the current model development. The most recent county-level socioeconomic projections were released in July of 2017 and form the base assumptions for all socioeconomic planning statewide.

2.0 TMIP PEER REVIEW RECOMMENDATIONS

In August 2008 the Dixie travel demand model was reviewed by a panel of experts from around the country to provide guidance and recommendations to the Dixie MPO regarding best modeling practices and suggestions on possible model improvements to the Dixie travel model. The peer review was part of the FHWA Travel Model Improvement Program (TMIP) and was hosted by UDOT.

The TMIP panel commented on each of the main steps in the Dixie model:

- Input data
- Trip generation
- Trip distribution
- Assignment.
- Modeling process (in general)

The peer review panel recommendations are summarized below. Many of these items were addressed with version 1 of the Dixie travel demand model or with this update of the model.

Input Data

- Revise and update the TAZ structure consistent with Census geography (completed in version 1)
- Revise and update the roadway network to accurately and reliably represent speeds and capacities (completed in version 1)

- Develop and outline a data collection program, and make the best use of available data (ongoing)
- In the long-term, initiate a home interview survey when adequate resources are available (completed in version 2)

Trip Generation

- Use households instead of dwelling units in the trip production models (completed in version 1)
- Incorporate other employment sources in the attraction models with careful validation of the resulting number of attractions (improve production and attraction balance) (completed in version 1)
- Reduce the number of special generators (completed in version 1)
- Consider adding additional trip purposes such as school/university trips (completed in versions 1 and 2)

Distribution

- Recalibrate friction factors as needed to match observed survey data such as the CTPP (work trips) and NHTS (for the State of Utah) (completed in version 1, then recalibrated in version 2 to the 2012 Household Travel Survey)

Assignment

- Utilize an equilibrium assignment procedure (completed in version 1)
- Avoid the reliance on unreasonable speed and capacity adjustments to “calibrate” the traffic assignment model – seek to identify and improve the underlying cause of significant assignment errors (which may be outside of the assignment step) (completed in version 1)

Other Model Improvements

- Ideally the MPO would have a dedicated staff person who understands modeling who can at a minimum thoughtfully direct consultant resources and review their work (ongoing)
- Consider ensuring consultant delivery of the following for all future model development and applications:
  - Model users’ manual (completed with version 1 as part of the calibration report)
  - Model calibration report (completed with versions 1 and 2)
  - Model estimation data set (essentially completed with version 2 and the use of the 2012 Household Travel Survey)
  - Control mechanism for usage (on going)
- Plan for periodic model updates (e. g. every three to five years) and identify and incorporate local issues of significance (ongoing)

- Consider ways to leverage the Utah Statewide Model (e. g. truck flows, and/or external flows) (partially completed with version 2)
- Consider adopting a software platform that is consistent with the rest of the State (i. e. CUBE) (completed in version 1)

3.0 MODEL USER'S GUIDE & DESIGN AND STRUCTURE

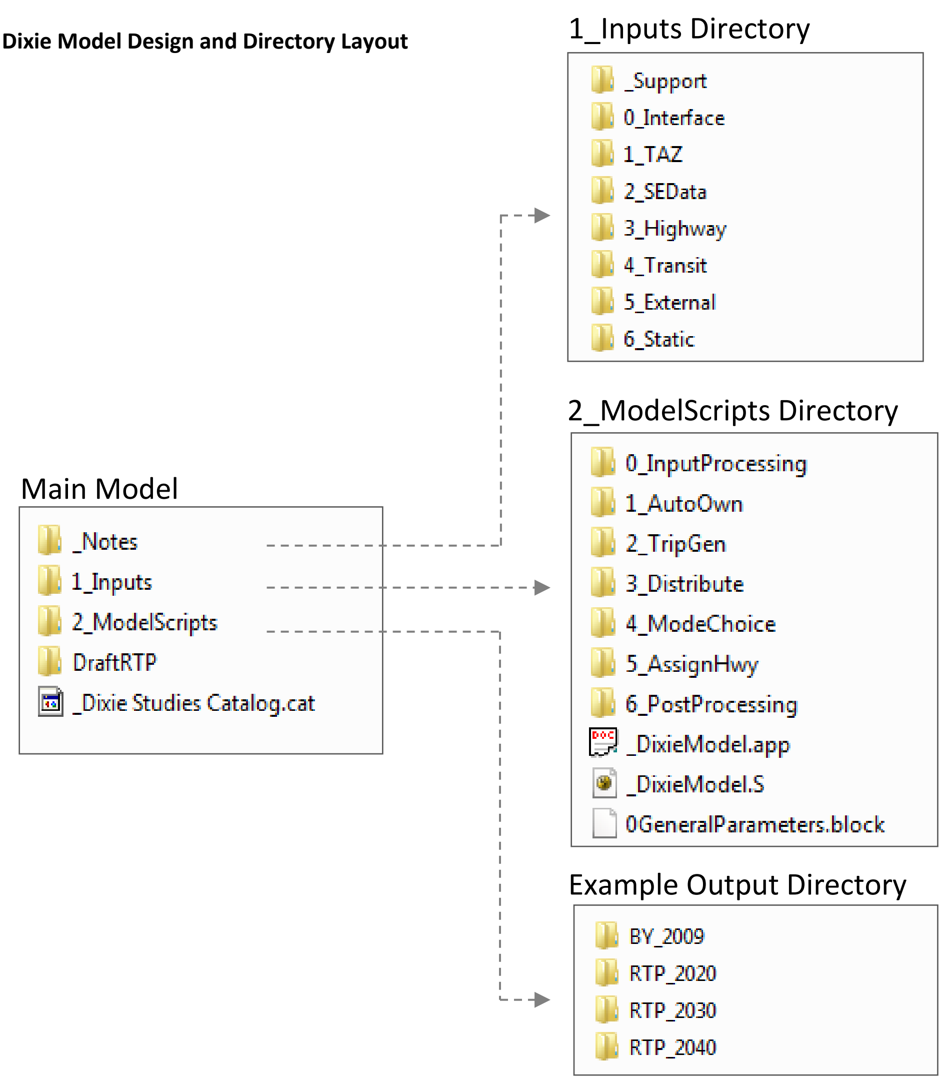
3.1 Software Platform & Model Design

The Dixie model uses Citilabs' CUBE Base and Voyager software to run its algorithms, perform data processing, and to allow the user to interact with the data. The Citilabs software platform is the most common travel model software platform currently being used in Utah. The Dixie travel demand model design is organized in a manner that parallels the key components of the model:

1. '1_Inputs' directory
2. '2_ModelScripts' directory
3. A scenario output directory

Each of these directories contains subdirectories laid out in an orderly manner to make access to the data and processes simple and logical.

Exhibit 1. Dixie Model Design and Directory Layout



3.1.1 1_Inputs Directory

The '1_Inputs' directory contains the collection of input data needed to run the model. Data for all scenarios are kept together in one of the subdirectories. A particular model run then points to the set of input data that will be used to define that particular scenario. For instance, all socioeconomic variations that the user may wish to choose from when defining a scenario are kept in the socioeconomic subdirectory and the modeler will select the one needed to run in a particular scenario. Selection between various input files is made using special pointers, called catalog keys, in CUBE's scenario manager.

3.1.2 2_ModelScripts Directory

The '2_ModelScripts' directory contains all the scripts, applications and instructions that make up the core of the model. These files tell the software how to process the data and how to visualize the model in CUBE Base. The scripts and applications are organized into subdirectories that follow in order the steps or flow of the model, starting with input processing and progressing to highway assignment. The '6_PostProcessing' directory is a collection of post processing scripts a user may use on occasion, but it is not part of the regular model stream.

One special file, '0GeneralParameters. block', is included in the root scripts directory. This file contains the many of the models global parameters. Great care should be taken when modifying these global parameters. It is recommended that changes to any of the parameters in this file be clearly documented. It is also recommended that since global parameters affect all scenarios in a model set, a separate complete model set be created any time these parameters are changed.

3.1.3 Output Directory

The output directory contains the results of all the scenarios in a particular set of model runs. The name of the output directory and all scenario subdirectories are set in the 'Dixie Catalog. cat' file (the catalog file is described in more detail in the following section) located in the root directory. As a scenario is defined in the catalog file, the model will automatically create the scenario output subdirectory in the output directory. The scenario directory will be blank until the model is run for the first time, at which point the model creates subdirectories representing each of the major steps in the model to hold the output for that scenario. Subsequent runs of the same scenario will not recreate the scenario subdirectory structure; rather it will simply overwrite the outputs inside the folders.

3.1.4 Notes Directory

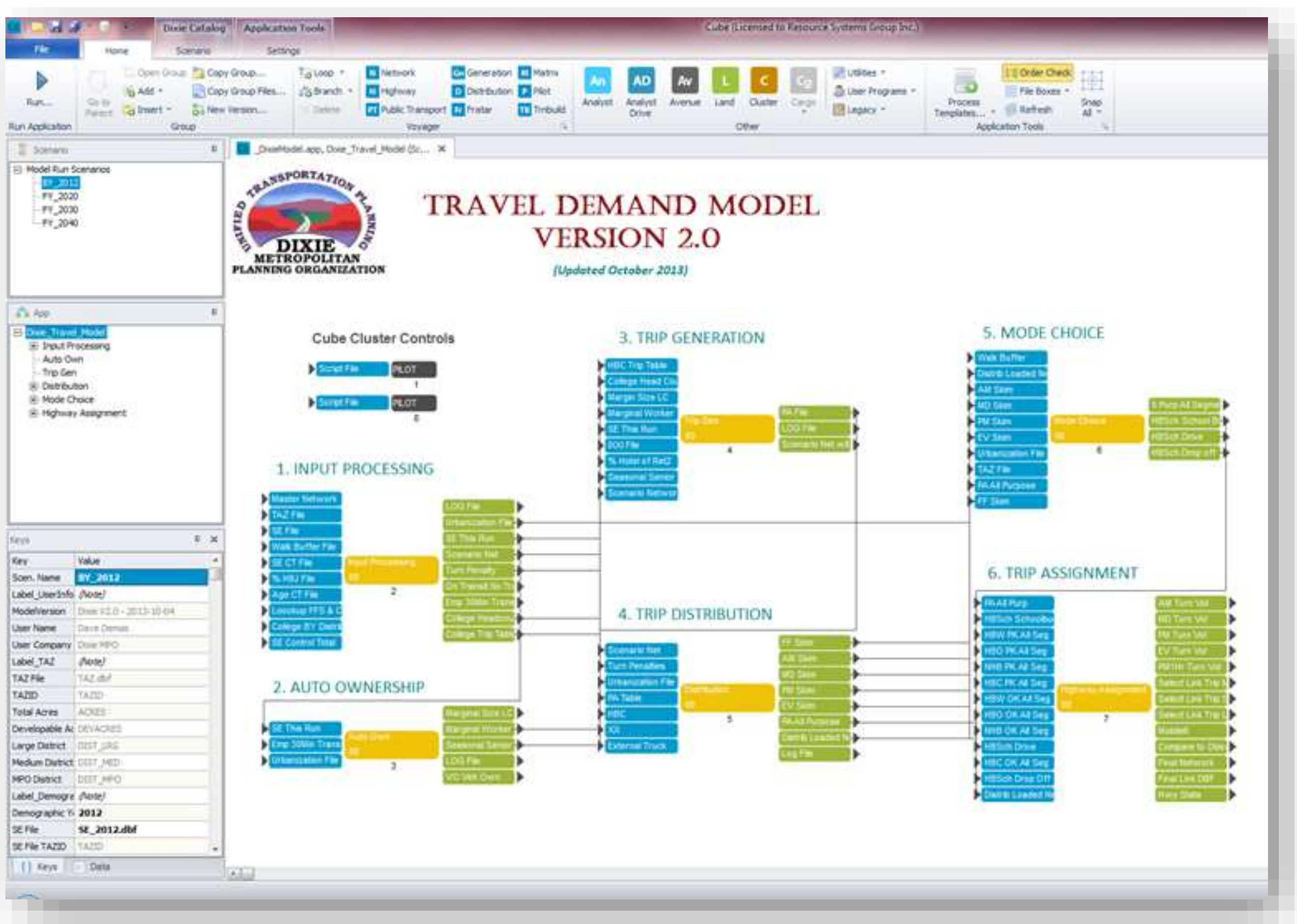
The root model directory also contains a '_Notes' directory. This folder is intended to be the place to store information relevant to the scenarios that make up the collection of model runs. Documentation on model approach, modified parameters, or post processing adjustments are examples of files that could be kept in this location for easy access and retrieval.

3.2 Model Interface and Running the Dixie Travel Model

The Dixie model uses CUBE's scenario and application managers as defined in the 'Dixie Catalog. cat' catalog file as the primary way in which the user interacts with the model. The catalog file contains a listing of the scenarios and the parameters used to define specific scenarios as well as the outline or flow chart of how the model is put together.

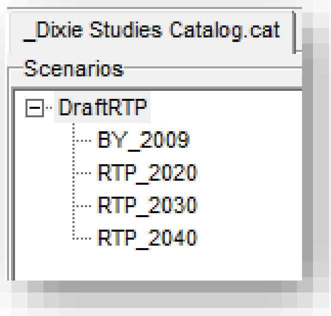
Opening the catalog displays the model's main window in Cube. The modeler sees in the largest pane on the right the Dixie travel demand model laid out in a flow chart. The dark blue and yellow boxes indicate steps in the model which are often groups of other individual steps. These steps can be accessed by double clicking on the yellow box to drill down into the group. To the left of the boxes are the inputs to that particular modeling step; to the right are the outputs. Text has also been added to help guide the modeler on the purpose of each step or subgroup step in the model. Double-clicking on the input, output or script files opens these files in CUBE. Double-clicking on the yellow box brings up the subgroup flow chart. Double-clicking on the dark blue box runs that particular program or step of the model.

Exhibit 2. Dixie Model Interface – Main Catalog Window



The catalog contains in the top-left pane CUBE's scenario manager (see Exhibit 3). The scenario manager contains the collection of scenarios for this set of model runs. Each scenario uses a unique set of attributes that define the scenario stored in CUBE's 'catalog keys'. Scenarios are created by right clicking on the parent directory in the scenario manager pane and selecting 'Add Child'. A new folder is created under the parent directory. The modeler then types the name of the new scenario.

Exhibit 3. Scenario Manager Pane



Scenarios are defined by double clicking on a scenario folder to access the catalog keys. There are about four pages of catalog keys for the modeler to define (the actual number of pages displayed will depend on the monitors screen resolution). These pages are shown in the following exhibits.

Exhibit 4. Scenario Catalog Keys – Page 1

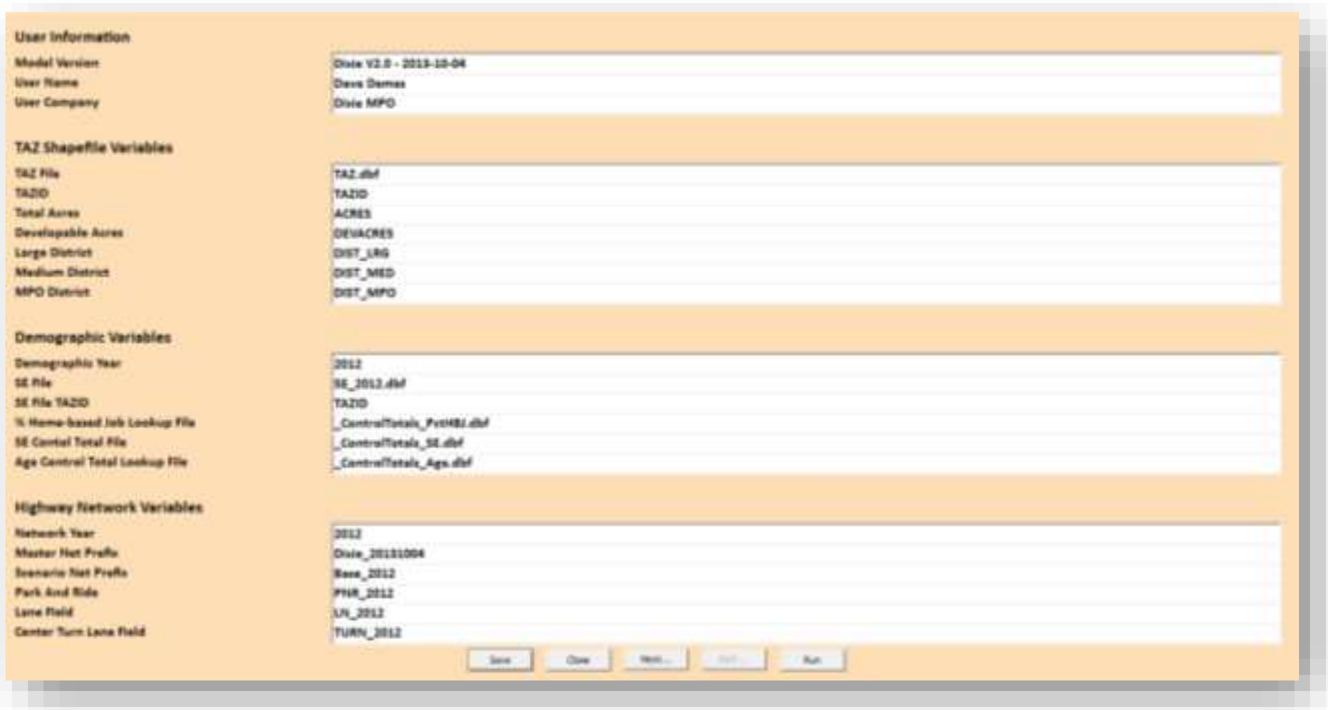


Exhibit 5. Scenario Catalog Keys – Page 2

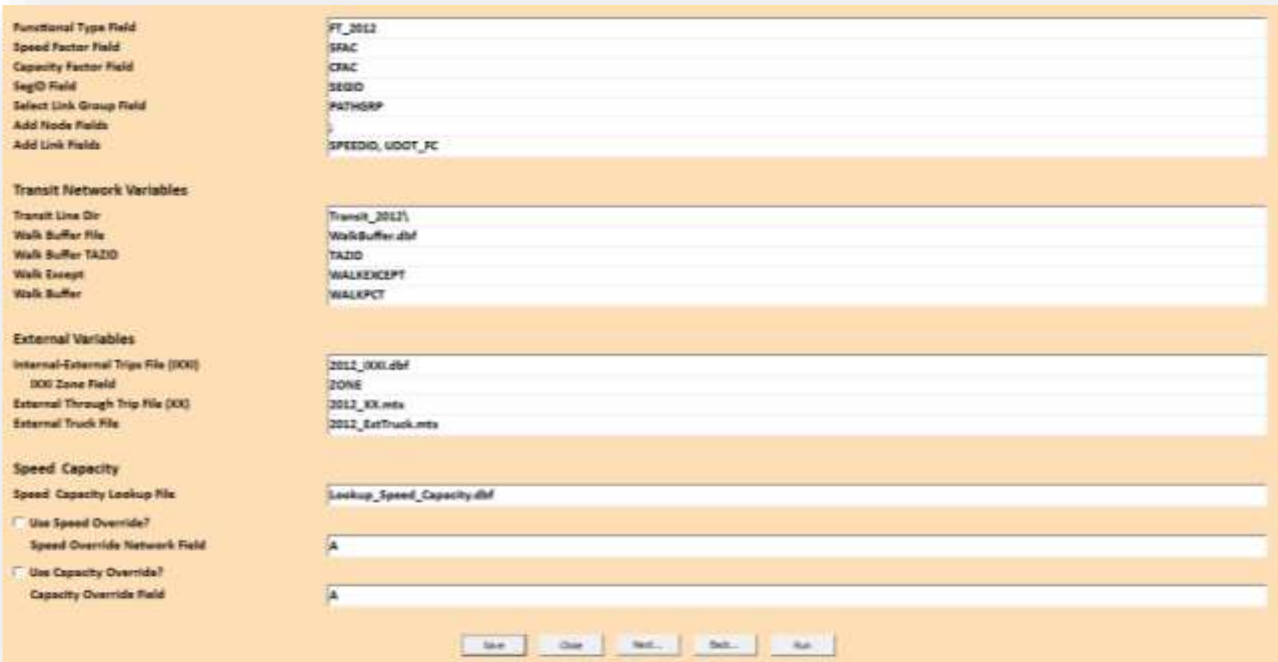


Exhibit 6. Scenario Catalog Keys – Page 3

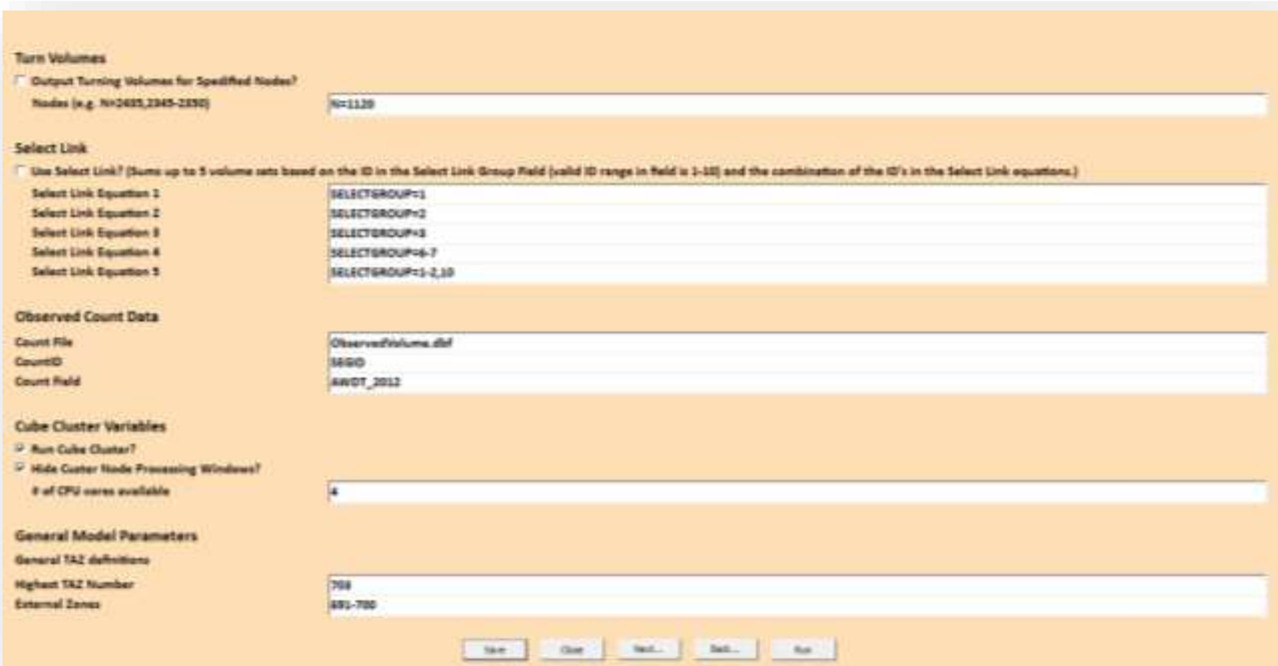
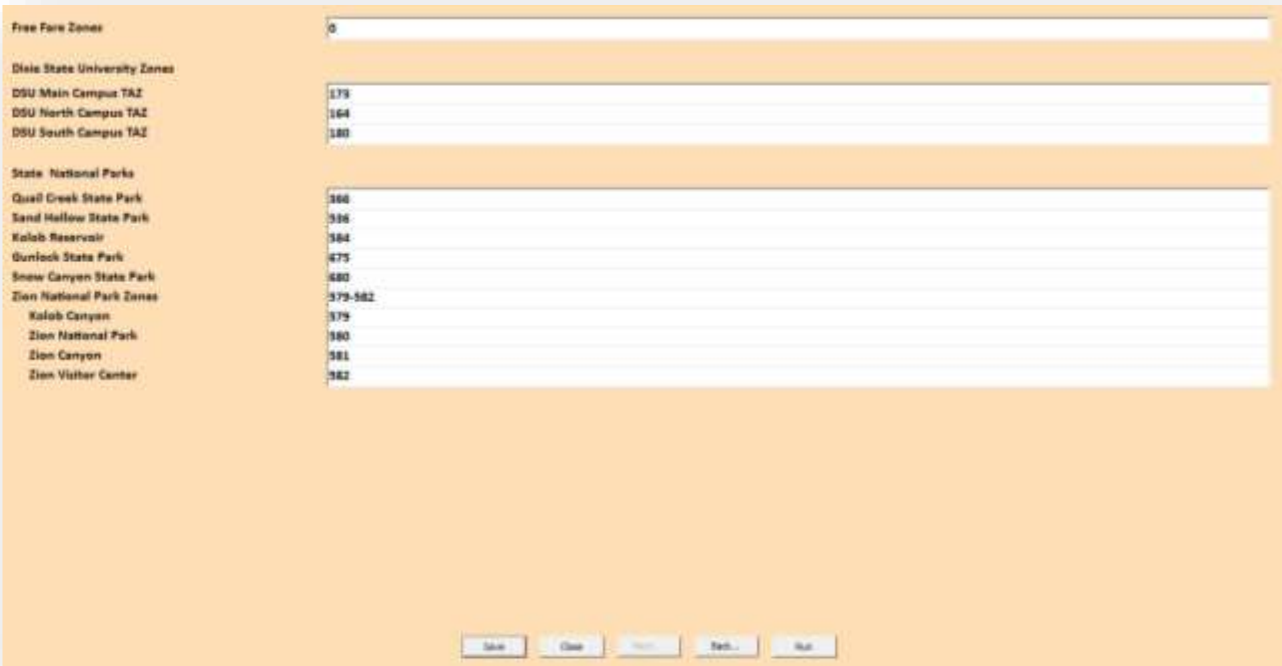


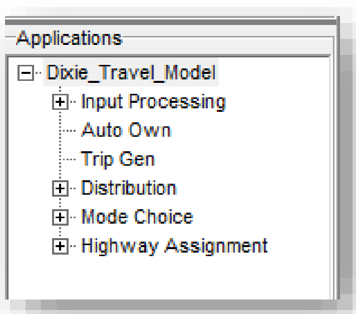
Exhibit 7. Scenario Catalog Keys – Page 4



Once the scenario's parameters have been set in the catalog keys, the modeler may click 'OK' to return to the main window or may click 'Run' to run this particular scenario. The user may also switch back and forth by using the tabs at the top of application window.

The middle-left pane shows CUBE's application manager. Application manager gives another way to peruse the flow charts or applications in the model. Each of the model's main groups is listed under the application title. Clicking on the '+' reveals any subgroups that may be associated with that step of the model. Clicking once on an item in the directory structure opens the application in the main application window. Double-clicking opens up the application in a new tab.

Exhibit 8. Application Manager Pane

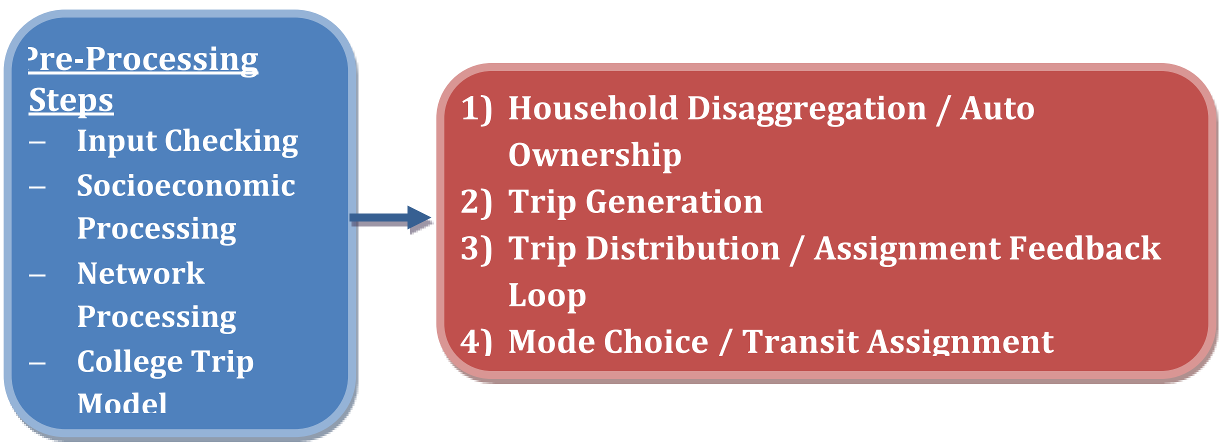


3.3 Model Structure

Many of the processes and data structure will seem familiar to those who have used other models in Utah. The commonality between this and other models in the state helps reduce the learning curve for practitioners using the model and allows the Dixie model to take advantage of other models' improvements thereby reducing the cost of model development.

The Dixie travel model is based on the 4-step modeling process: trip generation, trip distribution, mode choice, and assignment. In addition, the model has incorporated very robust pre-processing steps (including an input checking step, a socioeconomic processing step, network processing steps and a college trip model), a household disaggregation model and an auto ownership model.

Exhibit 9. Model Process



The Household Disaggregation and Auto Ownership models create a cross classification of households by life cycle, household size, income workers and vehicles owned. The household disaggregation models separate households into three life cycle categories (households with no children or seniors, households with children and no seniors, and households with seniors), six household size categories (1, 2, 3, 4, 5 and 6+ person households), two income categories (low representing the lowest income group or quartile and high representing the top three income groups or quartiles), four worker categories (0, 1, 2, and 3+ worker households). The household cross classifications pivot on TAZ average household size and average income. This information is then fed into the Auto Ownership model which estimates the probability a household in each household size-income-worker grouping will have 0, 1, 2, or 3+ autos. The Auto Ownership model uses a logit equation.

The Trip Generation model calculates trips ends for seven person trip purposes, 3 commercial vehicle trip purposes and 2 external trip purposes. Production rates are stratified by household workers, household size, and life cycle. Attractions are based on eight employment categories (2 retail, 2 industrial and 4 other). Attraction rates were derived from the ITE Trip Generation manual and scaled to production rates. The model classifies Dixie State University and the national and state parks in the area as special generators.

Trip Distribution uses a gravity model to link trip ends for all but external and home-based college trip purposes. The Trip Distribution model uses a full distribution/assignment feedback loop allowing distribution patterns to be sensitive to congestion levels. Path-building trips used in distribution and assignment use a generalized cost function which includes time, distance, cost and penalties. Auto operating costs and values of time are used to convert non-time terms into equivalent minutes. The assignment model uses an equilibrium assignment and a relative gap (RGAP) threshold of 0.0001 and a maximum number of iterations of 100. The distribution-assignment model uses a method of successive averages to average the distributed trip table starting with iteration 3 of the feedback loop. The distribution feedback loop is currently set to 10 iterations which may be shortened if the model achieves the defined convergence criteria.

Mode Choice uses a full nested logit model in estimating the mode of the trips. The model includes motorized and non-motorized modes in the first level of the nest. Motorized is further stratified into auto and transit. Transit is further defined by three modes, bus, enhanced bus and rail. As part of the mode choice step, transit trips are assigned to a transit network and reports are generated summarizing boardings, linked trips, and mode shares.

Final Traffic Assignment uses the same assignment method and path cost as Trip Distribution. Final Assignment also includes a 1-hour traffic assignment. Certain key highway statistics, such as vehicle miles traveled (VMT), vehicle hours traveled (VHT), average speed, and lane miles are summarized by functional type and by urban/rural area types. Output is also summarized for air quality modeling and model validation purposes.

The Dixie model reflects average weekday travel (AWDT) and the model disaggregates trips into four time periods.

Exhibit 10. Model Time Periods

AM	6:00 AM – 8:59 AM
Midday	9:00 AM – 2:59 PM
PM	3:00 PM – 5:59 PM
Evening	6:00 PM – 5:59 AM

Trips are stratified by 11 main trip purposes which are carried all the way through the model. Sub-trip purposes exist for HBO, NHB & HBSch in trip generation and distribution modeling steps to give further definition and detail.

Exhibit 11. Model Trip Purposes

HBW	Home-based Work
HBO	Home-based Other
	HBShp (Home-based Shopping)
	HBOth (Home-based Other)
NHB	Non Home-based
	NHBW (Non Home-based Work)
	NHBNW (Non Home-based Non Work)
HBSch	Home-based School (K-12)
	HBSch-PR (Primary Education, K-5)
	HBSch-SC (Secondary Education, 6-12)
HBC	Home-based College
IX	Internal to External
XI	External to Internal
XX	External to External
LT	‘Light’ Commercial Vehicles
MD	‘Medium’ or Single Unit Trucks
HV	‘Heavy’ or Multi-Unit Trucks

4.0 TRAVEL MODEL INPUTS

4.1 Traffic Analysis Zones

The Dixie model divides Washington County into 847 Traffic Analysis Zones (TAZ). TAZ in urban areas are usually smaller than in rural areas. TAZ boundaries were defined based on proposed 2010 Census geographies (block, block group, and tract), the highway network and land use. Census blocks were used as the lowest level of geography and were grouped to nest within Census block groups and tracts. As a general rule, TAZ boundaries were defined to not be divided by the model roadway network or major environmental features, such as rivers, and to be consistent with underlying land uses. Where Census geography and these rules were in competition, Census geography governed. This was done to ensure TAZ nested entirely within Census block groups and tracts in order for more direct matching with Census data. The relative size of the TAZ was also a factor in deciding new TAZ boundaries. Key zone number information is listed below. In general TAZ boundaries were numbered starting in the west model boundary and working east. Exhibit 12 shows the Dixie TAZ system.

TAZ Numbering

- External 838-847
  - I-15 South End 847
  - I-15 North End 843

National & State Parks

- Quail Creek 541
- Sand Hollow 545
- Kolob Reservoir 804
- Gunlock 12
- Snow Canyon 44
- Zion 795,813,827-828
  - Kolob Canyon 795
  - Zion Nattional Park 813
  - Zion Canyon 828
  - Zion Visitor Center 827

Dixie State University

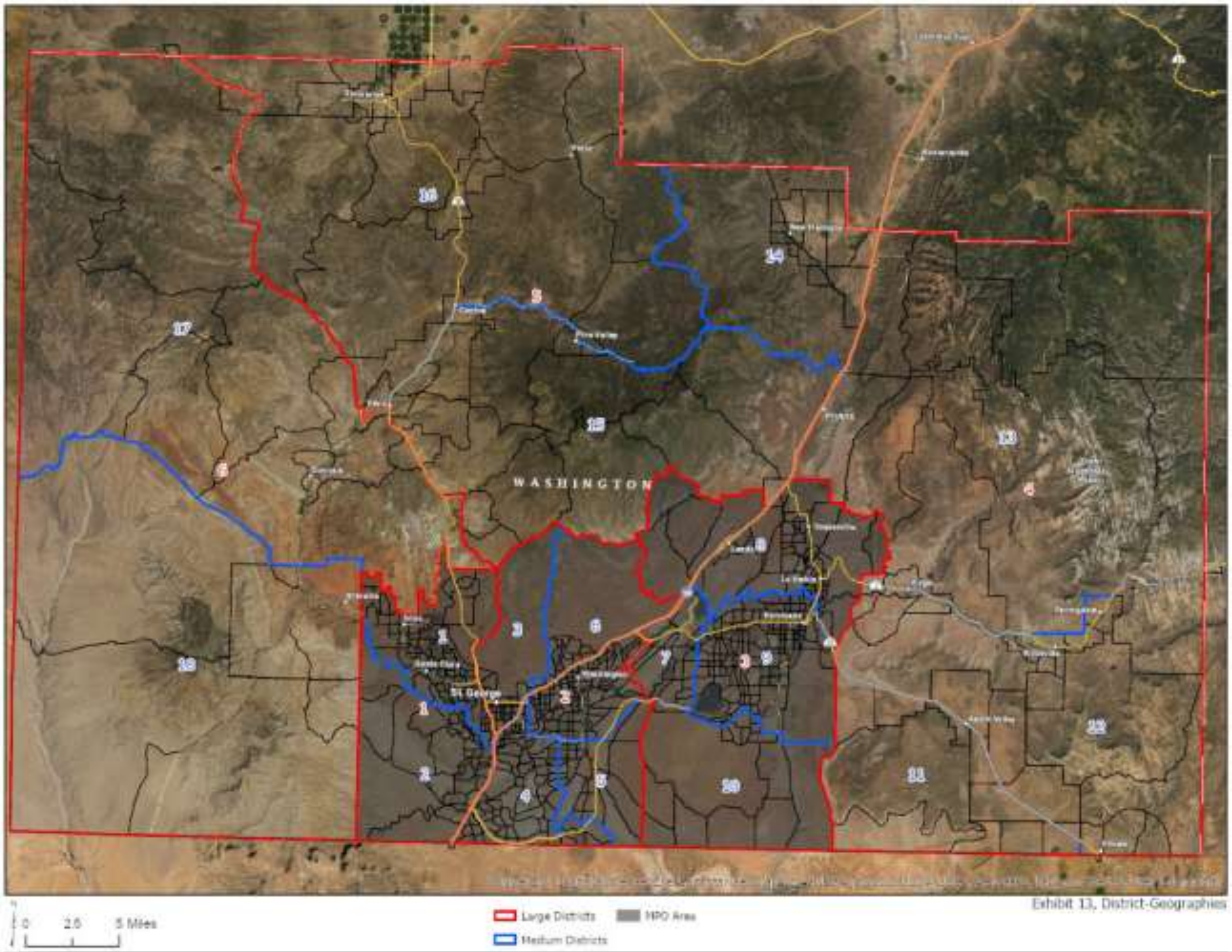
- North Campus 291
- Main Campus 294
- South Campus 290

Exhibit 12. Dixie TAZ Structure

4.2 Districts

It is often helpful to aggregate TAZ-level travel model data into larger geographies to better understand various aspects of model results. The Dixie travel model has default Large and Medium district sets that are part of the TAZ input shapefile. Alternate district sets can be developed in the TAZ shapefile and referenced in the scenario manager. As part of the scenario run, the travel model summarizes socioeconomic data and distribution trip tables by the Large and Medium district sets defined in the scenario manager.

Exhibit 13. District Geographies



4.3 Base Year Land-use Data

Travel models describe the movement of people and goods. Knowledge of the number of people, the number of jobs, the locations of activities and the characteristics of the people is crucial to understanding travel demand. Consequently, one of the initial steps in travel modeling is to gather current conditions and forecast how socioeconomic characteristics and locations are expected to change over time.

The Dixie model uses households, household population, senior population, seven employment categories (2 retail, 2 industrial, and 3 other) and income as the units of the socioeconomic data set. One socioeconomic data input file is supplied for every year in the model for which a model scenario is to be run.

Also included as part of the socioeconomic input set is a file of the county-level control totals for each socioeconomic category. One control total file is used for all scenario years.

The model is calibrated to 2016 conditions; as such 2016 is the base year of the model. Land-use and socio-economic data for the base year model comes from the following sources:

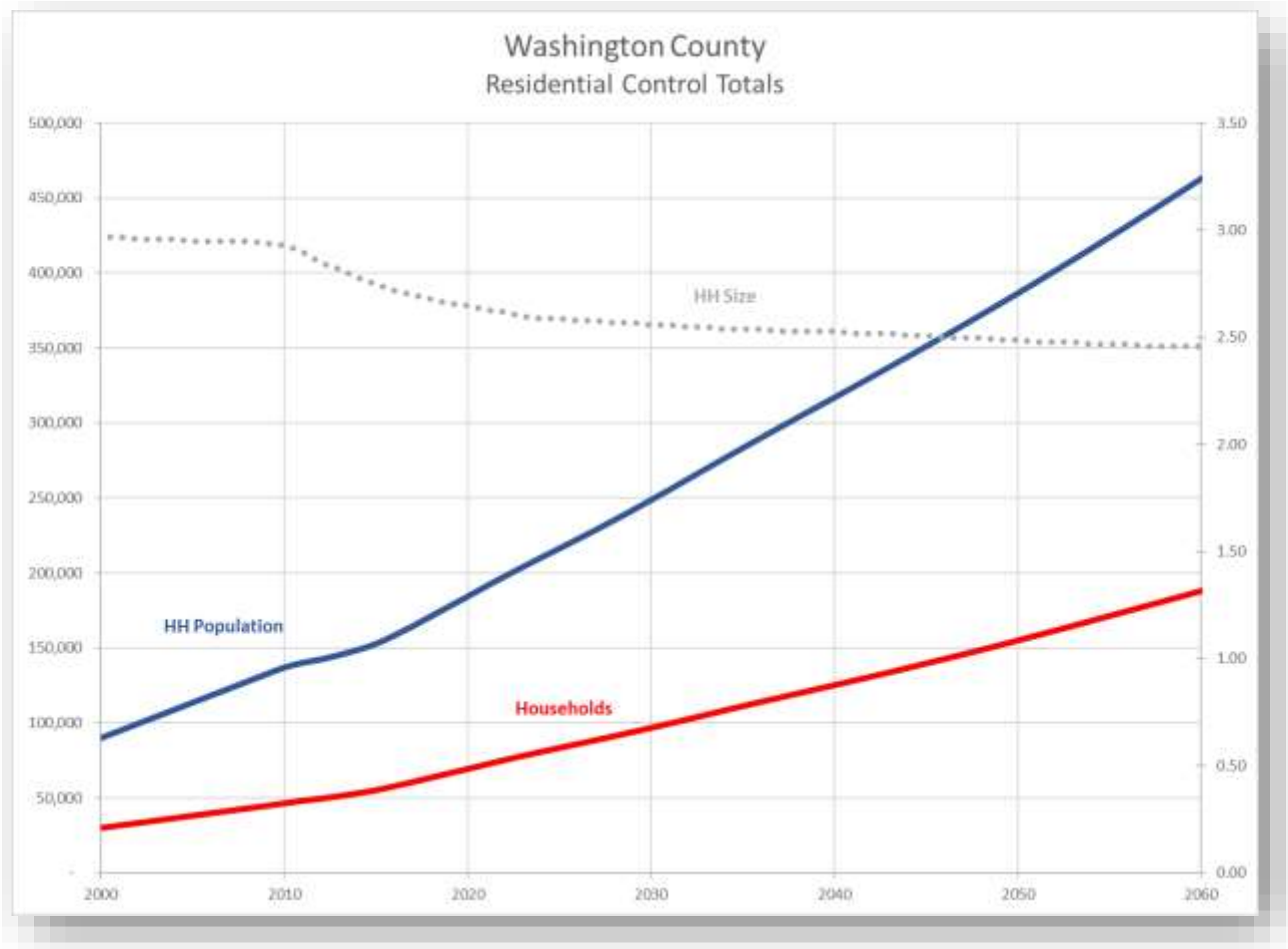
- 2010 Census and Census Transportation Planning Package (CTPP)
    - housing units and vacancy
    - household size & auto ownership
    - median income
- Buildings permits by year by TAZ (since 2010)
- 2016 parcel data for Washington County
- 2016 county-level population and household totals and average household size (Gardner's 2017 baseline projection)
- 2016 county-level employment estimates by sector (Gardner's 2017 baseline projection)
- 2016 establishment-level employment categorized by employment sector (Department of Workforce Services (DWS))

4.3.1 GPI County Control Total

GPI forecasts county-level residential and employment socioeconomic totals. These totals are used, as one of the base inputs, to control the model's socioeconomics. GPI's baseline projections which give county socioeconomic totals from 2010 to 2060 are used in this model.

Gardner residential data are given for total population, group quarters, household population, and households. The model uses household population and households as the controls for the TAZ residential variables. Exhibit 14 shows how the Gardner residential control totals change year by year.

Exhibit 14. Washington County GPI Residential Control Totals



GPI prepares employment data in two formats:

- Bureau of Labor Statistics (BLS) - does not include sole proprietors (e.g. business owners)
- Bureau of Economic Analysis (BEA) - includes sole proprietors

The travel model uses BEA format for the employment control total as it represents a more complete definition of the employment for trip making.

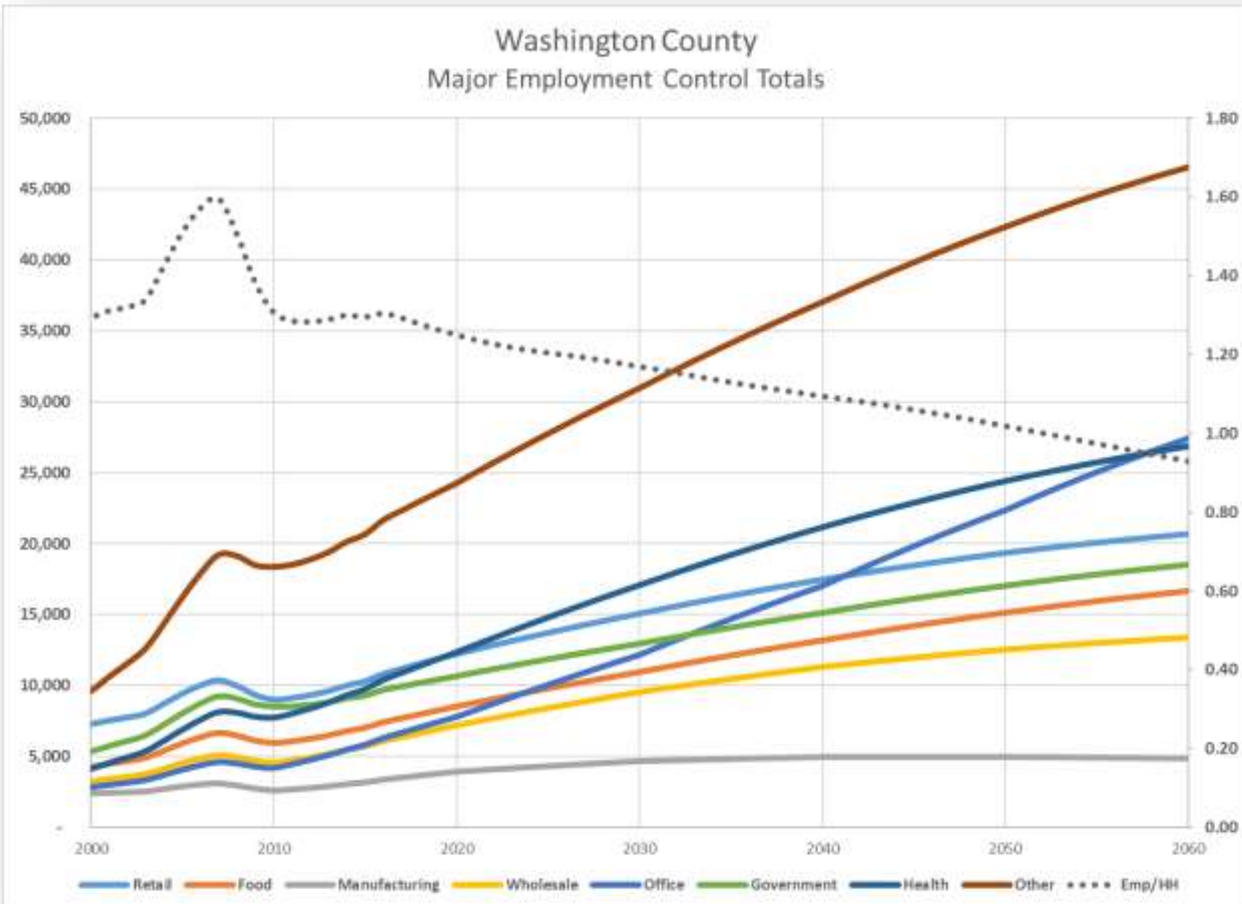
The 2017 release of the GPI employment data included information for the years 2016 through 2066. Data for historic years (2001-2015) were downloaded from the BEA website. Data for years prior to 2001 (1990-2000) were obtained from previous historical model data records.

The GPI employment projections include 23 employment sectors. These sectors were aggregated into 11 employment categories for use in the travel model. The following lists the travel model employment categories and their associated GPI employment sector:

- **RETL**
  - Retail trade

- **FOOD**
  - Accommodations and Food Service
- **MANU**
  - Manufacturing
- **WSLE**
  - Utilities
  - Wholesale Trade
  - Transportation and Warehousing
- **OFFI**
  - Information
  - Professional and Technical Services
  - Management
- **GVED**
  - Education
  - Military
  - Federal Government
  - State and Local Government
- **HLTH**
  - Health Care and Social Assistance
- **OTHR**
  - Finance and Insurance
  - Real Estate
  - Administrative and Waste Services
  - Arts, Entertainment, and Recreation
  - Other services
- **FM_AGRI**
  - Agriculture, Forestry, Fishing and Hunting
  - Farm
- **FM_MING**
  - Mining, Quarrying, and Oil and Gas Extraction
- **FM_CONS**
  - Construction

Exhibit 15. Washington County GPI Employment Control Totals



4.3.2 Base Year Households

The 2016 base year household estimates by TAZ starts with the 2010 Census. The Census reports the number of households and population at the block level, along with average household size and vacancy rates. These block-level totals are aggregated to the TAZ level, which are made up of one or more blocks. Household growth is then estimated from parcel residential year built data. The total households are then summed and compared to the 2016 county control total from GPI. The TAZ total households are then factored to match the county control total from GPI.

Base year population is estimated by multiplying the 2016 TAZ households by the TAZ-level average household size from the Census (using Block Group data). The TAZ population are then summed by county and compared with the GPI 2016 county population control total, and then factored to match the GPI total. The average household size in each TAZ is then recalculated. Household and population are then aggregated to medium and large districts and to the city level for quality control and to check for accuracy.

The total population control totals used in the model represent household population and exclude group quarter population, i.e. populations in prisons, nursing homes, dormitories and military barracks. It is assumed, however, that the population includes people who are temporarily away on business or vacation, as well as those attending school in the region and living off-campus, but not those away at school or on LDS missions.

In Washington County, current developments are mostly occurring in the MPO area. Exhibit 16 lists the residential data summarized for MPO and the balance of the county areas. Exhibit 17 shows the household density in 2016, which is number of households in each TAZ divided by the TAZ acreage.

Exhibit 16. 2016 Base Year Households & Population in Washington County

	MPO	Balance of County	County Total
Population	136,700	21,500	158,200
Households	51,400	6,700	58,100
Avg. Household Size	2. 69	3. 38	2.75

Exhibit 17. 2016 Base Year Household Density

4.3.3 Senior Households

Washington County has a relatively large portion of retirees living in the region, both permanently and seasonally. These individuals tend to have different trip-making characteristics, including the most obvious difference that they work less than the younger population. Therefore, an approach was implemented within the Dixie model to separately account for households with senior citizens heading the household.

Year-round senior households and seasonal housing units were identified using 2010 Census data. According to Census data, in 2010, approximately 25% of the housing units in the region were occupied by senior citizens. An additional 12% of the housing units were seasonally occupied. Therefore, seasonal and senior households accounted for approximately 37% of all housing units in the region in 2010.

Due to data limitations, the seasonal and senior populations are treated in a similar manner in the Dixie model in that they do not generate work trips. Additionally, they have smaller household sizes, consistent with the assumption that most of the seasonal occupants will be senior households. Since the household sizes are smaller than the average non-senior household, the non-work trip generation per senior/seasonal household is also less than a typical household. The exhibit below shows the 2010 census housing unit type distribution.

Exhibit 18. 2010 Seasonal/Senior Housing Units Data

	Housing Units	%
Total Year-round	50,535	88%
Non-Senior	35,864	62%
Senior Yearly	14,671	25%
Seasonal	7,201	12%
Total w/ Seasonal	57,736	100%
Total Senior/Seasonal	21,872	37%

4.3.4 Base Year Employment

Washington County obtains annual establishment-level employment data from the Department of Workforce Services (DWS). Since the DWS employment has a privacy and use restrictions agreement, users of the employment data must agree to follow the terms upon which the data have been released. The employment data contains information such as the name of the employer, the address of the employer, the number of employees, and the employer's industry code (NAICS classification).

Employer locations are geocoded using GIS and the employer's address to obtain a discrete point representing a number of employees. Each business is assigned to the TAZ in which the point resides. The points are then factored by the total employment for each NAICS classification to account for the employment addressed that could not be successfully geocoded.

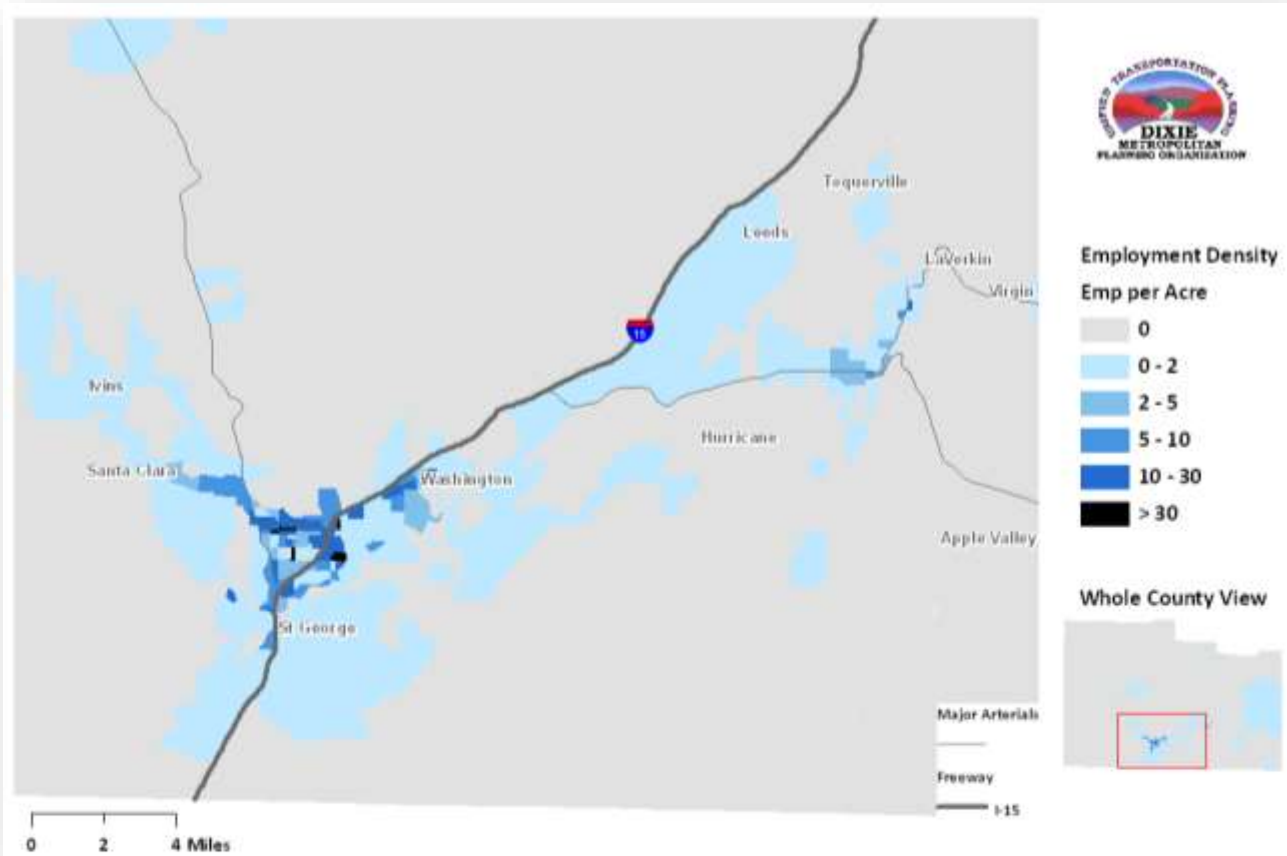
The DWS data is then converted to GPI employment definitions using the cross-walk table identified below and scaled to match the GPI employment sector totals at county level. A percentage of the employment representing home-based jobs are then skimmed off the top by sector and added to a new, home-based job classification. The 2000 Census (percentage of work at home jobs by county) is used to match or validate the number of home-based jobs in Washington County.

Exhibit 19 shows the base year employment by employment types. Exhibit 20 shows how employment density distributed geographically in 2016.

Exhibit 19. 2016 Base Year Employment by Category

Category	Employment
Retail	10,832
Food	7,425
Manufacturing	3,378
Wholesale	6,076
Office	6,279
Government	9,682
Health	10,422
Other	21,636
Total	75,730

Exhibit 20. 2016 Base Year Employment Density



4.4 Future Year Land-use Data

The socioeconomic forecasting process involves analytical models and local negotiation/review. Regardless of the analytical methods used to initially allocate population and job growth, the final projections are revised and agreeable to local city agencies. The socioeconomic forecasting process essentially follows the following process:

1. The Utah GPI provides county-level population and employment totals.
2. Constraint shape files are used to calculate developable acreage, excluding such items as:
    a. Steep slopes
    b. Streams, rivers and lakes
    c. Conservation lands
    d. State & National parks

3. Future land use plans from the county and each city are used as guide to calculate land capacity for residential and commercial use. Lands approaching capacity are not available for further development.
4. If necessary, the modeling process is iterative, considering the relative reasonableness of the different estimates.
5. Adjustments are made to the forecasts based on the historical trends in each city.
6. Cities and MPO planners review results, and their comments are implemented as applicable.

The results of this process are future land-use forecasts by TAZ for future years. Exhibits 21-23 show future year population, households, and employment for Washington County.

Exhibit 21. Future Population by Area

Area	2020 Population	2030 Population	2040 Population	2050 Population
MPO	160,000	214,900	273,600	328,100
Balance of County	24,100	33,500	43,300	58,300
Countywide	184,100	248,400	316,900	386,400

Exhibit 22. Future Households by Area

Area	2020 Households	2030 Households	2040 Households	2050 Households
MPO	61,800	85,800	110,800	135,000
Balance of County	7,700	11,200	14,700	20,300
Countywide	69,500	97,000	125,500	155,300

Exhibit 23. Future Employment by Area

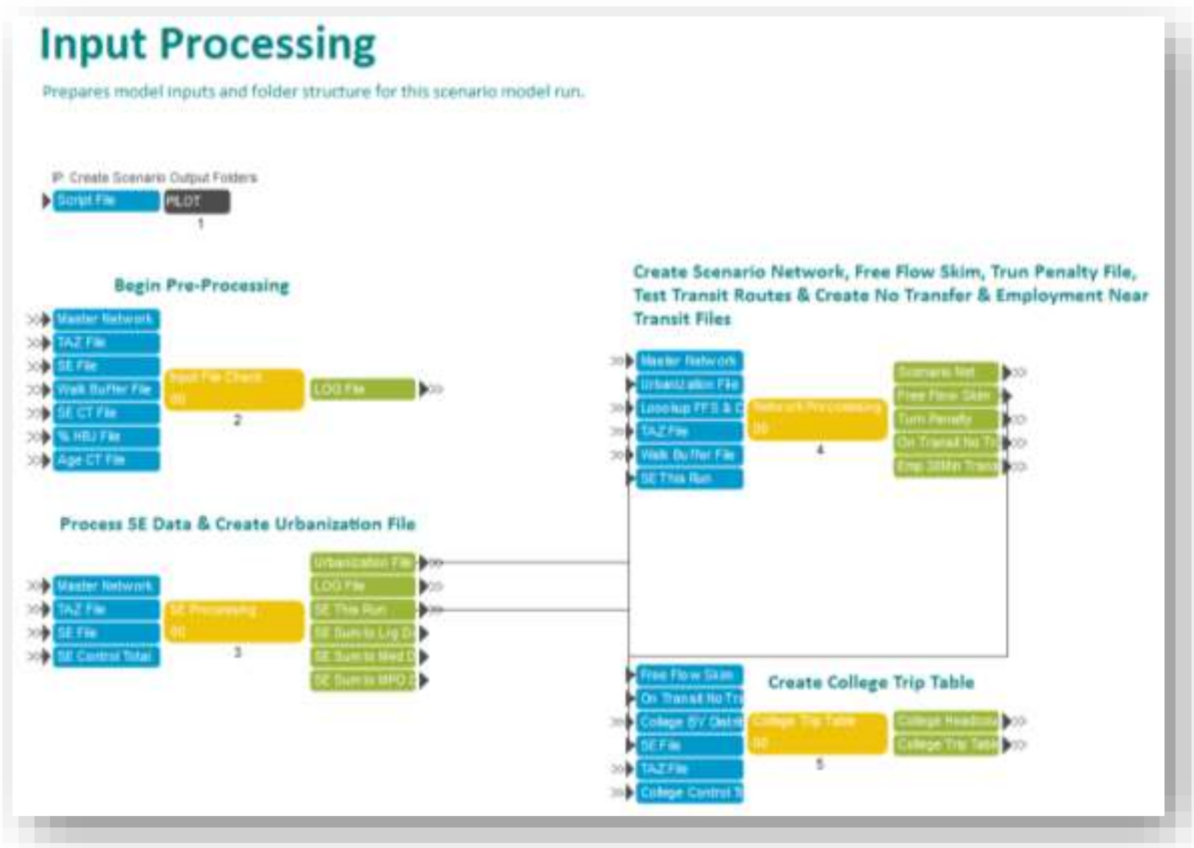
Area	2020 Employment	2030 Employment	2040 Employment	2050 Employment
MPO	82,500	107,600	130,100	149,100
Balance of County	4,400	5,800	7,100	9,000
Countywide	86,900	113,400	137,200	158,100

5.0 INPUT PROCESSING

Before beginning the traditional four step modeling process, the Dixie model performs several key functions. The collection of these is called the input processing phase of the model, wherein the model:

1) Checks if all the input files are valid and starts a model run “log” file
2) Processes socioeconomic data for the scenario year and summarizes the data by district
3) Calculates urbanization, area type and terminal time values
4) Creates a highway network for scenario year
5) Creates a college trip table

Exhibit 24. Model Structure of Input Processing



5.1 Input Check & Begin Log File

The Dixie Model begins its processing with a series of checks and processes to verify some of the required input data are present and to create other necessary data for the model run. If required data or fields are missing, the model immediately crashes instead of later on in the model stream when the problem may have otherwise occurred. Required input files and data fields are:

- TAZ: total acres, developable acres, permanent & temporary (hourly) parking costs, trip generation districts (Dist_TG), large/medium/MPO districts
- Socio-economics: average income, households, population, household size, all employment, percent of employment by categories (11 categories), seasonal seniors
- Highway node: N(node), X/Y coordinate, TAZID, park & ride lots
- Highway link: A/B node, distance, one-way designation, TAZID, lane field, center turn lane field, functional type field, speed/capacity factor field, SEGID, select link field, street name
- Transit: walk buffer and walk except fields
- SE Control Total: households, population, household size, all employment, 11 employment categories
- Home-based Job Control Total: 11 employment categories
- Age Control Total: population, pop age 0-17, pop age 18-64, pop age 65+

The input processing stage also checks the TAZ input shapefile for errors. These errors are recorded to a log file but do not crash the model. These errors include:

- TAZID fields with no values in them
- Missing or duplicate TAZs
- TAZs with no area (in acres) defined
- TAZs with developable acres greater than total acres

The “log” file is a text consisting lists of variables, summaries and reports (including errors) for a model run. It is located in scenario folder. The log file is created in the input processing step and is appended to by subsequent model steps which add more information to the file. The following exhibit shows an example of the log file just after it was created:

Exhibit 25. Example Log File

```
;**********************************************************************
;                    BY_2012 Travel Model Log
;**********************************************************************

General Identification
  Model Version                Dixie V2.0 - 2013-10-04
  User Name                    Dave Demas
  User Company                 Dixie MPO

Model Directories for This Run
  Parent Directory             C:\_Work\Dixie\13132 - Dixie Model v2 De
  Inputs Directory             1_Inputs\
  Scripts Directory            2_ModelScripts\
  Scenario Directory           BY_2012\


1) TAZ Variables
  TAZ Area File                TAZ.dbf
    TAZ Field                    TAZID
    Total Acres Field            ACRES
    Developable Acres Field      DEVACRES
    Large District Field         DIST_LRG
    Medium District Field        DIST_MED
    MPO District Field           DIST_MPO


2) Demographic Variables
  Demographic Year             2012
  Socio-economic File          SE_2012.dbf
    SE TAZ Field                 TAZID
  SE CT File                   _ControlTotals_SE.dbf
  % HBJ Lookup File            _ControlTotals_PctHBJ.dbf
  Age CT File                  _ControlTotals_Age.dbf


3) Highway Network Variables
  Network Year                 2012
  Master Network File          Dixie_20131004.net
  Scenario Network             Base_2012.net
```

5.2 SE Processing

5.2.1 Scenario Socioeconomics

The input socioeconomic data set includes income, population, households, household size, total employment and the percent of employment in each employment sub category, but not the actual number of employees in each of these sub categories. The SE processing step generates employees in each employment sub category by first multiplying the total employment by the category percent for each TAZ, however this will most likely not add up to the category total for all zones. The model uses an iterative proportional fitting routine (IPF), also known as a FRATAR routine, to balance the TAZ-level and county-level employment totals by category. Users can designate the maximum number of iterations to avoid endless looping. The default value is set to 15.

After finishing the IPF loop, all the socioeconomics are settled for each TAZ and controlled at county level. The model aggregates residential and employment data to large/medium district level and county level for reporting purposes. The Dixie model then checks the socioeconomic file and reports any inconsistence to log file, such as:

- Missing TAZ ID

- Socioeconomic data with negative values
- Household greater than population, or household size less than one
- Illogical zero households or population
- Total employment does not match the sum of sub categories

5.2.2 Area Type

The Dixie model uses the socioeconomic data and developable acres in a TAZ to calculate an urbanization value. This value is used to categorize the TAZ into one of five area types. Urbanization is represented by the socioeconomics in the target zone plus the four closest neighboring zones, as seen in the following equation:

$$Urbanization = (POP_{fivezone} + 2.07 * EMP_{fivezone}) / DEVACRES_{fivezone}$$

Where:

$POP_{fivezone}$ = the total population of one zone plus four closest neighbor zones

$EMP_{fivezone}$ = the total employment of one zone plus four neighbor zones

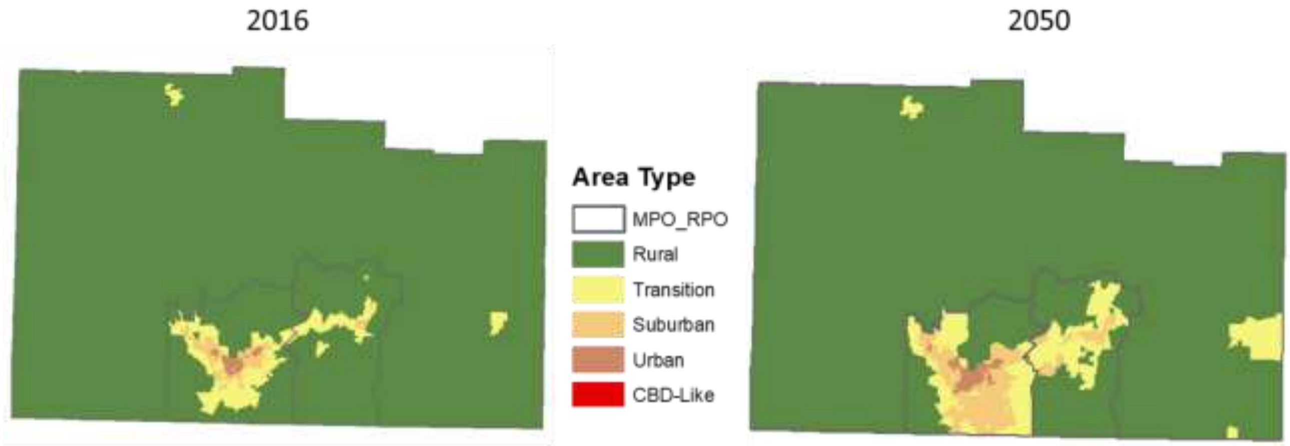
$DEVACRES_{fivezone}$ = the total developable acres of one zone plus four neighbor zones

The area type of the TAZ is set according to the following thresholds:

Urbanization	Area Type
0 - 1	Rural
1- 5	Transition
5 - 15	Suburban
15 - 45	Urban
> 45	CBD

The process of calculating urbanization to set area type lets the model be flexible to changes in socioeconomic data and greatly reduces the effort to code area type directly onto the network. Exhibit 26 shows the urbanization and area type designations for 2016 and 2050.

Exhibit 26. Urbanization & Area Type for 2016 & 2050



5.2.3 Terminal Time

Terminal time is the time people spend walking at either end of their trip, such as from home to car or from the parking lot or transit station to their final destination. It is usually around one to two minutes depending on how far the final destination may be. Typically, the terminal time is set to 1 minute, the smallest unit allowed. In more dense urban environments, it may be more difficult to get to/from a destination. Consequently, the terminal time is set to 2 minutes for urban and CBD-like area types. Dixie State University (DSU) has a terminal time of 3 minutes with the assumption that people need more time to walk through the campus to reach their destination.

5.3 Highway Network Processing

5.3.1 Scenario Network

The input highway network for the Dixie model is a “master” network, which contains data fields for multiple years or alternatives. In the input processing step the Dixie model extracts a “scenario” network based on network field values defined in the model scenario in the CUBE scenario manager. The scenario network then become the base network for processing network related data for a particular scenario.

In the network processing step, the Dixie model checks the distance and one-way fields on the network and assigns the large and medium district definitions from the TAZ shapefile to the highway links. The socioeconomic data is also copied onto the nodes for reference. The model then uses the functional type, area type, and number of lanes to calculate the link free flow speed and capacity, which are discussed in more detail in the following sections.

5.3.2 Free Flow Speed

Free flow speed (FFS) is primarily defined by the functional type assigned to the link. For centroid connectors, principal arterials, minor arterials, and collectors, the model also uses area type in setting the FFS. The FFS assigned to a given functional type / area type combination are illustrated in the following exhibits.

Exhibit 27. Free Flow Speed Table

			Speed by Area Type				
New FT	Old FT	Functional Type	1 Rural	2 Transition	3 Suburban	4 Urban	5 CBD-Like
1	1	Centroid Connector / Local	30	24	20	17	14
2	2	Principal Arterial	60	48	40	33	24
3	3	Minor Arterial	53	41	35	30	21
4	4	Major Collector	45	35	29	26	18
5	5	Minor Collector	42	32	26	23	15
6	-	Local	30	24	20	17	14
7	-	Unpaved	15	15	15	15	15

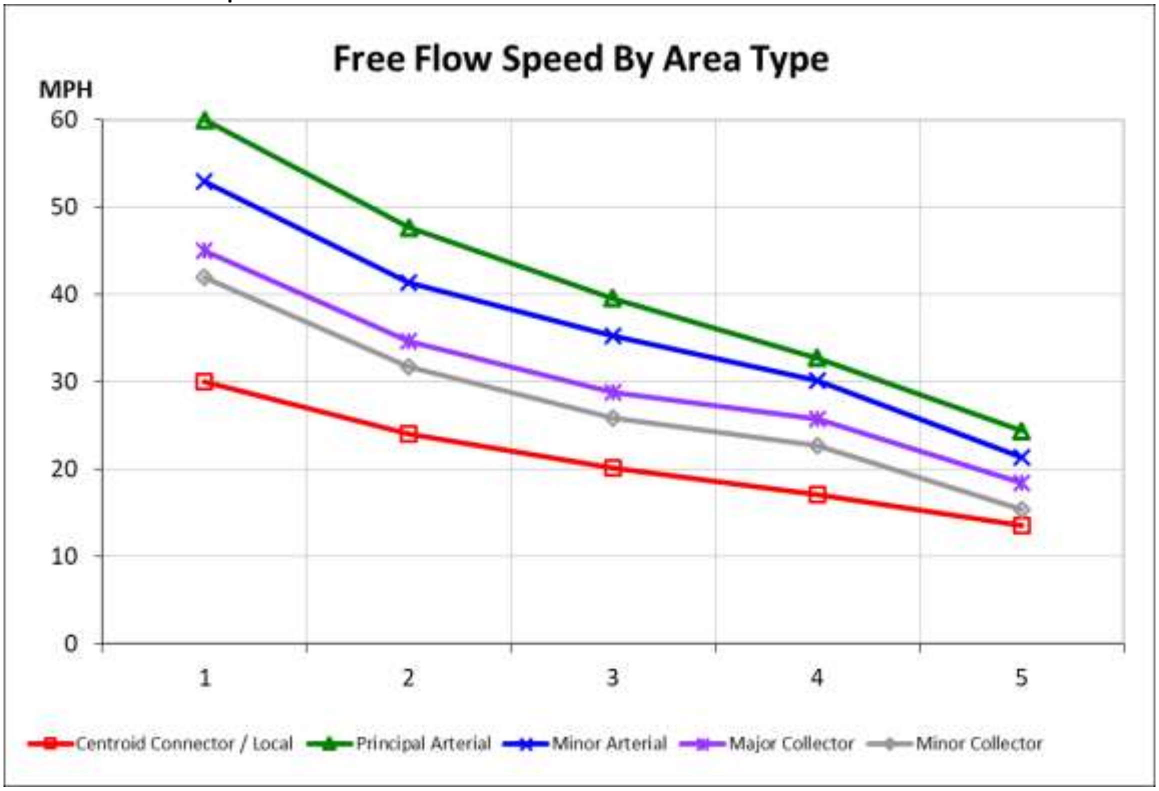
New FT	Old FT	Functional Type	New Speed	Old Speed	(These do not vary by Area Type)
12	-	Expressway, posted 60-70 mph	60		
13	-	Expressway, posted 55-65 mph	53		
14	11	Expressway, posted 50-60 mph	48	50	
15	-	Expressway, posted 45-55 mph	43		
30	29	Fwy: fwy-to-fwy loop ramp	35	40	
31	33	Fwy: C-D road, flyover ramp	55	55	
32	-	Fwy: posted 55-60 mph	62	-	
33	32	Fwy: posted 65 mph, no aux lane	67	67	
34	31	Fwy: posted 65 mph, aux lane	67	67	
35	-	Fwy: posted 75 mph, no aux lane	75	-	
36	35	Fwy: posted 75 mph, aux lane	75	75	
37	34	Fwy: HOV lane	70	70	
38	39	Fwy: Managed lane	70	70	
39	38	Fwy: Managed lane access	70	70	
40	40	Fwy: Tollway	77	77.5	
41	36	Fwy: On-ramp	23	23	
42	37	Fwy: Off-ramp	26	26	

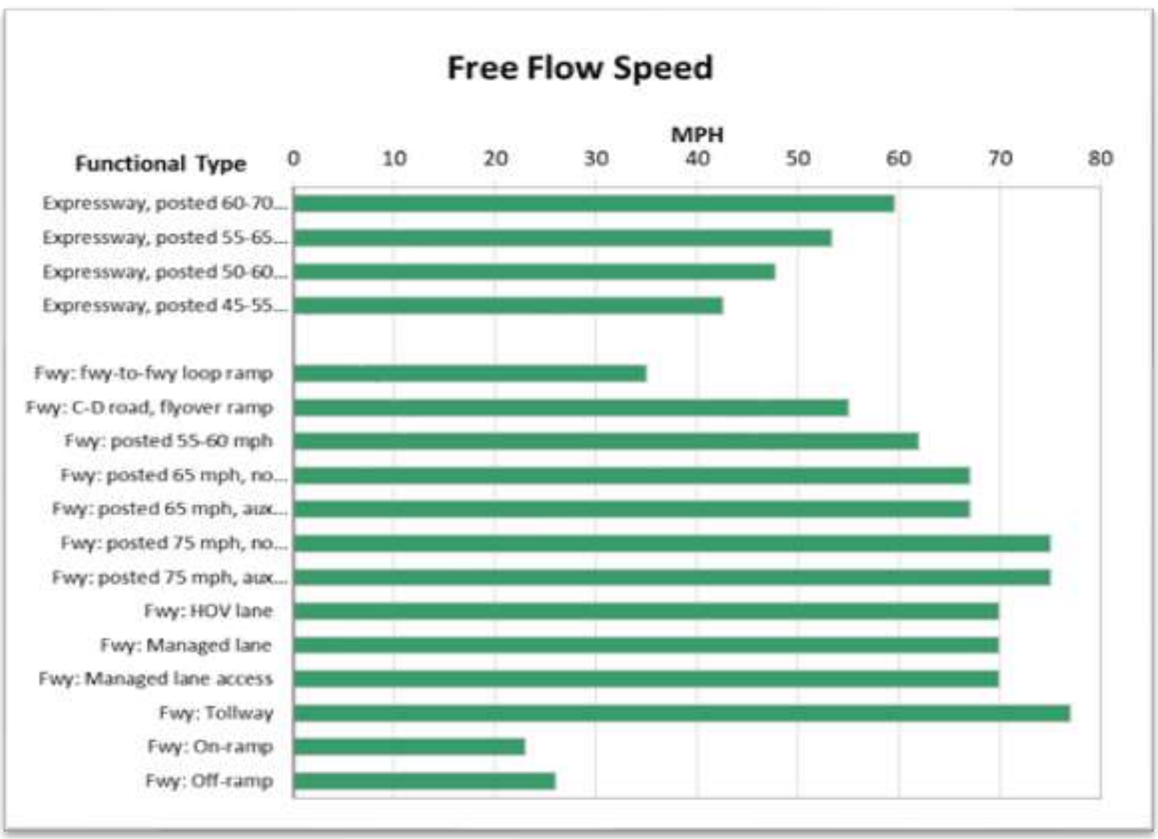
Notes

Arterial/collector speeds are reduced by 1 mph if only 1-lane per direction to account for inability to pass

Arterial/collector speeds are increased by 5% if one-way link

Exhibit 28. Free Flow Speed Charts





For centroid connectors, principal and minor arterials, collectors, multilane highways, and rural highways, the model uses the following equation to calculate FFS:

SFF = 1 / ((1 / unsignalized speed) + (num stops per mile * uncongested delay per V / 3600))

Where:

Unsignalized Speed

	Rural	Transition	Suburban	Urban	CBD-Like
Centroid Connector / Local	30	30	28	27	26
Principle Arterial	60	55	50	45	35
Minor Arterial	53	50	48	44	33
Collectors	45	43	40	37	34
Expressway, posted 60-70 mph	65				
Expressway, posted 55-65 mph	60				
Expressway, posted 50-60 mph	55				
Expressway, posted 45-55 mph	50				

Required stops/mile due to signals or stop signs

	Rural	Transition	Suburban	Urban	CBD-Like
Centroid Connector / Local	0.0	3.0	5.0	6.0	8.5
Principle Arterial	0.0	1.0	1.9	2.3	3.0
Minor Arterial	0.0	1.5	2.7	2.9	4.0
Collectors	0.0	2.0	3.5	3.3	6.0
Expressway, posted 60-70 mph	0.50				
Expressway, posted 55-65 mph	0.75				
Expressway, posted 50-60 mph	1.00				
Expressway, posted 45-55 mph	1.25				

Uncongested delay per stop - all types (Sec/veh between LOS B-C)

	Rural	Transition	Suburban	Urban	CBD-Like
All types	0	10	10	13	15
Expressway, posted 60-70 mph	10				
Expressway, posted 55-65 mph	10				
Expressway, posted 50-60 mph	10				
Expressway, posted 45-55 mph	10				

After all FFS have been set, the Dixie model applies a final adjustment based on any user specified parameters (SFAC or Speed Override) coded on the master network.

5.3.3 Capacity per Hour per Lane

Capacity is defined as the capacity per hour per lane (capphpl) for a link. Capacity is based on functional type, lanes and area type. Similar to free flow speed, capacity of principal and minor arterials and collectors vary by area type while capacities for the remaining functional types use the same value for all area types. For certain roadway types the capacity also varies by the number of lanes. The capacity assigned to a given functional type / area type / # of lanes combination can be seen in the following table and charts.

Exhibit 29. Capacity Table

FT	Functional Type	Capacity per hour per lane	Area Type
1	Centroid Connector	10,000	Suburban

FT	Functional Type	Capacity per hour per lane						
		1 lane	2 lanes	3 lanes	4 lanes	5 lanes	6 lanes	7 lanes
2	Principal Arterial	930	892	854	835	815	796	778
3	Minor Arterial	840	806	772	754	737	720	703
4	Major Collector	666	633	606	586	567	548	530
5	Minor Collector	515	489	468	453	438	423	409
6	Local	412	391	375	362	350	339	328
7	Unpaved	300	300	300	300	300	300	300

** Capacity on one-way arterials/collectors increases by 20%*

FT	Functional Type	1 lane	2 lanes	3 lanes	4 lanes	5 lanes	6 lanes	7 lanes
12	Expressway, posted 60-70 mph	1,058	1,016	984	963	942	922	902
13	Expressway, posted 55-65 mph	1,021	981	950	930	910	890	871
14	Expressway, posted 50-60 mph	985	946	916	896	877	858	840
15	Expressway, posted 45-55 mph	948	911	882	863	845	826	809

FT	Functional Type	Capacity per hour per lane						
		1 lane	2 lanes	3 lanes	4 lanes	5 lanes	6 lanes	7 lanes
30	Fwy: fwy-to-fwy loop ramp	1,600	1,300	1,100	900	900	900	900
31	Fwy: C-D road, flyover ramp	1,758	1,758	1,670	1,599	1,547	1,511	1,476
32	Fwy: posted 55-60 mph	2,021	2,021	1,920	1,839	1,779	1,738	1,698
33	Fwy: posted 65 mph, no aux lane	2,065	2,065	1,962	1,879	1,817	1,776	1,735
34	Fwy: posted 65 mph, aux lane	2,065	2,415	2,195	2,054	1,957	1,893	1,835
35	Fwy: posted 75 mph, no aux lane	2,109	2,109	2,004	1,919	1,856	1,814	1,772
36	Fwy: posted 75 mph, aux lane	2,109	2,459	2,237	2,094	1,996	1,930	1,872
37	Fwy: HOV lane	2,280	2,280	2,166	2,075	2,006	1,961	1,915
38	Fwy: Managed lane	2,280	2,280	2,166	2,075	2,006	1,961	1,915
39	Fwy: Managed lane access	2,280	2,280	2,166	2,075	2,006	1,961	1,915
40	Fwy: Tollway	1,800	1,800	1,710	1,638	1,584	1,548	1,512
41	Fwy: On-ramp	1,200	900	600	600	600	600	600
42	Fwy: Off-ramp	924	887	850	830	811	792	773

Notes

Arterial & collector capacities are adjusted up or down by 5% as area type moves away from suburban

Fwy: off ramp capacity is 10% higher than a minor arterial

Links with functional types not identified in the lists are reported to the log as errors.

Link capacities for arterials and collectors are based on the Highway Capacity Manual capacity estimation methodology as shown in the following equations:

Exhibit 30. Capacity Calculation Equations

Arterial / Expressway Capacity Calculation Parameters

Cap1hr1ln = _SatRate * Fhv * Fbb * Flu * Fgrn * Fatype

	_SatRate	Fhv	Fgrn
Principal Arterial	1,900	0.96	0.52
Minor Arterial	1,900	0.96	0.47
Major Collector	1,700	0.98	0.40
Minor Collector	1,500	0.98	0.35
Expressway, posted 60-70 mph	1,900	0.96	0.58
Expressway, posted 55-65 mph	1,900	0.96	0.56
Expressway, posted 50-60 mph	1,900	0.96	0.54
Expressway, posted 45-55 mph	1,900	0.96	0.52

Fbb values	1 lane	2 lanes	3 lanes	4 lanes
Arterial	0.98	0.99	0.99	1.00
Collector	1.00	1.00	1.00	1.00
Expressway	1.00	1.00	1.00	1.00

Flu	1 lane	2 lanes	3 lanes	4 lanes
Arterial	1.00	0.95	0.91	0.88
Collector	1.00	0.95	0.91	0.88
Expressway	1.00	0.96	0.93	0.91

	1 Rural	2 Transition	3 Suburban	4 Urban	5 CBD
Area Type	1.10	1.05	1.00	0.95	0.90

Freeway Capacity Calculation Parameters

Cap1hr = (Sat * LANES * PHF * Fle * Fhv) + AuxVolAtCapacity ;AuxVol = 0 for FT 31; 700 for FT 32

Cap1hr1ln = Cap1hr / LANES ;distributes AuxVolAtCapacity across the GP lanes

	Sat	Aux		Fle
Fwy: fwy-to-fwy loop ramp	1,800	-	1 lane	1.00
Fwy: C-D road, flyover ramp	2,000	-	2 lanes	1.00
Fwy: posted 55-60 mph	2,300	-	3 lanes	0.95
Fwy: posted 65 mph, no aux lane	2,350	-	4 lanes	0.91
Fwy: posted 65 mph, aux lane	2,350	700	5 lanes	0.88
Fwy: posted 75 mph, no aux lane	2,400	-	6 lanes	0.86
Fwy: posted 75 mph, aux lane	2,400	700	7 lanes	0.84
Fwy: HOV lane	2,400	-		
Fwy: Toll lanes	2,400	-		
Fwy: Managed Ln access	2,400	-		
Fwy: Tollway	2,400	-		

PHF	0.95
Fhv	0.925

Notes

Fhv = 1/(1+ PCThv * (Ehv - 1)) Ehv = 2.0 (Meaning a heavy vehicle has effect of 2 autos in urban areas)

Model assumes 8% trucks on all freeways, which makes Fhv = .925.

The highway network also has "CFAC**" variable, which if not zero, will be multiplied by Cap1hr1ln

CFAC < 1 means the road has less capacity than normal (high side friction, no center turn lane, no right pockets, etc)

CFAC > 1 means the road has better capacity than normal (good access control, high-efficiency intersections, etc).

The Dixie model bumps up capacity based on the presence of a center turn lane coded onto the highway network. Arterials with a center turn lane are assumed to have 7.5% higher capacity, while 12% higher capacity is assumed on collectors with a center turn lane.

After all capacities have been set, the Dixie model adjusts the capacities based on user specified parameters (CFAC or Capacity Override) coded on the master network.

5.3.4 Free Flow Skim

Free flow skim is a step to find shortest free flow time path from zone to zone, and trace cumulative distance and travel time. Travel time (in minutes) is summed up from the following three components:

Inter-zonal time = (Distance/FFS)*60

Intra-zonal time = Intra-zonal distance/intra-zonal speed = (0. 5* (Zone Area)^2) / 20mph *60

Terminal time in both origin zone and destination zone

As part of the free flow skimming process, the Dixie model also checks for TAZ that are not connected to the highway network. Unconnected zones are reported to the log file.

5.3.5 Turn Penalty File

As part of the network preprocessing, the Dixie model creates a "turn penalty" file which is used to prevent direct zone to zone access via just centroid connectors and to ensure these trips use the highway network. The resultant text file is stored in the model run's '0_InputProcessing' directory.

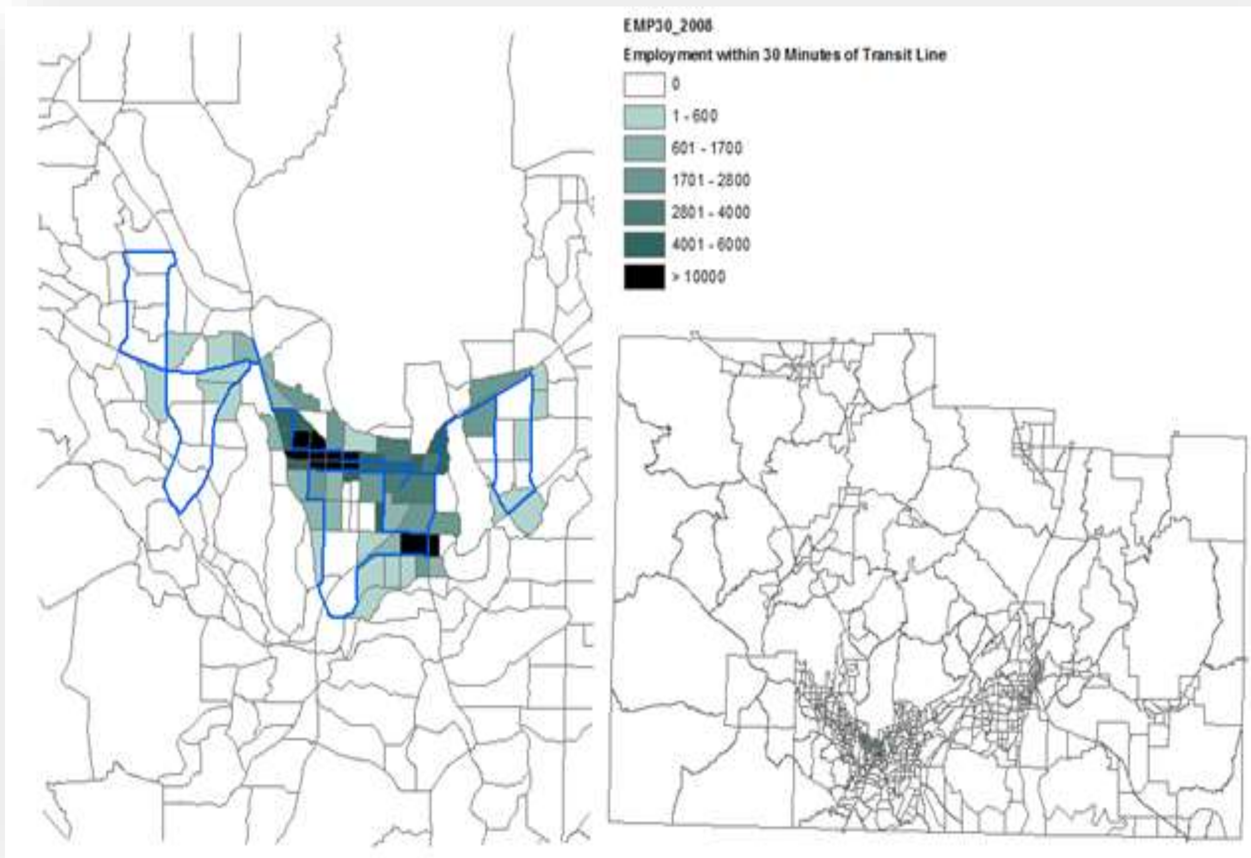
5.3.6 Transit Route Tester

The transit route tester performs three key functions related to the transit data. This step of the model is named after the first and primary step in this piece of the model, which is to make sure the scenario's transit line files in the input directory load onto the scenario network. If the transit lines cannot be built onto the network, the model crashes and the resultant errors are found in the model run print file.

In the second function, the model identifies which zone pairs can be accessed by transit without transferring. The results are found in a matrix file in the '0_InputProcessing' directory. The values in the matrix are 1 or 0, with 1 indicating a trip can be made between zones without transferring.

In the third function, the model calculates for each TAZ the amount of employment that can be accessed within 30 minutes by transit (based on a free flow speed condition). The results are found in a text file in the '0_InputProcessing' directory and a graphical representation is seen in Exhibit 31.

Exhibit 31. Employment within 30 Minutes of Transit Travel Time



5.4 College Trip Table

Home-based college (HBC) trips are define as trips made by college students going directly from home to college or from college to home. HBC trips are estimated based on a student home location model (production end of the trip – the college is the destination end) and a enrollment based trip rate estimated from the college portion of the 2012 Household Travel Survey.

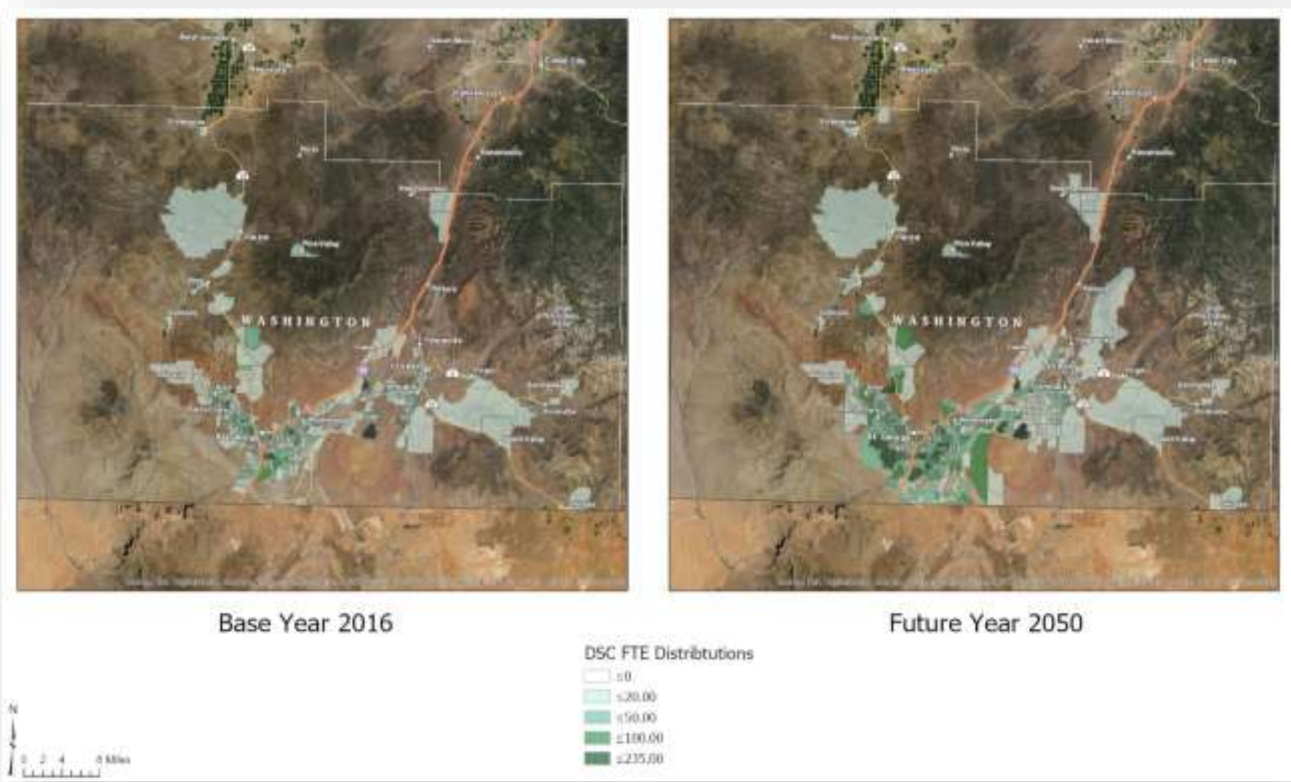
The student home location model is a linear regression model transferred from the WFRC/MAG model. The model uses the following variables:

- Base year student distribution
- Student headcount control total
- TAZ population
- TAZ household density
- Distance to the DSU campus
- Accessibility of DSU via transit with no transfers

The HBC trip model takes the base year distribution and forecasts the change in the number of students for the scenario year. If the scenario year has more students than the base year, the model will add the difference to the base year distribution. Conversely, if the scenario has fewer students than the base year, the model will remove students from the base year distribution.

The student location is estimated by multiplying the TAZ population by a coefficient based on the proximity of the TAZ to DSU, the household density of the TAZ and the accessibility of the campus by transit. The initial student distribution is then scaled to the difference between the scenario year student total and base year student distribution total.

Exhibit 32. DSU Student Distribution for 2016 and 2040



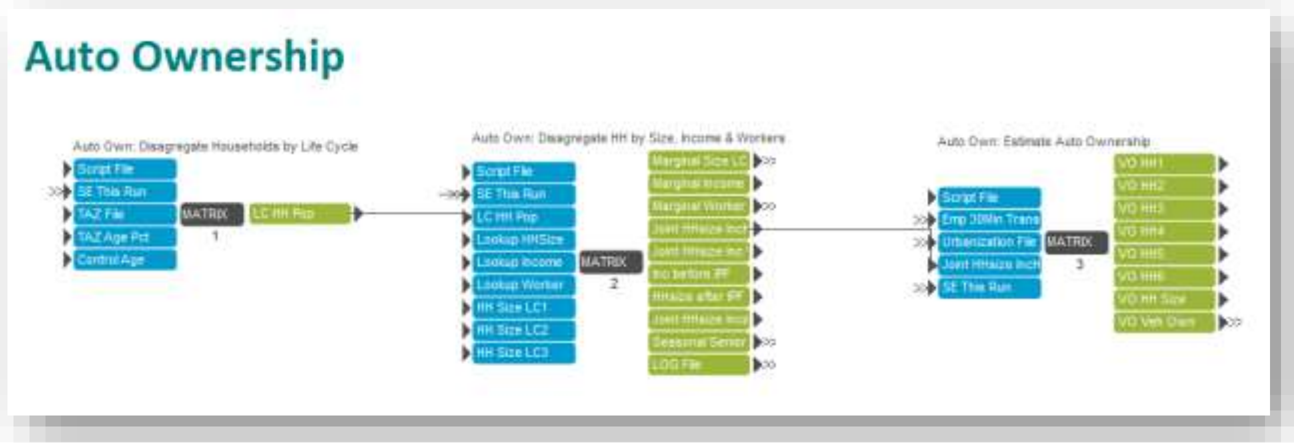
The student control total is based on total headcount for the college. The total is reduced in the model by a factor to account for students who are taking concurrent enrollment classes while in high school and students who are only taking online courses resulting in students who actually make trips to campus.

The student trip rate calculates the number of HBC trips per day. The trip rate is based on a student population that has the concurrent enrollment and online only students removed. The student distribution file and the HBC trip matrix are found in the '0_InputProcessing' directory.

6.0 HOUSEHOLD DISAGGREGATION & AUTO OWNERSHIP

The Dixie travel model uses the data in the socioeconomic files, input control total files, and statistical curves estimated from the 2010 Census and the 2012 Household Travel Survey to stratify the input household data into life cycle, household size, income, and worker segments as well as estimate the number of autos a household will own. The steps of the household disaggregation and auto ownership model are shown in Exhibit 33.

Exhibit 33. Auto Ownership Model



6.1 Life Cycle Disaggregation

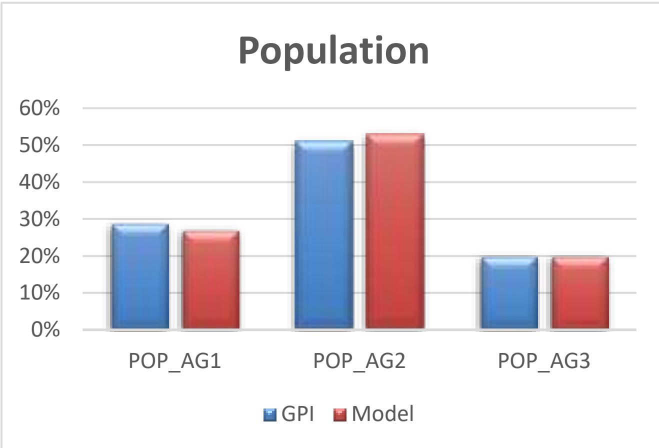
The household disaggregation model first classifies households by three life cycle categories:

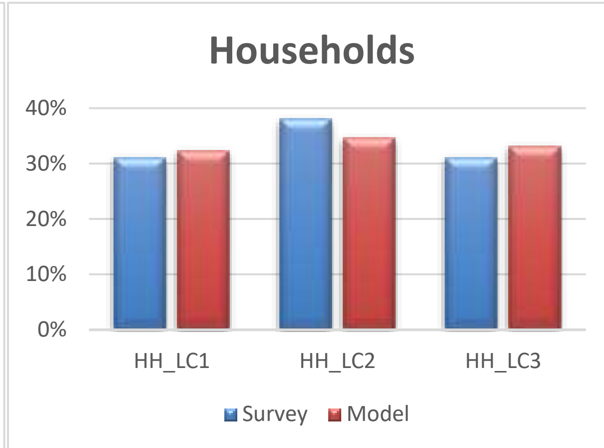
- Households with no children and no seniors
- Households with children and no seniors
- Households with seniors (may have children)

The model estimates life cycle categories based on the age of the population in a TAZ adjusting for how age groups may change over time. The TAZ level age distribution is calculated from the 2010 Census. The county level change in age over time is calculated from the GPI age forecasts. Both of these input files are found in the static directory. The model then uses parameters estimated from the 2012 Household Travel Survey to convert population in an age group to population in a life cycle category and then ultimately to households in a life cycle category.

The results of the life cycle model were compared to GPI county control totals and to the 2012 Household Travel Survey for validation, as seen in the following figure. The results of the model appear reasonable.

Exhibit 34. Life Cycle Model Validation





6.2 Household Size Disaggregation

The household disaggregation model also classifies households into the following household size (the number of people in the household) groups:

- 1 person households
- 2 person households
- 3 person households
- 4 person households
- 5 person households
- 6 or more person households

The model uses the average household size in a TAZ and statistical distributions create the household disaggregation. The disaggregation is performed independently for each of the three life cycle groups, each using its own set of statistical distribution curves estimated from the 2012 Household Travel Survey. The household disaggregation statistical curves are shown in the following exhibits.

Exhibit 35. Household Size Disaggregation Curve – Life Cycle 1

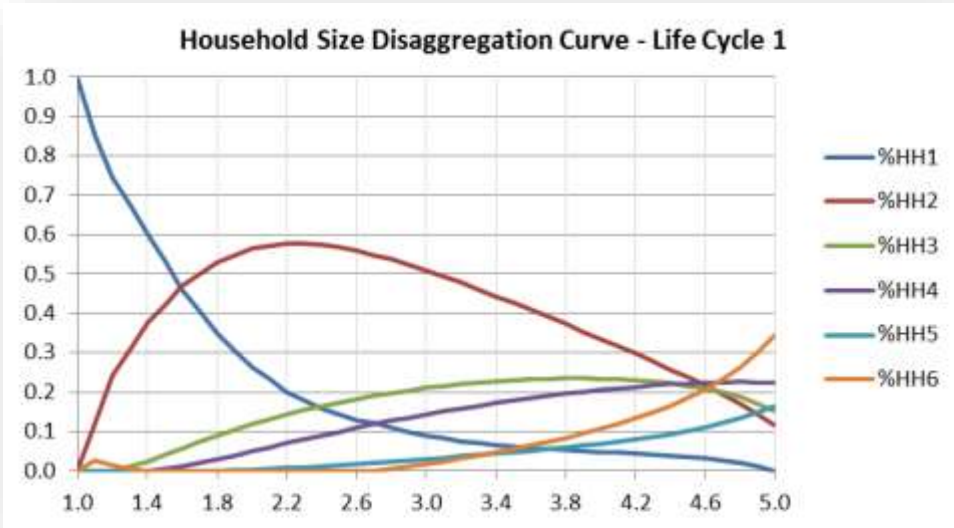


Exhibit 36. Household Size Disaggregation Curve – Life Cycle 2

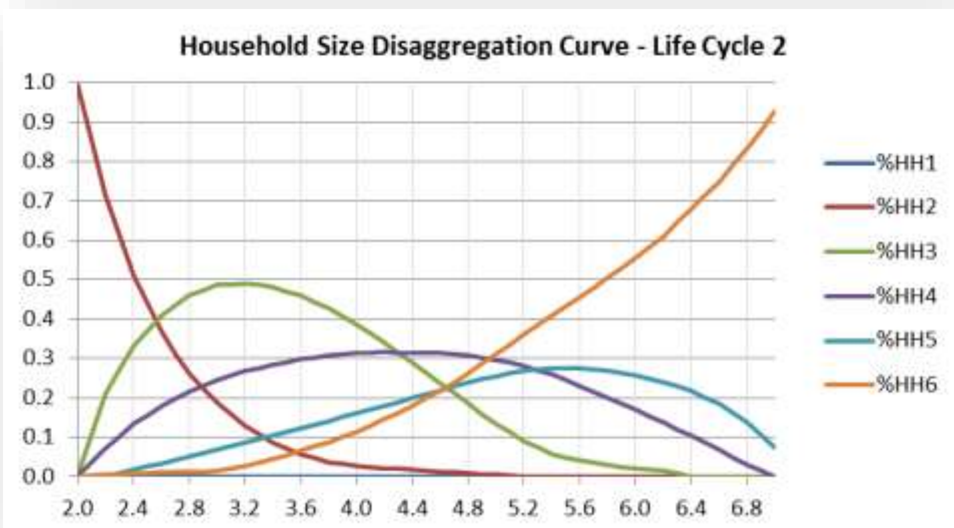
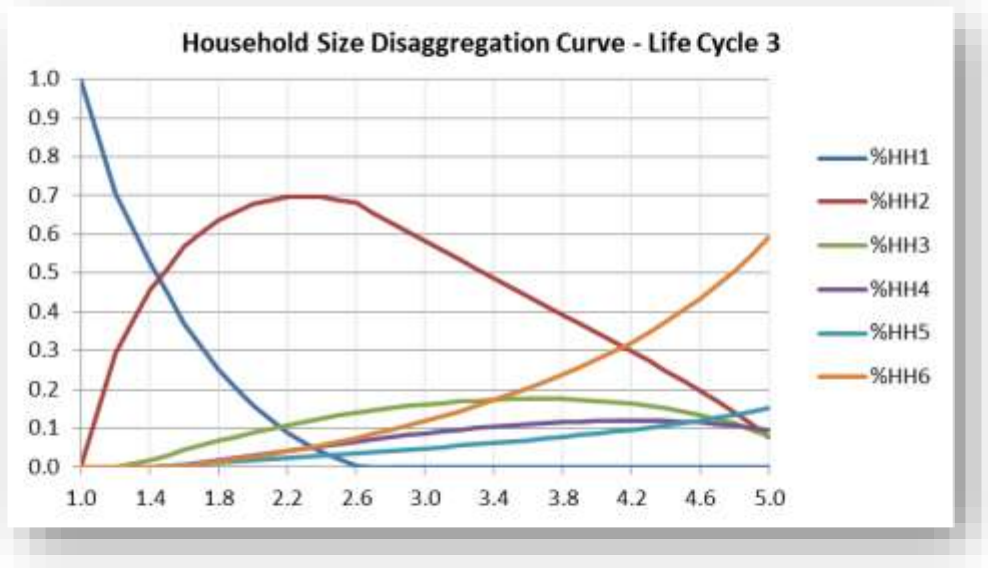


Exhibit 37. Household Size Disaggregation Curve – Life Cycle 3



The results of the household size disaggregation model were validated against the 2012 household Survey and the 2010 Census, which can be seen in the following exhibits:

Exhibit 38. Household Size Validation by Life Cycle (2012 Household Travel Survey)

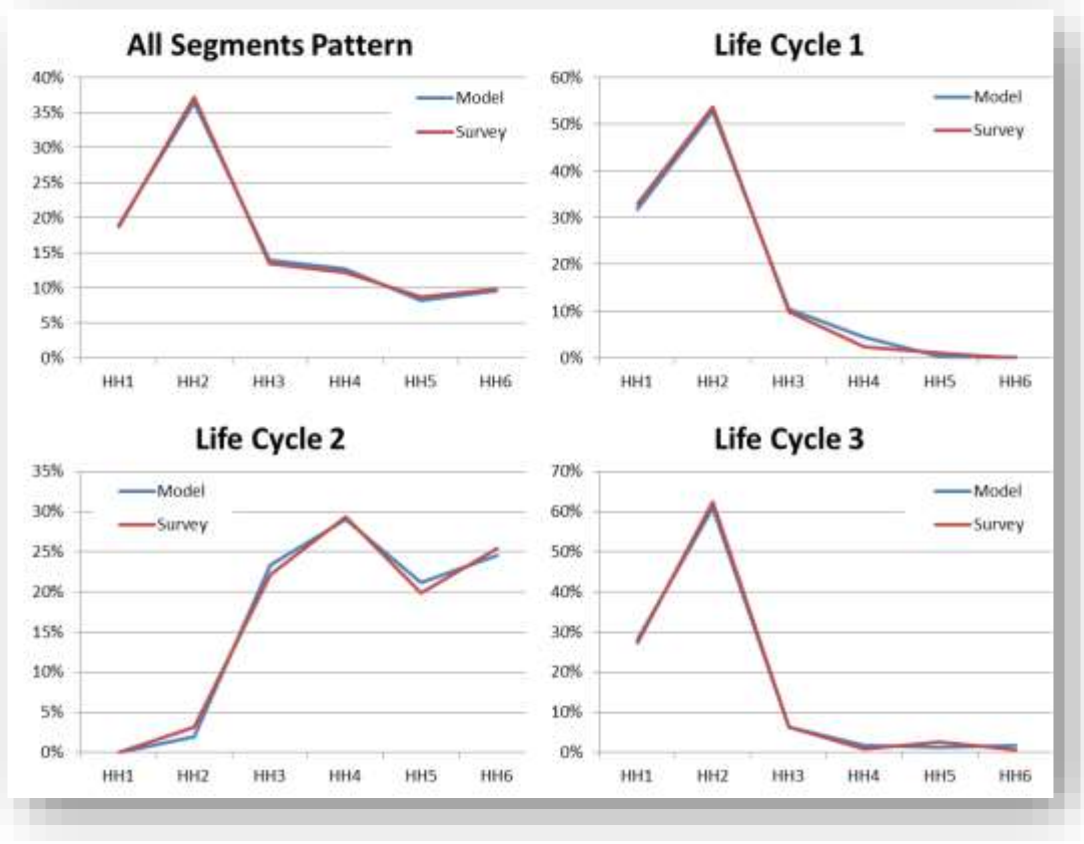
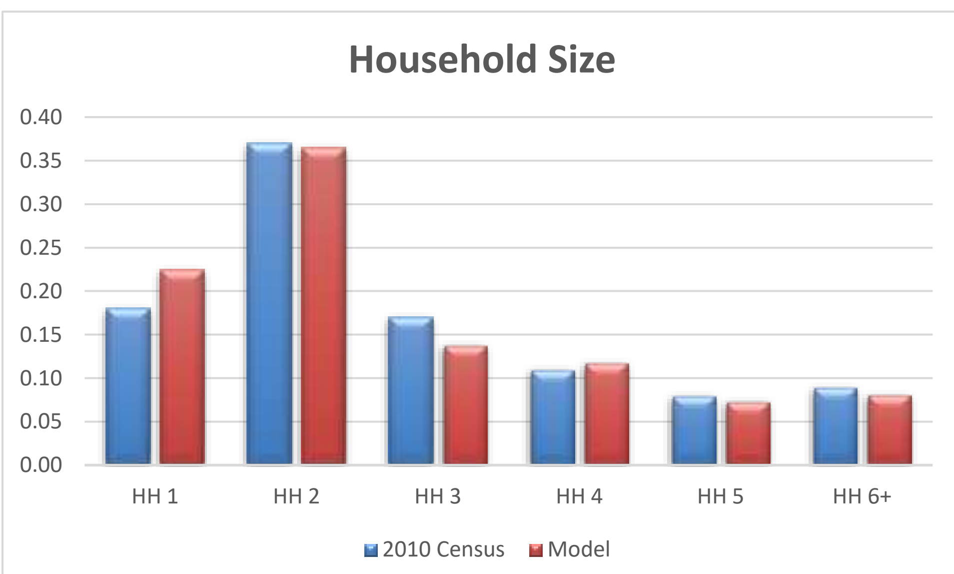


Exhibit 39. Household Size Validation (2010 Census)



6.3 Income Group Disaggregation

The household disaggregation model estimates the number of households in the following income groups:

- Households in income Group 1 - $0 to $34,999
- Households in income Group 2 - $35,000 to $49,000
- Households in income Group 3 - $50,000 to $99,999
- Households in income Group 4 - $100,000+

These groups were collapsed from the 2010 Census income groupings and roughly approximate income quartile for the income groups 1 and 4. Assignment of households into one of the four income groups is based on the ratio of the zonal median income to the county median income and statistical distributions estimated from the 2010 Census, as seen inExhibit 40. The following exhibits show the income distribution graphically and the validation of the income disaggregation model to the 2010 Census data.

After the marginal household size and income disaggregation totals have been calculated for a zone, a two-dimensional matrix balancing routine is used to create a joint distribution by size and income group. A seed matrix is used to provide the initial values for the balancing routine. The seed matrix input was generated using 2012 Household Travel Survey data.

Exhibit 40. Income Disaggregation Curve

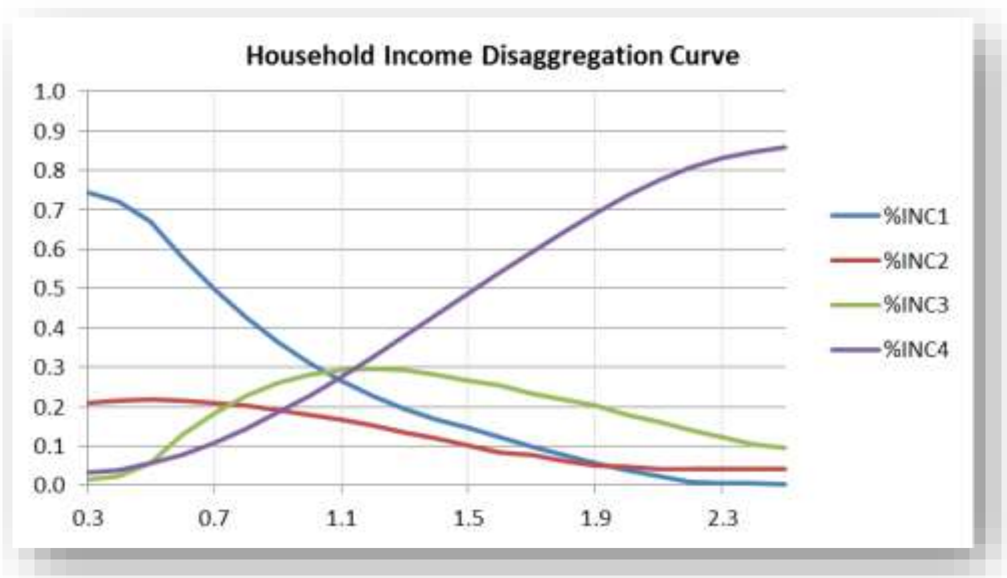
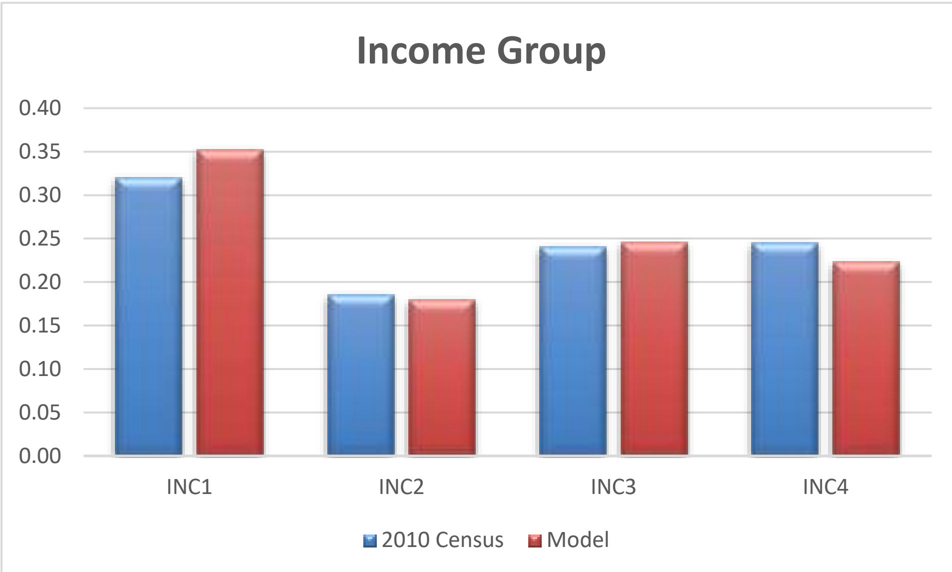


Exhibit 41. Income Group Validation (2010 Census)



6.3.1 Number of Workers

The final step of the household disaggregation model estimates number of workers in a household into one of the following groups:

- 0 worker households
- 1 worker households
- 2 worker households
- 3 or more worker households

The worker disaggregation model uses the joint household size-income table and a lookup table to assign to the joint household size, income, worker cross-classification table. The worker distribution curves were developed using 2000 Census data which were smoothed and calibrated to reproduce the marginal distribution at the region level. The following exhibits show the lookup table numerically and the validation vs. census data.

Exhibit 42. Workers Disaggregation Lookup Table

SIZE	INCQRT	INDEX	%WKR0	%WKR1	%WKR2	%WKR3	Sum
1	1	1	0.77251	0.22749	0.00000	0.00000	1.0000
1	2	2	0.43009	0.56991	0.00000	0.00000	1.0000
1	3	3	0.36143	0.63857	0.00000	0.00000	1.0000
1	4	4	0.33199	0.66801	0.00000	0.00000	1.0000
2	1	5	0.56318	0.29536	0.14147	0.00000	1.0000
2	2	6	0.48201	0.25277	0.26522	0.00000	1.0000
2	3	7	0.46990	0.24857	0.28154	0.00000	1.0000
2	4	8	0.29288	0.28672	0.42040	0.00000	1.0000
3	1	9	0.29751	0.50203	0.11831	0.08215	1.0000
3	2	10	0.08076	0.48601	0.31855	0.11468	1.0000
3	3	11	0.03474	0.39828	0.40864	0.15833	1.0000
3	4	12	0.01721	0.26151	0.49304	0.22823	1.0000
4	1	13	0.24706	0.52071	0.13522	0.09701	1.0000
4	2	14	0.07426	0.47288	0.30124	0.15162	1.0000
4	3	15	0.02292	0.35705	0.41609	0.20395	1.0000
4	4	16	0.01546	0.26164	0.49240	0.23050	1.0000
5	1	17	0.16941	0.56427	0.15545	0.11086	1.0000
5	2	18	0.03757	0.46320	0.32222	0.17702	1.0000
5	3	19	0.02285	0.33523	0.41474	0.22719	1.0000
5	4	20	0.01539	0.23991	0.49076	0.25393	1.0000
6	1	21	0.12899	0.57280	0.17441	0.12380	1.0000
6	2	22	0.03013	0.46942	0.32300	0.17745	1.0000
6	3	23	0.01525	0.34124	0.41575	0.22776	1.0000
6	4	24	0.00772	0.24574	0.49198	0.25455	1.0000

Exhibit 43. Worker Validation (2010 Census)

6.4 Auto Ownership

The auto ownership model is a multinomial logit model that estimates the number of vehicles each household owns based on:

- household size
- household income
- density of the nearest five zones
- the amount of employment within 30-minutes of transit

These variables were determined to be significant in replicating the behavioral characteristics of a household's decision to own or not to own vehicles. For instance, low-income or smaller household sizes or households with fewer workers are less likely to own as many vehicles as larger-income households or households with more people or more workers. Likewise, higher density locations also correlate with lower auto ownership and with more transit-accessible neighborhoods. The model's structure was transferred from the WFRC/MAG model and the logit model's constants were calibrated to the Dixie area using the 2010 Census.

The coefficients of the household parameters, HH1 through HH4, are relative to the households with five or more persons in them. As such the HH5 and HH6+ parameters are set to zero. Since these parameters are set to zero, the HH5 and HH6+ parameters are excluded from the utility equations. Likewise, WRK0 through WRK2 are relative to 3+ workers per household, so the WRK3+ parameter is also set to zero and excluded from the equations. The other parameters displaying zero coefficients in the utility equations are listed for clarification purposes. The 0, 1, and 2 vehicle utility equations are relative to the 3+ vehicle utility, hence the 3+ vehicle utility is set to zero.

Utility for Owning 0 Vehicles:

```
U0veh[I] = -5.103 + 3.777      * HH1          +
                    1.314      * HH2          +
                    0.145      * HH3          +
                    0.001      * HH4          +

                    0.998      * WRK0         +
                    0          * WRK1         +
                    0          * WRK2         +

                    2.733      * INCL         +

                    0.05159    * PopDen5Zones +
                    0.0000199  * zi.1.emp30tran
```

Utility for Owning 1 Vehicle:

```
U1veh[I] = -1.970 + 3.368       * HH1          +
                    0.973       * HH2          +
                    0.139       * HH3          +
                    -0.720      * HH4          +

                    0.514       * WRK0         +
                    0.552       * WRK1         +
                    0           * WRK2         +

                    1.557       * INCL         +

                    0.07346     * PopDen5Zones +
                    0.000008342 * zi.1.emp30tran
```

Utility for Owning 2 Vehicles:

```
U2veh[I] = 0.150  + 0.929      * HH1          +
                    0.892      * HH2          +
                    -0.316     * HH3          +
                    -0.919     * HH4          +

                    0          * WRK0         +
                    0.081      * WRK1         +
                    0.07       * WRK2         +

                    0.538      * INCL         +

                    0.02366    * PopDen5Zones
```

Utility for Owning 3+ Vehicles = 0

Where:

HH1 = 1 if a 1 person household, 0 otherwise

HH2 = 1 if a 2 person household, 0 otherwise

HH3 = 1 if a 3 person household, 0 otherwise

HH4 = 1 if a 4 person household, 0 otherwise

WRK0 = 1 if a 0 worker household, 0 otherwise

WRK1 = 1 if a 1 worker household, 0 otherwise

WRK2 = 1 if a 2 worker household, 0 otherwise

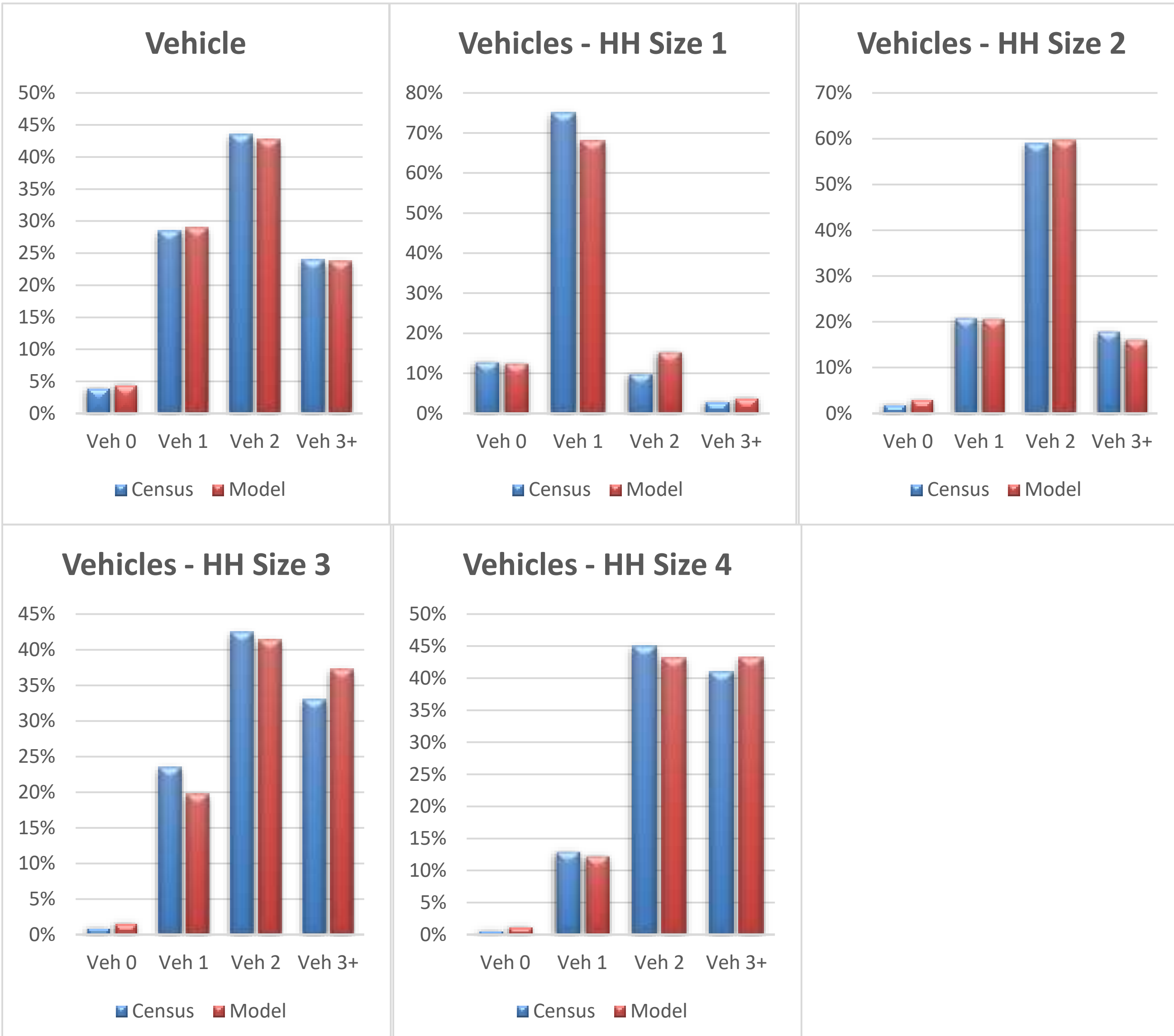
INCL = 1 if lowest income quartile, 0 otherwise

POPDEN = population density of nearest 5 zones (population/acres)

EMP30TRAN = employment within 30 minutes of transit

The utility equations are used to establish the probability or likelihood that a household displaying certain characteristics will own a vehicle. Auto ownership results are summarized into a cross-classification table by the six household size categories and four auto ownership categories. Exhibit 44shows the validation of the base year model to 2010 Census data.

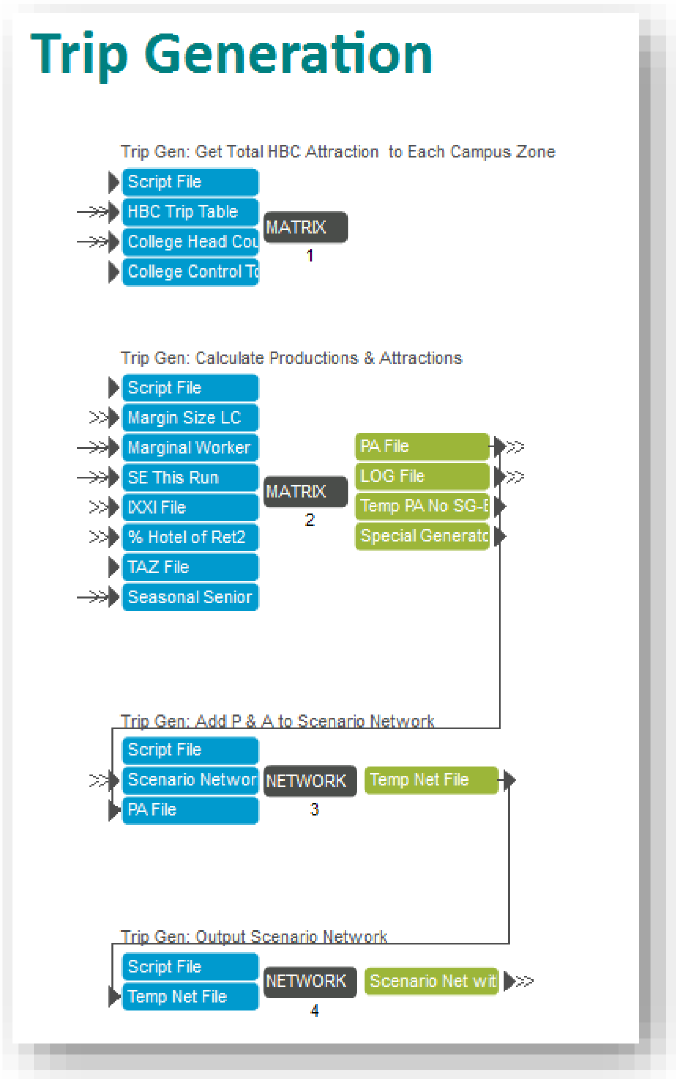
Exhibit 44. Auto Ownership Validation (2010 Census)



7.0 TRIP GENERATION

The Dixie trip generation model estimates production and attraction trip ends for each TAZ. The main steps in the model are shown in the following graphic.

Exhibit 45. Model Structure of Trip Generation



The trip generation model calculates internal trip ends for the following person trip purposes:

- Home-based work (HBW)
- Home-based school-primary, grades K-5 (HBSchPR)
- Home-based school-secondary, grades 6-12 (HBSchSC)
- Home-based shopping (HBSHP)
- Home-based other (HBOth)

- Non-home-based work (NHBW)
- Non-home based non-work (NHBNW)

In addition the model also calculates internal trip ends for the following vehicle trips:

- Short-haul commercial vehicle
  - 4-tire vehicles or light trucks (SH_LT)
  - Single unit or medium trucks (SH_MD)
  - Multi-unit or heavy trucks (SH_HV)
- Internal-external (IX)
- External-internal (XI)

Home-based college (HBC), external-external passenger trips (XX) and external truck trips (LH_MD and LH_HV) are calculated previously in an off-line process or in an earlier stage of the model.

7.1 Trip Productions

7.1.1 Person Trip Production Rates

The person trip production rates were estimated using the 2012 Household Travel Survey data. HBW and NHBW trip productions are estimated based on the number of workers in a household. HBSch, HBShp, HBOth and NHBNW trip productions are based on household size and life cycle. The following charts show the production rates for the specific trip purposes.

Exhibit 46. HBW and NHBW Trip Production Rates

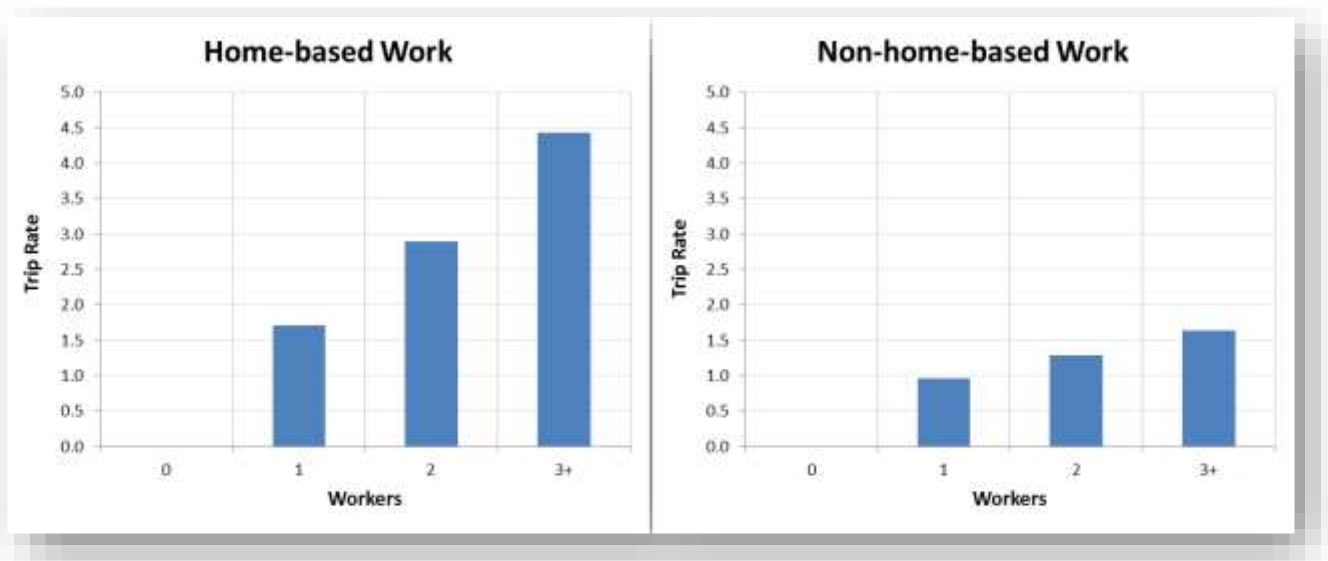


Exhibit 47. HBSch and HBShp Trip Production Rates

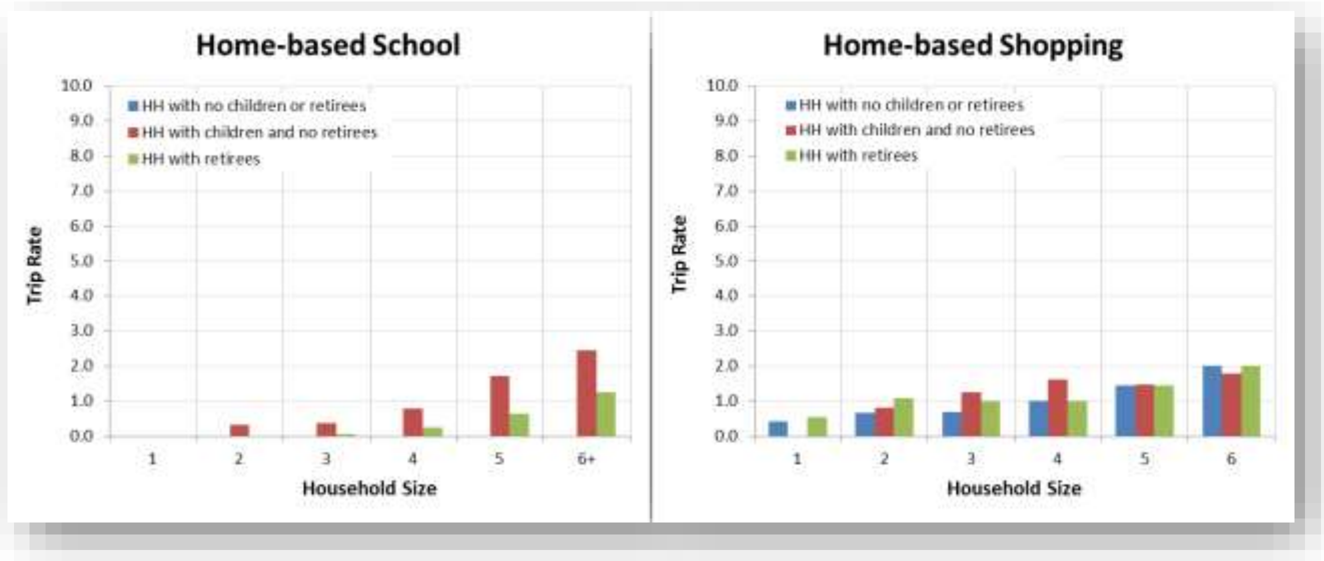
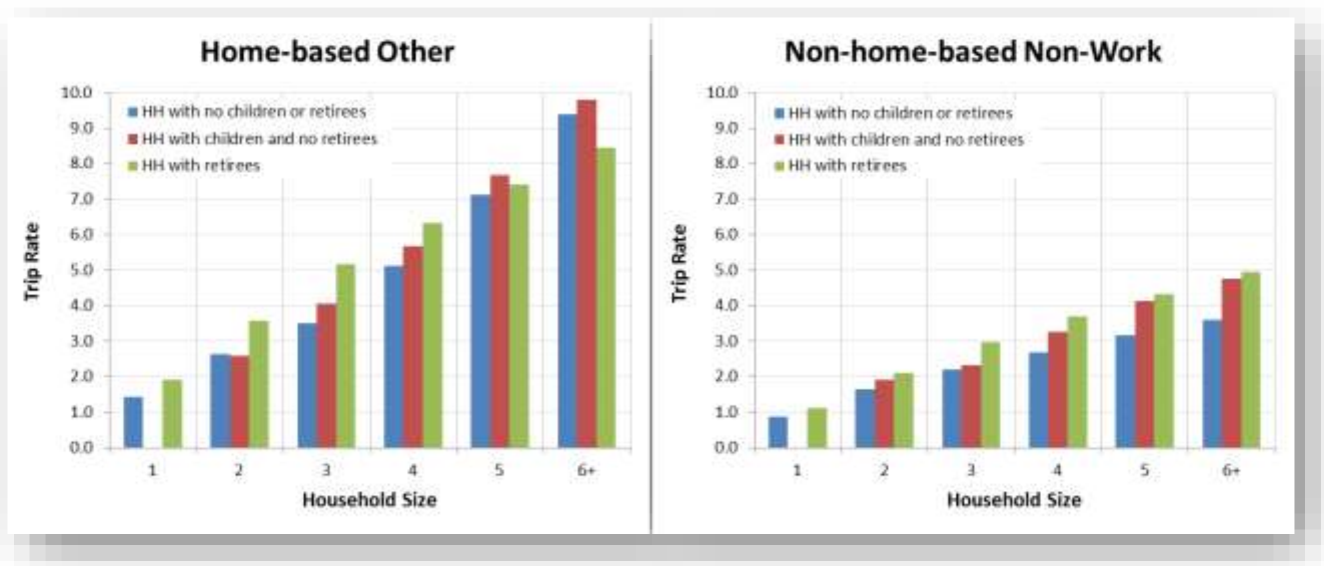


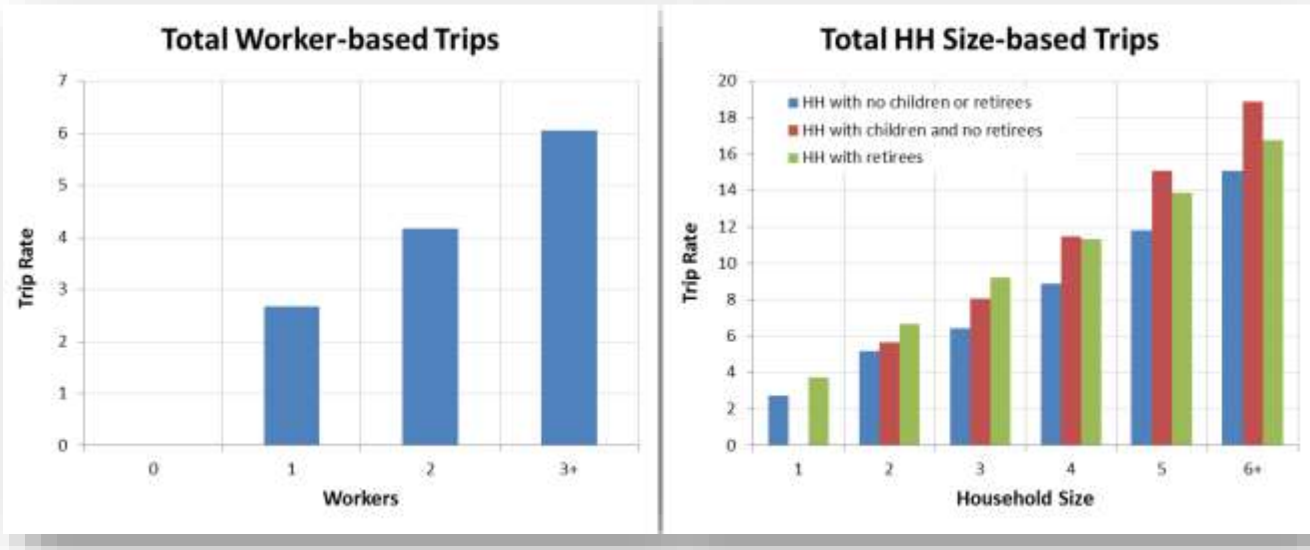
Exhibit 48. HBOth and NHBNW Trip Production Rates



Seasonal senior trip generation is also calculated for HBShp, HBOth and NHBNW trip purposes. It is assumed that seasonal seniors do not make school trips or work-related trips. Trip productions for seasonal seniors use the 'households with retirees' life cycle rates.

Each of the above charts uses a similar scale to better show the relative trip productions for each purpose. The cumulative trip production can be shown by adding the individual trip rates by variable class. These can be seen in the following figure. The HBW and NHBW trip rates were combined to show the total worker-based trip productions. Similarly, the HBSch, HBShp, HBOth and NHBNW were combined to show the total household size-based trip productions.

Exhibit 49. Total Worker and Household Size-based Trip Production Rates



7.1.2 Short-haul Commercial Vehicle Trip Production Rates

The primary source for definition, model structure and parameters of the short haul commercial vehicle model comes from the FHWA report, "Accounting for Commercial Vehicles in Urban Transportation Models" which defines commercial vehicles as a range of vehicle types that are used for commercial, rental, educational or government services. Commercial vehicles are grouped into three main categories based on what is being carried and the economic, demographic and land use factors influencing the magnitude and distribution of the commercial vehicle trips. These categories are:

- **Commercial Passenger Vehicles (Moving People)** – includes school buses, shuttle services, rental cars, taxis, and paratransit vehicles.
- **Freight Vehicles (Moving Goods)** – includes mail delivery, trash collection, warehouse delivery, parcel pickup and delivery, and construction vehicles.
- **Services Vehicles** – includes household/building services such as plumbers and cleaning services as well as public safety, utility maintenance, and retail support functions.

The short haul commercial vehicle model assumes that the commercial vehicles do not include trips from outside the model region based on the understanding that the long-haul freight model captures the inter-regional movements.

Trip rates were estimated based on vehicle per capita and trips per vehicle rates from the FHWA research and Washington County 2012 socioeconomic data for all but the urban freight goods movement. For the urban freight goods movement, trip rates were based on the San Joaquin freight model. Rates were further adjusted to fit the Dixie area.

Short haul commercial vehicle trip rates were further stratified by light, medium and heavy vehicle classes. The final short-haul commercial vehicle trip rates are shown in the following table. School bus trips are excluded in the calculation as these trips are estimated by the HBSch trip model.

Exhibit 50. Short-haul Commercial Vehicle Trip Production Rates

	Vehicle Type	Variables	Light	Medium	Heavy
Moving People	School Bus	Households	-	-	-
	Shuttle Service	Households + Employment	0.00250	0.00028	-
	Private Transport	Employment	0.00795	-	-
	Paratransit	Households + Employment	-	0.00126	-
	Rental Cars	Households + Employment	0.05980	0.00664	-
Goods	Package/Product/Mail	Households + Employment	0.06665	0.00210	0.00140
	Urban Freight	Ag. + Mining + Construction Emp	0.32908	0.33920	0.49432
		Industrial	0.27809	0.28404	0.29545
		Retail	0.26327	0.29695	0.18466
		Other	0.12956	0.07981	0.02557
		Households	0.07441	0.11620	0.10795
	Construction	HH + Emp + 2 * Construction Emp	0.02391	0.00717	0.01673
Services	Safety	Households + Employment	0.01145	0.00561	0.00631
	Utility Vehicles	Households	0.02104	0.01031	0.01159
	Public Service	Households + Employment	0.03834	0.01418	-
	Business/Personal Services	Households + Employment	0.05840	0.01196	-

Note: Employment refers to total employment not all employment

7.1.3 External Trip Production Rates

IX productions are based on the total HBW, HBOth and NHBNW total productions in a zone, which are used to establish the production distribution pattern. XI productions are generated outside the travel model and are read in as an input to trip generation.

7.2 Trip Attractions

7.2.1 Person Trip Attraction Rates

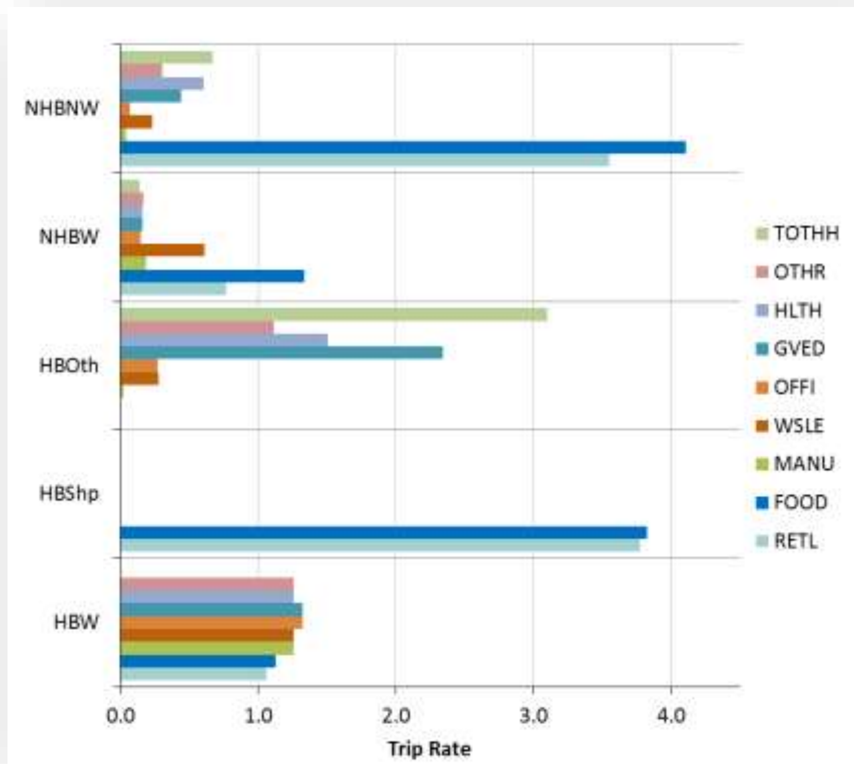
Person trip attraction rates were derived based on ITE trip generation patterns and scaled to be in line with trip totals from the trip production models. Rates were estimated for the following trip purposes:

- HBW
- HBSHp
- HBOth
- NHBW
- NHBNW

HBSch attractions are read in as a socioeconomic variable and not calculated.

Person trip attraction rates use the eight employment sub-categories. Values chosen for the rates represent a weighted average or a composite rate for each of the employment classifications represented. Households are also used as a variable in the attraction equations as households attract, as well as produce, trips. The following are the trip attraction rates in the Dixie model.

Exhibit 51. Person Trip Attraction Rates



7.2.2 Short-haul Commercial Vehicle Trip Attraction Rates

Short-haul commercial vehicle attractions are set to be equal to the trip productions at the TAZ level.

7.2.3 External Trip Attraction Rates

IX attractions are generated outside the travel model and are read in as an input to trip generation. XI attractions are based on total households plus total employment.

7.3 Special Generators

The Dixie trip generation model has special generators for Dixie State University and the national and state parks. The trip generation adjustments for each are described below.

7.3.1 Dixie State University

The model uses the ITE trip generation manual to calculate trips attracted to the college to account for the extra activity surrounding a college not captured in the employment attraction equation or the student trips to campus. Total trips are calculated instead from the FTE students in a zone * 2. 4 vehicle attractions/student * 1. 7 persons per vehicle. From this total, the HBC and HBW trips are subtracted and the remainder is proportionally deducted from the HBO and NHB trip purpose attractions. The HBW and HBC attractions are unadjusted.

7.3.2 National and State Parks

Recreation trip attraction rates to Zion National Park and the surrounding state parks are based on annual visitation data and an assumed growth rate. Base year and historic visitation data was obtained. Growth rates were calculated from the historic data. Based on the year being modeled, the Dixie model calculates the total growth anticipated from the base year to the scenario year. This growth factor is applied to the base year annual visitation total, which is then divided by 365 to reflect an average day. The exhibit below shows the growth rate and the expected daily trips attracted to the national and state parks for the base year and several horizon years.

	Quail Creek State Park	Sand Hollow State Park	Zion National Park	Kolob Reservoir	Gunlock State Park	Snow Canyon State Park
Growth Rate	0. 5%	4. 5%	0. 8%	0. 5%	0. 5%	1. 7%
2009	266	507	7,554	110	113	844
2020	281	823	8,246	116	119	1,016
2030	295	1,278	8,930	122	125	1,203
2040	311	1,985	9,671	128	132	1,424

Zion National Park comprises four TAZs; as such the total trips to Zion are divided among the four zones. The total recreation trips are divided among the home-based other and non-home-based trip purposes and added to the trips calculated using the normal trip generation equations. In addition, the NHBNW trip purpose is increased to account for the secondary trips of non-resident visitors by multiplying the hotel employment by 20.9 (ITE rate).

7.4 Trip Balancing

HBW, HBShp, HBOth, NHBW and NHBNW trip productions are used to scale total trip attractions. For NHBW and NHBNW trips, productions are set to attractions. The NHB production equations are used to determine the countywide trip totals used to scale both the NHB productions and attractions. HBSch productions are scaled to the attraction totals. IX productions are scaled to attractions. XI attractions are scaled to productions.

7.5 Trip Generation Validation

Aggregate trip totals were assessed for reasonableness after the senior population, the national/state park and rural area adjustments were made. These results are found in Exhibit 52.

After the adjustments are made, the model shows an average 3.83 trip productions per person which is slightly higher in line with the national average of 3.79 (2009 National Household Travel Survey) and the other Utah models. The trips per household are slightly higher than the national average at 10.8 but are considered reasonable as the area has higher persons per household than the national average. The after adjustment rates also seem reasonable.

The relative share between HBW, HBO and NHB trips looks reasonable with HBW at about 14% of the total and the highest share going to HBO. The adjusted results show a slightly higher NHB trip share accounting for the NHBNW adjustment from the national and state parks adjustment.

Commercial vehicles account for about 14% of the total internal trips generated by the model. This appears to be within the expected range based on industry experience.

IXXI trips account for around 3 % of the total trip generation. This also appears to be reasonable.

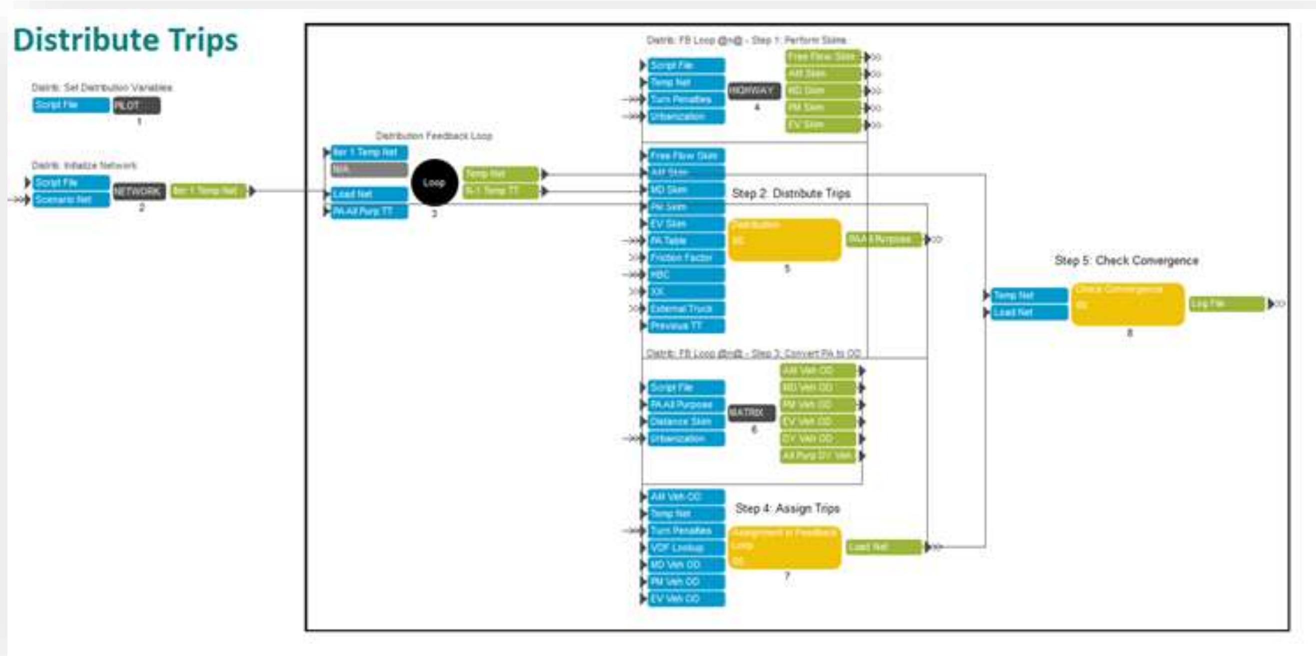
Exhibit 52. Trip Generation Validation (Reasonableness Check)

	After Adjustments
HBW	92,027
HBSch	24,742
HBShp	67,100
HBOth	249,387
NHBW	44,764
NHWNW	168,930
Total	646,950
Total HH	59,925
Total Pop	168,803
Total P/HH	10.8
Total P/Person	3.8
HBW	14%
HBO	53%
NHB	33%
Commercial Vehicle (CV)	104,979
Person Trips + CV	751,929
% CV	14%
IXXI	19,862
Person Trips + CV + IXXI	771,791
% IXXI	3%

8.0 TRIP DISTRIBUTION

The trip distribution model uses a "gravity" equation to distribute trips and an assignment feedback loop to get congested travel times. Trip distribution is done independently for HBW, HBSch_PR, HBSch_SC, HBShp, HBOth, NHBW, NHBNW, SH_LT, SH_MD, SH_HV, IX and XI trips. HBC, XX, LH_MD and LH_HV trips are already in a distributed trip matrix but are included in the assignment feedback loop. Trip distribution's main steps are shown in the following figure.

Exhibit 53. Model Structure of Trip Distribution



The trip distribution model includes a medium and large district summary as well as computes time and distance trip length frequencies. The trip distribution model also reports VMT and convergence values in the LOG file for each iteration of the distribution feedback loop.

8.1 Gravity Model

The concept underlying a gravity model is that trip-end locations that are closer together or that have higher concentrations will exhibit a stronger attraction than those that are farther apart or that are less concentrated. The functional form of the gravity model is as follows:

$$T_{ij} = P_i * \frac{A_j * f(d_{ij})}{\sum_{all\ zones\ z} A_z * f(d_{iz})} \quad \text{(Constrained to Productions)}$$

Where: T_{ij} = the forecast flow produced by zone i and attracted to zone j
P_i = the forecast number of trips produced by zone i
A_j = the forecast number of trips attracted to zone j
d_{ij} = the impedance between zone i and zone j
$f(d_{ij})$ = the friction factor between zone i and zone j

8.1.1 Trip Impedance

The distribution model uses a generalized cost function to measure impedance between zones. (Note: the distribution model uses the same generalized cost functions in calculating the skim values used in distribution that are used in the assignment models.) The generalized cost uses time, distance and penalties in determining the best path between zone pairs (there are no toll roads in the Dixie model so cost is not a factor). The distribution model uses six cost functions as seen in the following equations:

1) WORK = Time + Distance * AOC_Auto / VOT_Auto_Wrk + Penalties
2) PERSONAL = Time + Distance * AOC_Auto / VOT_Auto_Wrk + Penalties
3) EXTERNAL = Time + Distance * AOC_Auto / VOT_Auto_Ext + Penalties
4) LIGHT TRUCK = Time + Distance * AOC_LT / VOT_LT + Penalties
5) MEDIUM TRUCK = Time + Distance * AOC_MD / VOT_MD + Penalties
6) HEAVY TRUCK = Time + Distance * AOC_HV / VOT_HV + Penalties

Where:

AOC = auto operating cost

VOT = value of time

Auto operating costs are in cents/mile and include the cost of fuel, maintenance and tires (in 2010 dollars). The following auto operating costs are used in the equations above:

AOC_Auto = 18.3

AOC_LT = 24.6

AOC_MD = 47.8

AOC_HV = 63.7

Values of time are in cents/minute and are relative to the median wage. Median wage is defined by the median household income divided by 1.22 workers/household. Work trip value of time is calculated as 50% of the median wage. Personal trip value of time is equal to 80% of the work value of time. External trip value of time is the average of work and personal trip values of time. Light, medium and heavy truck values of time are based on typical values seen in the industry.

VOT_Auto_Per = 13

VOT_Auto_Wrk = 17

VOT_Auto_Ext = 15

VOT_LT = 30

VOT_MD	= 40
VOT_HV	= 50

The following table shows which generalized cost functions are used by which purposes:

WORK	HBW
PERSONAL	HBSch, HBShp, HBOth, NHBW and NHBNW
EXTERNAL	IX and XI
LIGHT TRUCK	SH_LT
MEDIUM TRUCK	SH_MD
HEAVY TRUCK	SH_HV

All generalized costs contain a ramp penalty to account for the added friction that occurs near freeway interchanges. The penalty is equal to 0.5 times the ramp free flow time. The MEDIUM TRUCK and HEAVY TRUCK generalized costs also contain a facility type penalty in the path building to reflect the fact that medium and heavy trucks tend to favor higher class roads whenever possible.

Even though distribution represents daily trips, the model performs skims for all four trip purposes. Diurnal factors for each purpose are used to weight the period skims in the daily generalized cost functions.

8.1.2 Friction Factors

The distribution model's friction factors are based on the exponential equation:

$$e^{x\,t}$$

Where:

e = the exponential function

x = purpose-specific parameter

t = generalized cost value (expressed in minutes)

The following table shows the values of x used in the friction factor calculations. The resultant friction factors by purpose are shown in the figures following the table.

Exhibit 54. Exponential Function "x" value Used in Friction Factor Calculation

Purpose	x
HBW	-0.08
HBSCH_PR	-0.5
HBSCH_SC	-0.22
HBSHP	-0.14
HBOTH	-0.14
NHBW	-0.09
NHBNW	-0.11
IX	-0.04
XI	-0.04
LT	-0.1
MD	-0.03
HV	-0.03

Exhibit 55. Friction Factors – Person Trips

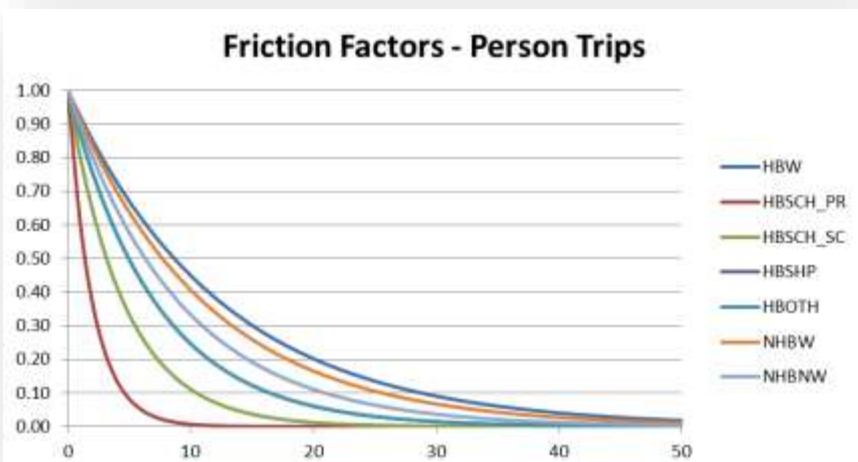


Exhibit 56. Friction Factors – External Trips

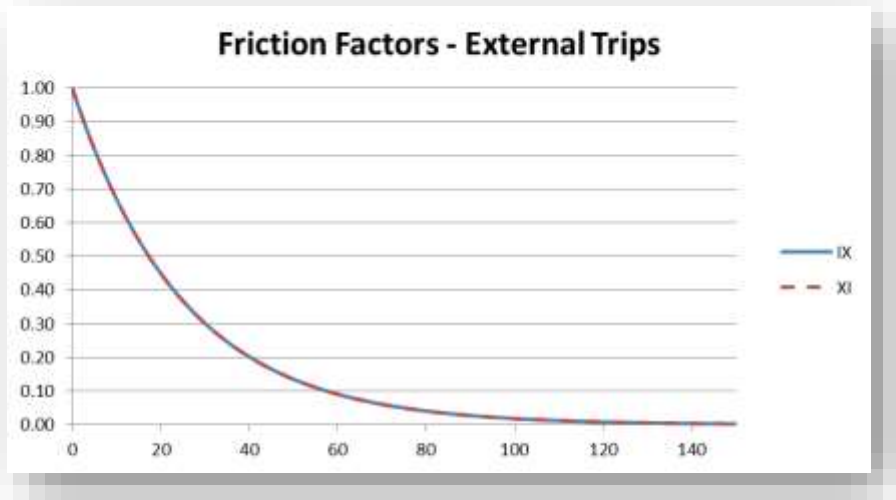
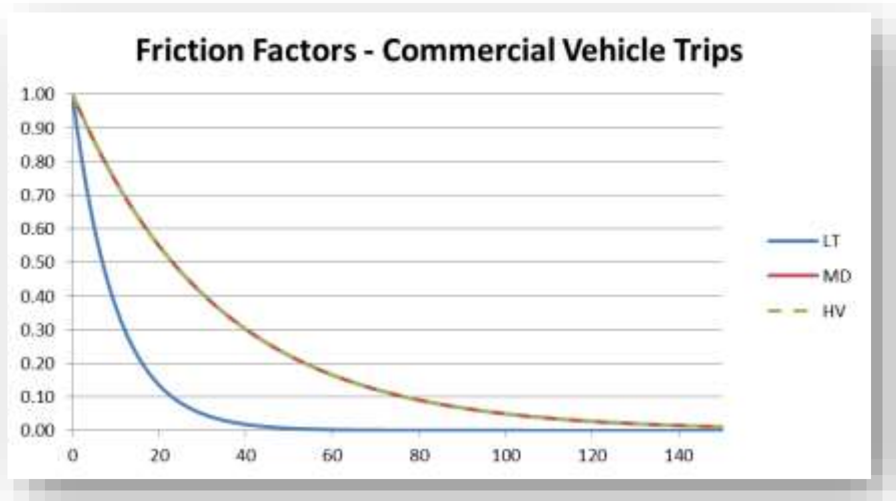


Exhibit 57. Friction Factors – Commercial Vehicle Trips



8.2 Distribution Feedback Loop

The distribution model contains a feedback loop with the assignment model so congested travel times may be used in calculating the impedances. The feedback loop has a maximum of 10 iterations. If the model reaches convergence before the maximum iterations, then the model will break out of the distribution feedback loop. The model uses the following criteria in determining to continue or break out of the distribution feedback loop:

- 95% of the link volumes are unchanged from the previous iteration
- 95% of the trip origin/destinations are unchanged from the previous iteration

The base year Dixie model typically converges in about 5 iterations. Typically the trip origin/destination criterion is met early on and the link volume criterion requires a few more iterations to be met.

The method of successive averaging (MSA) is used to average the distributed trip tables, beginning in iteration 3 of the distribution feedback loop. The averaged trips are assigned for each period and the resulting congested times are then skimmed for use in the next iteration of the feedback loop.

8.3 Distribution Validation

8.3.1 Trip Length Frequency Distributions

Modeled trip lengths for the base year were compared to the 2012 Household Travel Survey. The following exhibits show the modeled and observed time and distance average trip lengths and trip length frequencies:

Exhibit 58. Base Year Average Trip Lengths (Time)

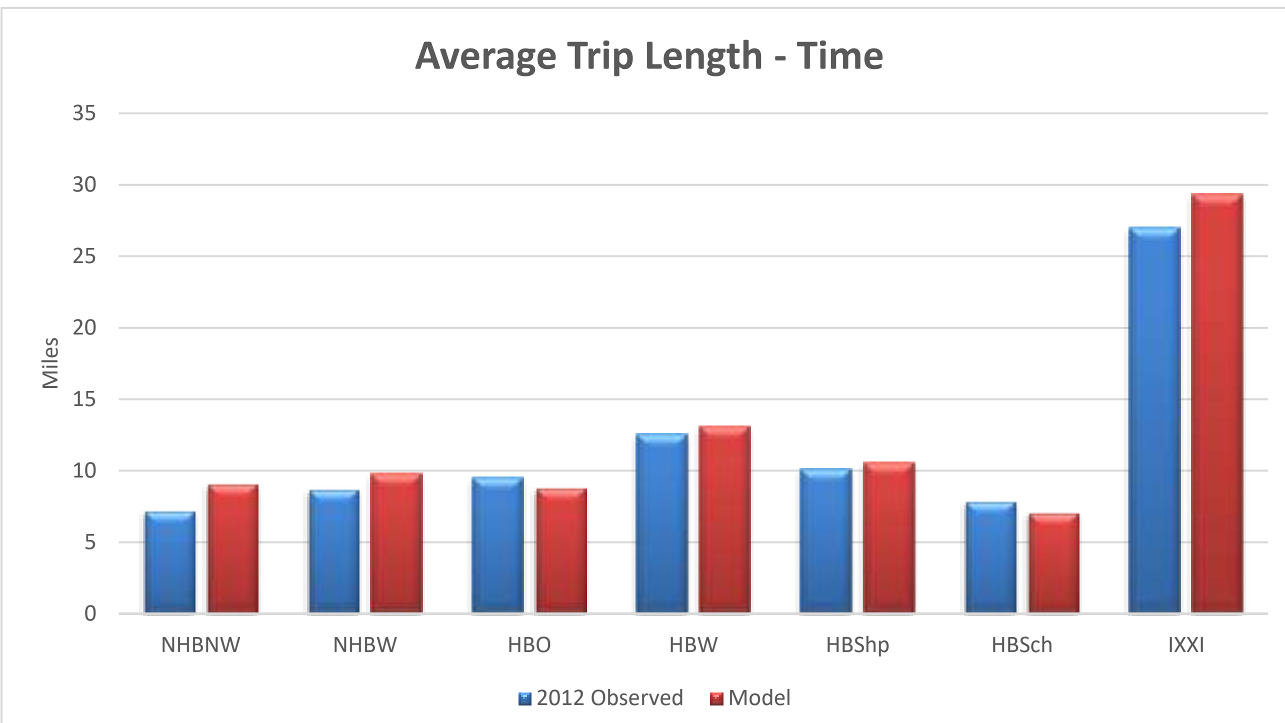


Exhibit 59. Base Year Average Trip Lengths (Distance)

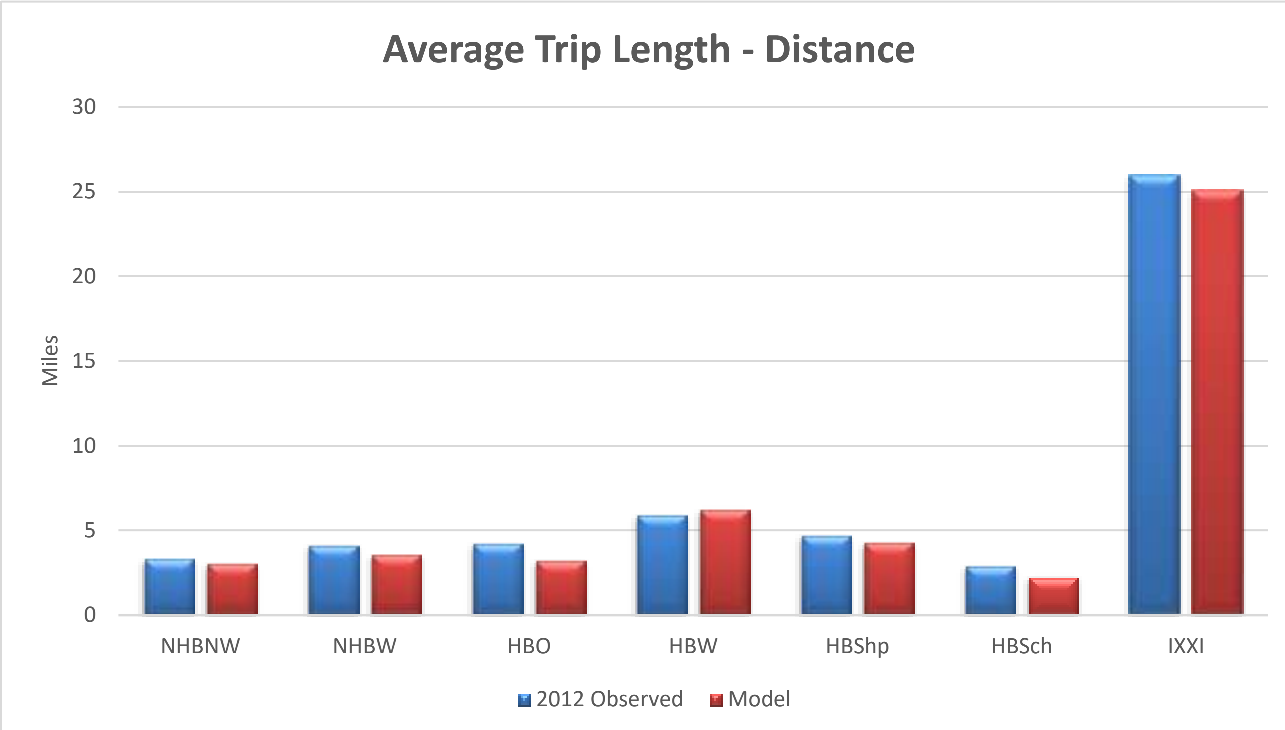
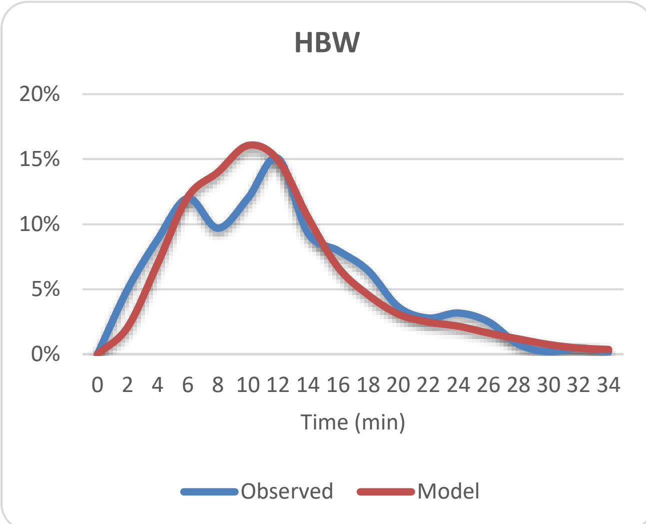
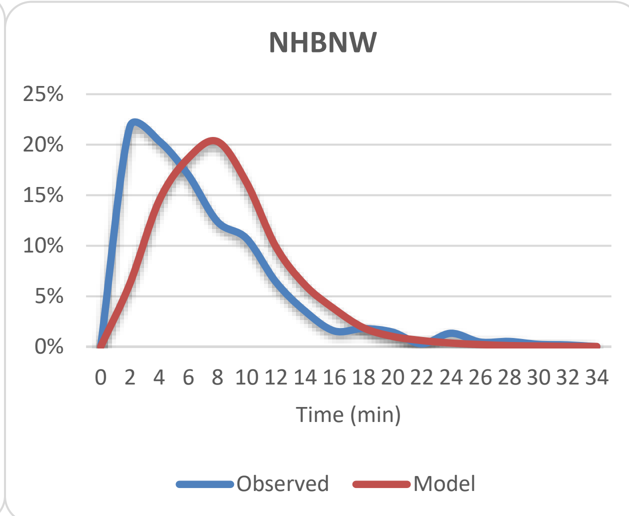
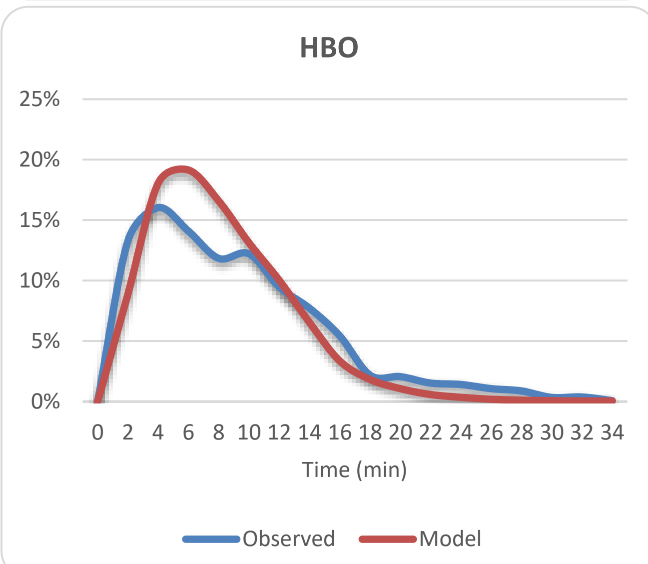
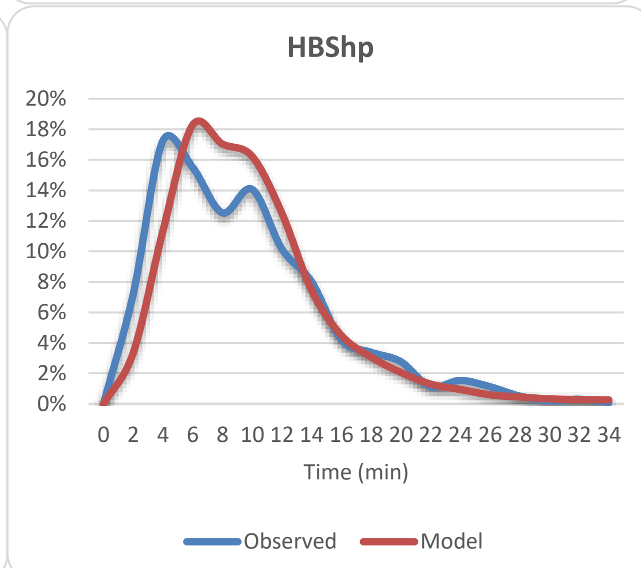


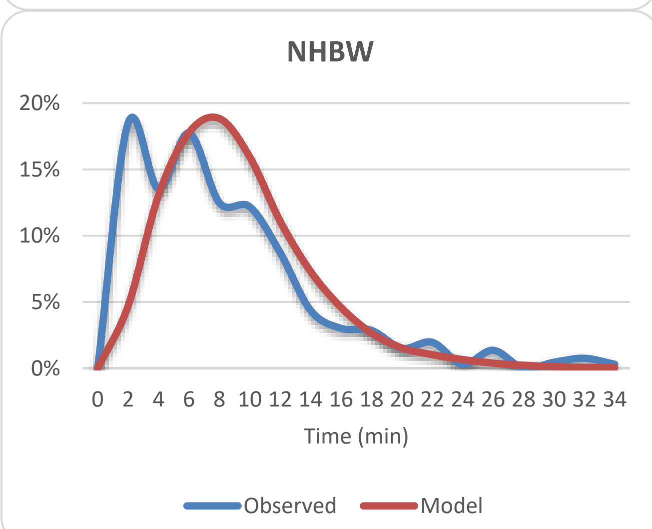
Exhibit 60. Base Year Trip Length Frequencies - Time











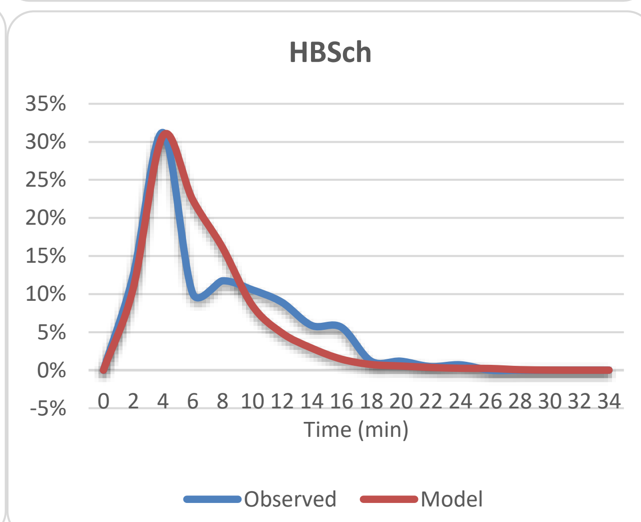
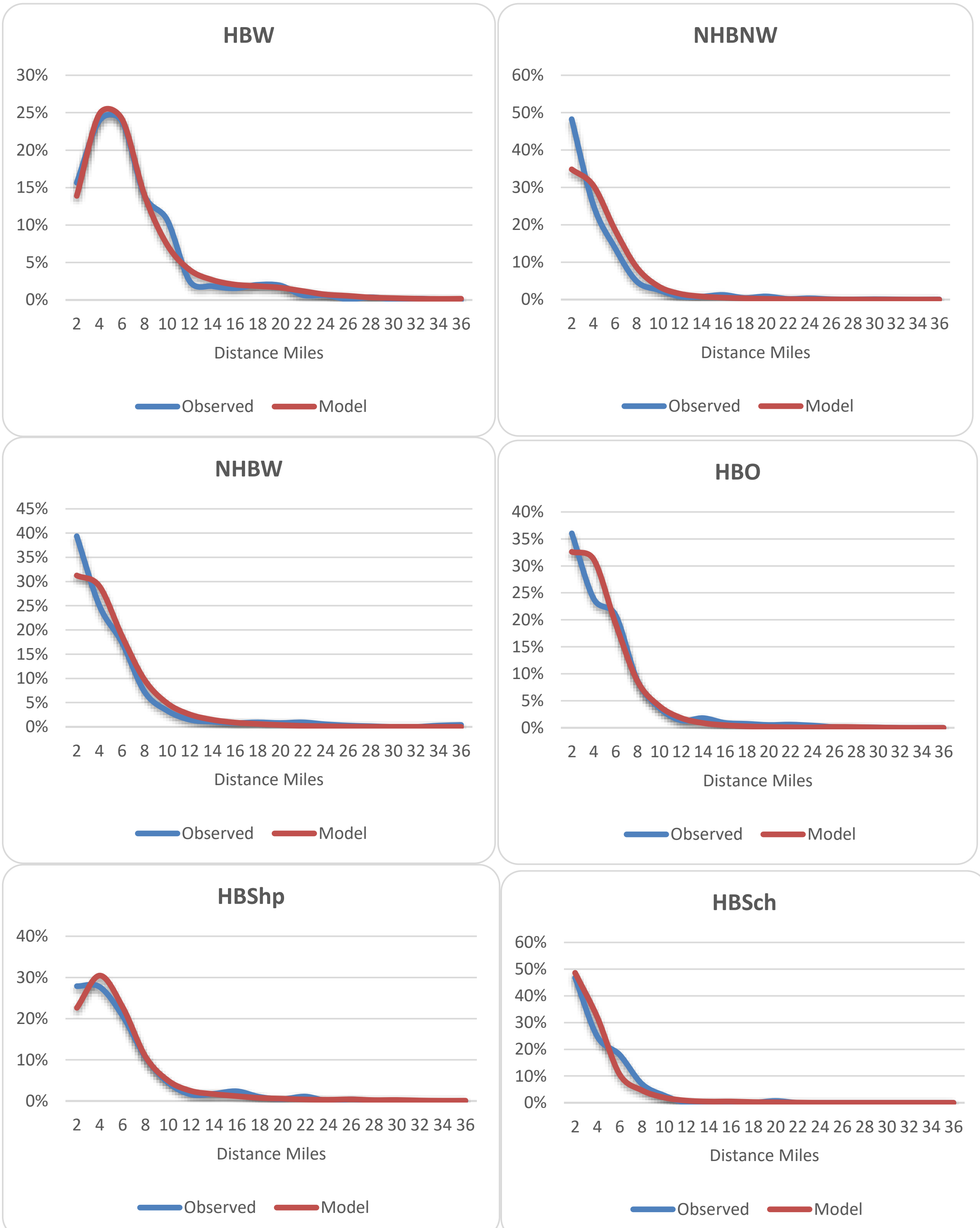
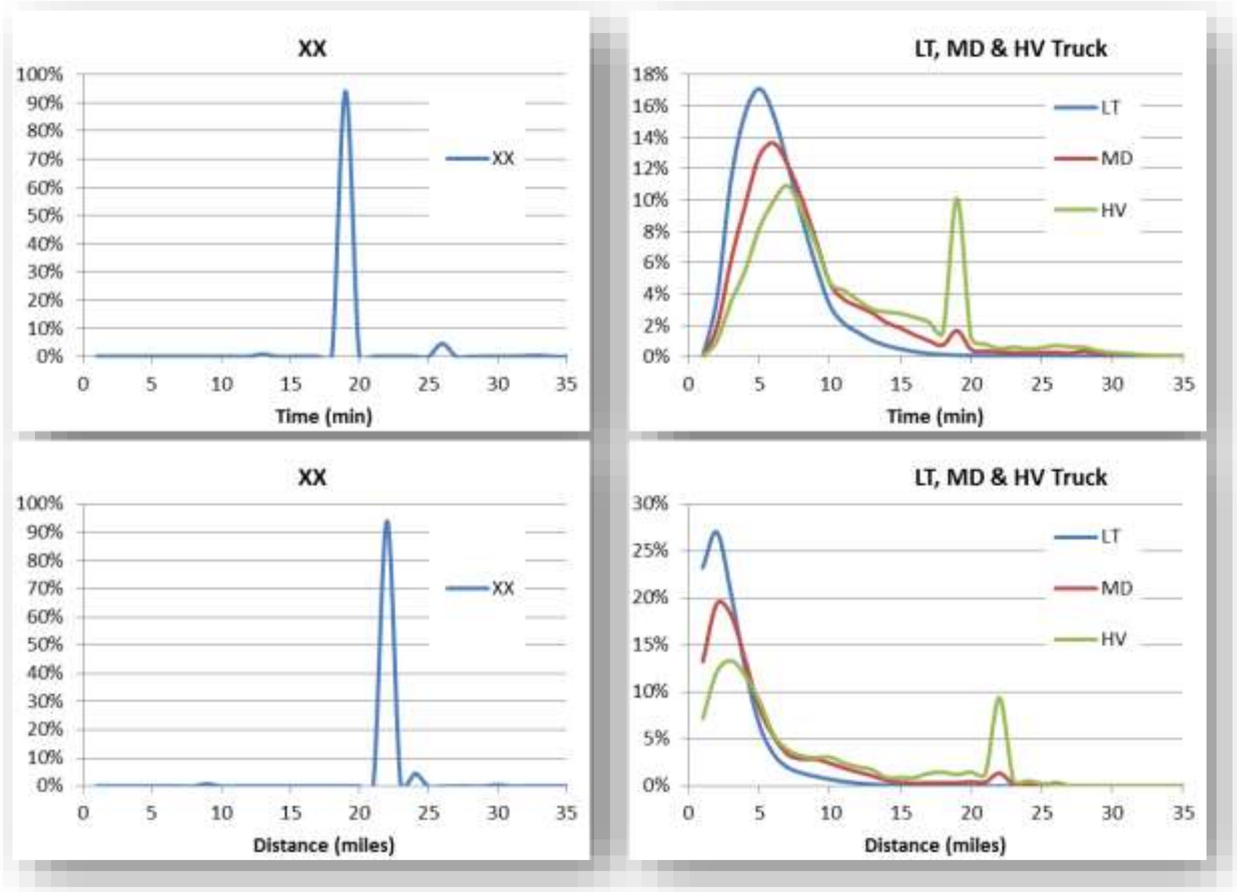


Exhibit 61. 2009 Base Year Trip Length Frequency - Distance



Observed data did not exist for the following trip purposes and summaries are shown for reasonableness checking. The model results seem reasonable relative to the other trip purposes for which observed data was available.

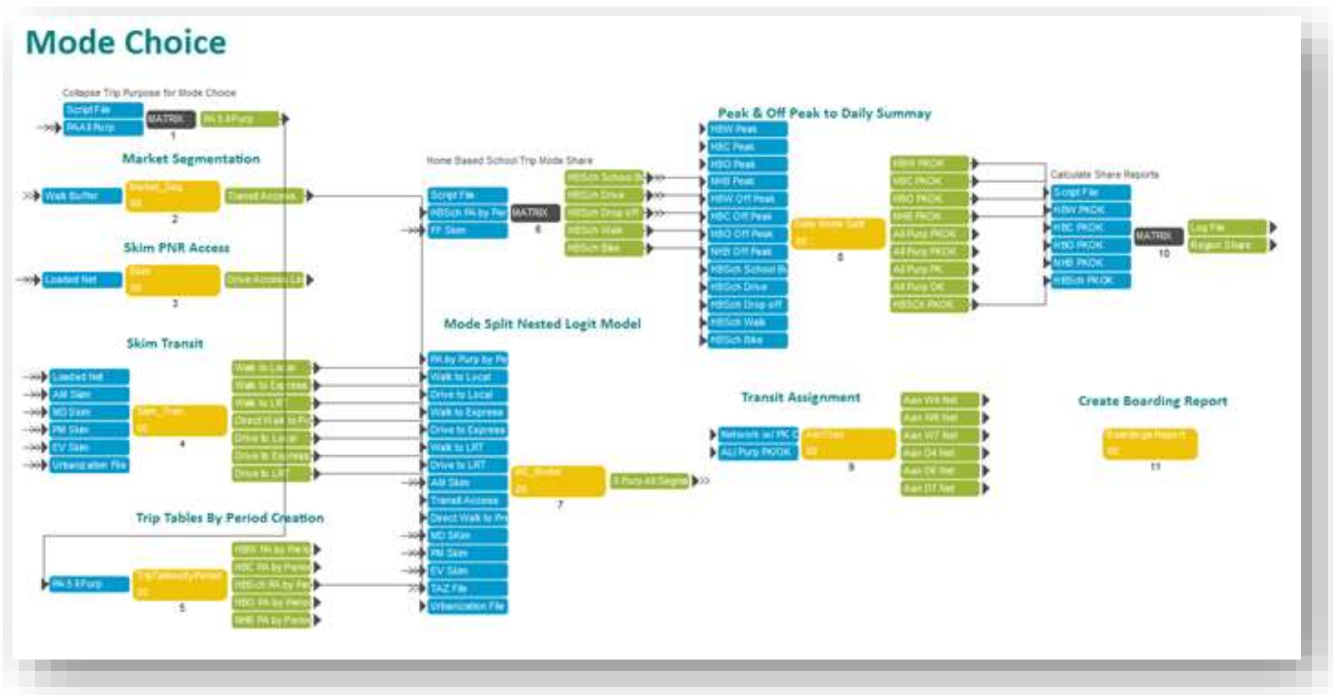
Exhibit 62. Base Year Time and Distance Trip Length Frequencies – XX and LT, MD and HV Truck



9.0 MODE CHOICE

A nested multinomial logit mode choice model is used to estimate the split among non-motorized (walk/bike) and motorized (auto and transit) trips. The 2012 Household Travel Survey and 2012 On Board Travel Survey were used to estimate the mode choice model. The layout of the mode choice model can be seen in Exhibit 63.

Exhibit 63. Model Structure of Mode Choice



The mode choice model estimates the mode of travel separately for HBW, HBO, HBC and NHB trips. Before mode choice, more purpose detail is kept. For the mode choice model however, HBShp and HBOth are combined into the HBO trip purpose and the NHBW and NHBNW are combined into the NHB trip purpose. The following modes of travel are considered by the mode choice model:

- Non-motorized
- Auto
- Local bus
- Enhanced bus
- Rail

As the Dixie model does not currently have premium transit modes as part of the transportation options, the enhanced bus and rail mode parameters are borrowed from the Wasatch Front travel model.

Mode choice model also evaluates the mode of a trip separately for peak (AM plus PM) and off-peak (MD plus EV) periods.

9.1 Transit Network

A key component of the mode choice model is the transit network. This section describes the various elements that comprise the transit network.

9.1.1 Transit Modes in the Model

The starting point for transit network is the transit line file. The line file describes the route characteristics and alignment. The information needed for each transit line includes:

- Route name
- Mode number
    - Local bus (mode 4)
    - Enhanced bus (mode 6)
    - Rail (mode 7)
- Route stops
- Speed (typically used for fixed guideway only)
- Peak/off-peak period headway

The base year transit system includes all existing bus routes in the SunTran system.

9.1.2 Transit Access/Egress Support Links

Access and egress links are necessary in the model so that trips can get from the TAZ or roadway network onto the transit network. The access/egress links specify which TAZs are connected to which bus and rail stops. There are separate links for walk access/egress, for transferring between transit lines, and for drive access to transit.

- **Walk access/egress**: Two-way links between zone centroids and transit stop nodes. These are auto-generated based on the distance from the centroid to the transit stop (mode 11 links). Where the user wants to ensure walk access connectivity, access/egress links can be added manually (mode 12 links).
- **Drive access**: These directional links provide a connection from TAZ centroids to park-and-ride (PNR) and transit stop nodes on the roadway network. Separate links are built to PNR lots for each transit mode and the drive access links are modes 40, 60, and 70. Drive access links can be manually added to the network using the same mode numbering.
- **Transfer links**: Two direction walk link to allow transfers between pairs of stop nodes that are nearby (mode 21 for auto-generated links, mode 22 for user-specified links).

Coding walk and drive access support links and specifying the walk distance is an arduous and potentially arbitrary part of mode choice models. In order to facilitate the use of the model in a consistent manner for transit path-building, a set of routines was developed to automate the construction of support links. While user judgment must never be removed, these processes are run as part of the path building process and ensure generally consistent transit access coding regardless of the model user.

9.1.2.1 Walk Access/Egress Links

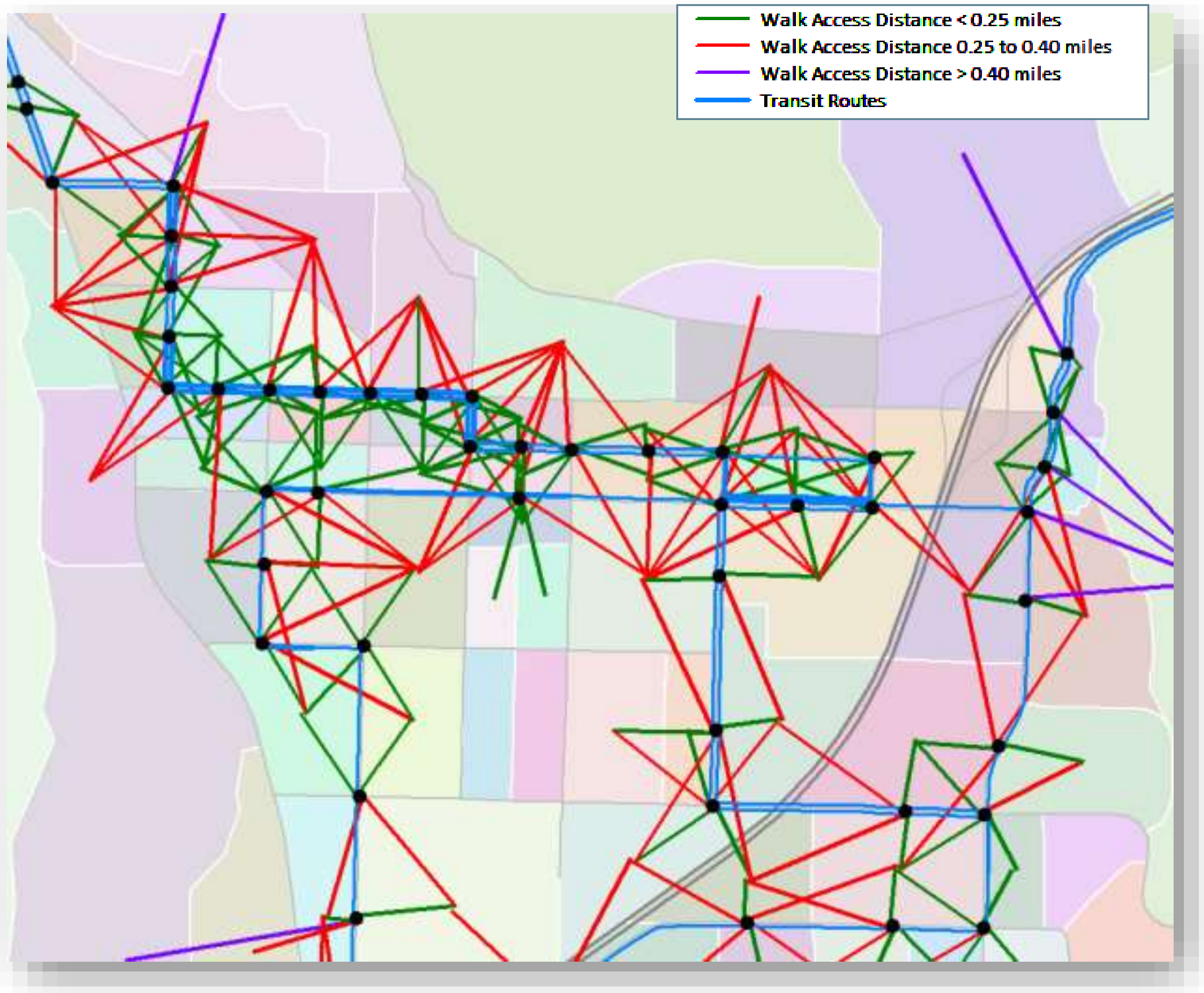
Walk access and egress links are developed based on the distance between the TAZ centroid and a transit stop. The walk access/egress link generator identifies and builds the shortest access link to each transit stop that falls within the maximum walking distance threshold. There are a couple of important aspects of the automatic walk access/egress links generator process. First, the X-Y distance between centroids and transit stops is used, and not the over-the-network distance, which ensures that an access link is built to all transit lines that run on links that form the border of a TAZ. Secondly, there is a maximum walking distance threshold. The walk distance threshold varies by TAZ size, and this approach is used to assure that larger TAZs are connected to the transit system.

Exhibit 64. Maximum Walk Access/Egress Link Distances (X-Y distance)

TAZ Area (Sq. Miles)	Example Dimensions (square TAZ)	Maximum Walk Link Length	Typical Location
<= . 0625	. 25 mi X . 25 mi	1/4 mile	CBD/Urban
. 0625 to . 25	. 5 mi X . 5 mi	4/10 mile	Suburban
> . 25	> . 5 mi X . 5 mi	6/10 mile	Transition/Rural

Exhibit 65 shows a sample of the walk access and egress links that are generated from this process, with the link color distinguishing links of different lengths (green for <. 25 mi, red for <. 4 mi, and purple for >. 4 mi). The walk links tend to reach only to the edge of the TAZ boundary, generally in all directions (if there is a transit line adjacent to each edge). This exhibit illustrates that walk access links in the suburbs extend to the TAZ boundary but do not tend to extend beyond.

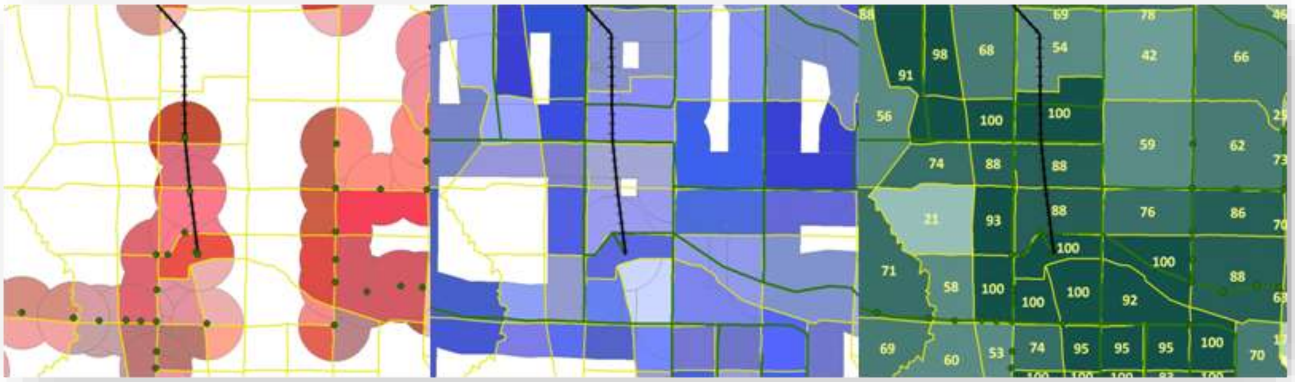
Exhibit 65. Automated Walk Access/Egress Links



9.1.2.2 Walk Access Buffers

A walk access link does not mean the entire TAZ has walk access to transit. The model uses a GIS process to estimate transit walk accessibility. The methodology assumes a 0.4-mile buffer around transit services. Buffering is done around a point shape representing the transit stops for express bus routes and rail lines. For local bus routes, the buffering is done around a line shape to account for frequent stopping by a local bus. These buffers are intersected with the TAZ to calculate the percentage of the TAZ area within walking distance of transit. The percentages calculated for local bus routes and transit stops are considered independently and the maximum of the individual percentages is used to estimate the transit walk accessibility for the zone.

Exhibit 66. Example of Walk Buffers for Limited Stop Services (Red), Local Bus (Blue) and combined (Green)



9.1.2.3 Drive Access Links

The drive access links are also automatically generated based on a process borrowed from the WFRC/MAG model. Drive access trips can utilize a park-and-ride lot, or not (where a passenger is dropped off). Regardless, the drive access links process requires the user to specify the location of the drive access location (referred to as a park and ride lot). Separate mode numbers are used for drive access locations that serve different modes, which helps display, understand, and control drive access to each mode. The park and ride lot is coded onto the roadway network, adjacent to a transit stop. A model script identifies the closest PNR lots for each transit mode and generates drive access links. Here is a brief description of that process:

- **(User) Code PNR lots on roadway network**: All PNR lots or drive access locations are coded as node attributes on the master street network.
- **(Model) Confirm that lot coincides with routes for scenario**: First, the model identifies all transit stops by node and mode. The script then writes out a list of nodes where a transit stop node was identified as a PNR lot and that mode actually stops at that node.
- **(Model) Print PNR access links from TAZs to nearby PNR nodes with transit service (separately for each mode)**: The nearest lots to a given zone are identified, and a PNR record is printed for that path. The number of access links printed varies by mode. For commuter rail, the nearest two lots are printed. For light rail, BRT, and express bus, the nearest three lots are identified from each TAZ.

Locations for which drive access is allowed must be coded with a PNR lot on the network node and can represent a transit parking lot, an important informal parking location, such as a side street or business lot, or a drop-off location. The lots are identified based on what modes stop at the PNR lot, and access links are generated to allow each TAZ to access each type of service, with some exceptions or restrictions.

9.1.3 Transit Operating Speeds

9.1.3.1 Bus Speeds

Bus speeds are estimated inside the model, and pivot off the auto speeds. In general, bus speeds are slower than auto speeds and this relationship varies by the type of road on which the bus is traveling. Bus speeds closely approximate auto speeds on freeways, where buses are not stopping or merging in and out of traffic, but on arterials, buses travel measurably slower than autos due to the need to pick up and drop off passengers.

The estimated relationship between local bus speeds and auto speeds is as follows:

- **Freeways** – buses travel at 95% of auto speeds
- **Principal arterials** – buses travel at 60% of auto speeds
- **Minor arterials**
    - Urban areas – buses travel at 55% of auto speeds
    - Suburban/rural areas – buses travel at 65% of auto speeds
- **Collectors** – buses travel at 60% of auto speeds

9.1.3.2 Rail Speeds

Rail lines are typically coded on dedicated rail links, rather than on the roadway network (even if the rail line runs in the road median). One of the necessary details, in addition to coding the rail links, is the coding of a rail operating speed.

To assist with this, WFRC developed a rail speed calculator based on observed rail speed and relating the observed speed to operating conditions. Key variables in the model include acceleration/deceleration ability of the rail vehicle, maximum cruise speeds, distance between stations, station dwell times, number of stop lights, and speed limit, if in street operation. Should the need arise; this tool could be applied in the Dixie area.

9.2 Transit Paths

The following parameters and assumptions are used to define transit paths specific to each transit sub-mode. The perceived/weighted time is used to identify the fastest path by sub-mode. These parameters are used to define a feasible transit choice set, and the perceived/weighted time is not actually seen by the mode choice model.

Exhibit 67. Global Transit Path-finding Parameters

Variable	Value
Transfer penalty (1, 2+ transfers)	(10, 60) min
Walk speed	2. 5 mph
Minimum wait time (bus/rail)	(3, 5) min
Weight applied to initial wait time	Factor of 2
Weight applied to transfer wait time	Factor of 3
Weight applied to walk access/egress time	Factor of 2
Weight applied to drive access time	Factor of 1. 5
Combine headways if headways are within	10 min
Max perceived path time	240 min

Exhibit 68 summarizes the hierarchy and definition of transit modes in the model. Each row in the table indicates the transit modes that can be included in a path for each primary mode. The "path type" is synonymous with "mode" as far as the model is concerned. For a "path type" to be included in a mode choice set, the mode in the path type description MUST be included in the path. For example, looking across the express bus row, express bus paths in the model can include local bus, BRT, express bus or light rail as part of the express bus path. However, of all these sub-modes, express bus must be part of the path for this mode to be included as a choice.

Exhibit 68. Transit Mode Hierarchy and Transfer Restrictions

Path Type	Local Bus allowed?	Exp. Bus allowed?	LRT allowed?
Local Bus	REQUIRED	no	no
Express Bus	YES	REQUIRED	YES
Light Rail	YES	no	REQUIRED

Summaries of the secondary mode weights used in transit path-building can be seen in Exhibit 69. The path weights are used to encourage the model to find paths for the primary mode in each path type.

Exhibit 69. Weight Applied to Secondary Transit Modes

Path Type	Local Bus weight	Exp. Bus weight	LRT weight
Local Bus	1	N/A	N/A
Express Bus	3	1	3
Light Rail	3	N/A	1

There are two simple rules used to exclude transit paths from the mode choice set for specific OD pairs. These rules target unreasonable transit trips and simply zero-out the transit skims so that the mode choice model does not assign even a small share of travelers to these paths. These rules are:

- If the transit access/egress distance plus the in-vehicle distance is greater than 50% of the auto distance, then exclude the path
- No drive access trips are allowed if the auto distance is less than three miles

9.3 Mode Choice Parameters

9.3.1 Mode Nesting Structure

The logit model contained the following nests in the model structure:

- Motorized / Non-motorized
- Auto / Transit
- Drive-to-transit / walk-to-transit

The nesting constants used in the mode choice model are as follows:

- nest_driveacc = .5 / nest_walkacc = .5
- nest_transit = .75
- nest_motor = .85 / nest_nonmotor = .85

These nesting constants are applied for all purposes in the model.

9.3.2 Mode Choice Model Coefficients

There are many coefficients that go into the model choice model. These coefficients are presented in the exhibit below. Mode choice model coefficients vary by purpose but are not by period. Differences in period utility equations are handled by the mode specific constants.

Exhibit 70. Mode Choice Model Coefficients

	HBW	HBO	NHB	HBC	
ivt_coef	-0.0221	-0.016	-0.0221	-0.0221	In-vehicle time
initwait_coef	-0.0442	-0.032	-0.0442	-0.0442	first wait time (asserted)
xferwait_coef	-0.05	-0.048	-0.0663	-0.05	transfer wait (asserted)
walk_coef_1	-0.0442	-0.032	-0.0442	-0.0442	walk access/egress/transfer Out-of-vehicle time - first mile (24 min)
walk_coef_gt_1	-0.0663	-0.048	-0.07	-0.0663	walk access/egress/transfer Out-of-vehicle time - after first mile
drive_coef	-0.033	-0.024	-0.035	-0.033	drive access time
bike_coef	-0.05	-0.032	-0.0514	-0.05	bike time (asserted)
cost_coef	-0.0013	-0.0012	-0.0015	-0.0018	cost
parkcost_coef	-0.0013	-0.0012	-0.0015	-0.0018	parking cost
premium_walk_access	0.22	0.16	0.22	0.22	(asserted) indicator for direct walk access to premium service (brt, express, rail)
drive_time_to_ivt	0	0	0	0	ratio of drive time to IVT
drive_dist_ratio	-0.33	-0.25	-0.35	-0.33	ratio of drive access distance to drive distance
transfers_coef	-0.221	-0.16	-0.221	-0.221	transit transfers
bus_xfer	0	0	0	0	additional transfer penalty for rail paths (penalize bus xfers)
CBD_dummy	0	0	0	0	CBD bias coefficient (transit only)
CBD_dummy_walk			0	0	CBD bias coefficient (walk only)
trip_distance_walk	-1	-1	-1	0	in-vehicle transit distance (inverse function: coef*(1/distance))
trip_distance_drive	-3	-3	-3	-1	in-vehicle transit distance (inverse function: coef*(1/distance))
zonal_urbanization	0.0033	0.0024	0.0034	0	zonal urbanization density measure (non-auto only)

9.3.3 Transit Mode Specific Constants

The mode choice model constants were calibrated to reflect mode share targets from the 2012 Home Interview Survey and the 2012 On Board Survey. The alternative specific constants in the mode choice model are seen in Exhibit 71.

Exhibit 71. Alternative Specific Constants

	transit	non moto	drive
HBW PK	-0.2301	-1.5311	-1.6109
HBW Ok	-0.2315	-1.5372	-1.6241
HBO Pk	-1.8046	-2.9459	-1.4162
HBO Ok	-1.8058	-2.9475	-1.417
NHB Pk	-2.2277	-4.6205	-1.1863
NHB Ok	-2.2225	-4.6193	-1.2089
HBC Pk	-0.0767	-1.3988	-1.741
HBC Ok	-0.0697	-1.3926	-1.7416

9.4 HBSch Mode Share Model

The HBSch_PR and HBSch_SC trips were combined into one HBSch purpose in the mode choice section of the Dixie travel demand model. The HBSch trips did not go through the mode choice model, rather a mode share model was applied to estimate the following modes:

- Walk/bike
- Drop-off / pick-up
- School bus
- Drive and park

The mode shares were stratified by the distance students lived away from school based on the bussing threshold rules of the school district. For modeling purposes, an average of the primary and secondary bussing rules was used to calculate the bussing threshold of 1.75 miles. The HBSch mode share model assumed that below this threshold bussing is not allowed and it is unlikely a student will drive and park. Above this threshold, it is unlikely students will walk/bike to school. The end result of applying these rules to the base year was just under 50% of the K-12 students who were on a school bus, less than 5% who drove and parked, 16% who were dropped off or picked up, and about a third who walked or biked, as seen in the following exhibit.

Exhibit 72. HBSch Mode Share Parameters

	< 1.75 miles	> 1.75 miles	All Students
school bus	0%	79%	47%
drive & park	0%	5%	3%
drop off	15%	16%	16%
walk/bike	85%	0%	34%
	100%	100%	100%

Student trips on the bus were converted to vehicle (bus) trips by using an average student per bus factor of 70. The resultant vehicle trips were then added to the SH_MD vehicle classification for assignment. Drive and park trips were added to the HBO trip purpose in assignment. Drop-off/pick-up trips calculated the student and non-student portion of the trip and were then added to the HBO trip purpose in assignment.

9.5 Transit Validation – 2012 Model Version

The mode shares from the model were compared to observed data from the surveys by purpose. Exhibit 73 shows the mode share validation:

Exhibit 73. Mode Share Validation

	HBW		HBO		NHB		HBC	
	Model	Observed	Model	Observed	Model	Observed	Model	Observed
non-moto	2.7%	2.7%	10.0%	9.9%	2.5%	2.5%	14.3%	14.3%
auto	96.4%	96.5%	89.7%	89.8%	97.3%	97.2%	82.4%	82.5%
transit	0.8%	0.8%	0.2%	0.3%	0.2%	0.2%	3.3%	3.2%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

The model appeared to replicate the mode share fairly well when compared to the observed data. However, the bus boardings from the model are high when compared to the observed data. In fact, the calibration routine was not able to achieve a realistic calibration of the observed transit boarding data, as seen in the following exhibit.

Exhibit 74. Bus Boarding Validation

	Observed	Modeled	% Difference
HBW	510	735	44%
HBC	186	308	66%
HBO	643	665	3%
NHB	286	383	34%
	1625	2091	29%

In addition, future forecasts of the boarding data appear to be illogical. The conclusion for the mode choice model is that the model works well for estimating auto and non-motorized trips but more work would need to be done to the model before using the model for transit forecasts. Care should therefore be taken when using the transit forecasts from the model.

10.0 TRIP ASSIGNMENT

The purpose of the traffic assignment model is to locate a specific route along links and through intersections for every vehicle trip. The assignment model uses the Bi-Conjugate Frank Wolfe algorithm with the following assignment parameters:

- MAXITERS=100
- RELATIVEGAP=0.0001

These parameters are set high enough to ensure a convergent assignment solution, though the impact to the model is a significant increase in model runtime.

The trip assignment model uses essentially the same parameters in both the distribution and final assignment models. The distribution assignment model uses a set of factors to estimate the number of non-auto trips, as mode choice is run after distribution, in order to not over-assign trips in determining the congested travel times. These parameters were estimated from the 2012 Household Travel Survey. The final assignment model uses the post mode choice trip tables so the non-auto trips are already removed. In addition the final assignment model includes options for outputting select link and turn volumes which are not coded into the distribution assignment model.

The following sections describe some of the elements used in the trip assignment model.

10.1 Diurnal Factors

Diurnal, or time of day, factors are used to convert the daily production-attraction (PA) trip table to period origin-destination (OD) trip tables. Diurnal factors were estimated from the 2012 Household Travel Survey for the person trip purposes and for the IX and XI trip purposes. XX diurnal factors were taken as the average of the IX and XI factors. Truck diurnal factors were estimated from UDOT hourly truck count data.

The diurnal factors are a composite of two factors:

1) Percent of daily trips occurring in a period
2) Percent of period trips occurring in the PA direction (remainder assumed to be in the AP direction)

The distribution assignment model uses separate diurnal factors for each of the detailed trip purposes. Post-mode choice, the HBShp and HBOth as well as the NHBW and NHBNW trip purposes are collapsed into HBO and NHB, respectively. Consequently, the final assignment uses the HBO and NHB factors. The diurnal factors can be seen in the following exhibits.

Exhibit 75. Diurnal Factor - % of Trips in Period

	HBW	HBC	HBSch	HBShp	HBOth	NHBW	NHBNW	IX	XI	XX	Truck	HBO	NHB
AM	28.5%	21.3%	35.5%	7.9%	9.7%	6.9%	4.1%	17.8%	16.0%	17.0%	13.0%	9.3%	4.8%
MD	24.8%	46.2%	35.4%	43.7%	34.8%	62.1%	50.8%	38.4%	35.5%	37.0%	38.6%	36.5%	53.6%
PM	28.3%	14.5%	25.5%	27.1%	25.1%	20.1%	31.1%	21.6%	26.8%	24.2%	21.6%	25.5%	28.3%
EV	18.4%	18.1%	3.6%	21.3%	30.4%	11.0%	14.0%	22.2%	21.6%	21.9%	26.8%	28.6%	13.2%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

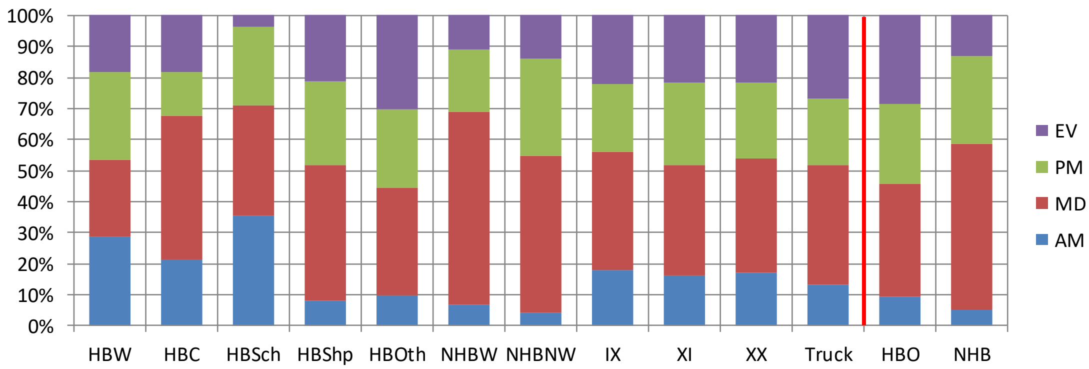
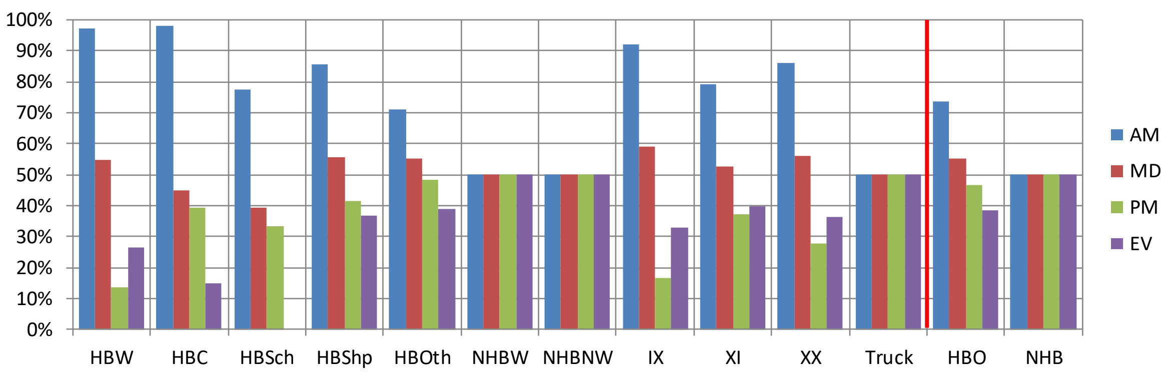


Exhibit 76. Diurnal Factor - % of Period Trips in PA Direction

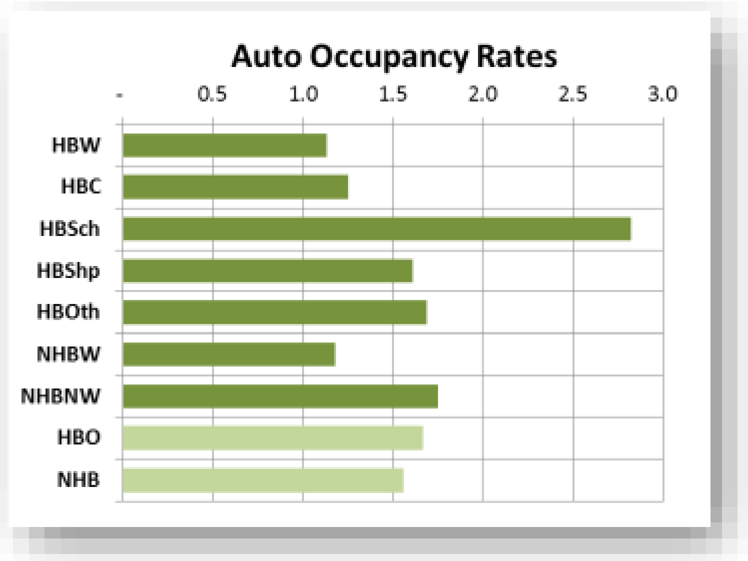
	HBW	HBC	HBSch	HBShp	HBOth	NHBW	NHBNW	IX	XI	XX	Truck	HBO	NHB
AM	97.3%	98.1%	77.4%	85.6%	71.0%	50.0%	50.0%	92.2%	79.3%	86.2%	50.0%	73.4%	50.0%
MD	54.6%	45.0%	39.5%	55.4%	55.1%	50.0%	50.0%	59.1%	52.6%	56.0%	50.0%	55.2%	50.0%
PM	13.7%	39.4%	33.5%	41.5%	48.2%	50.0%	50.0%	16.4%	37.3%	27.8%	50.0%	46.8%	50.0%
EV	26.5%	14.7%	0.0%	36.6%	38.9%	50.0%	50.0%	33.0%	39.8%	36.3%	50.0%	38.6%	50.0%



10.2 Auto Occupancy Rates

The assignment model converts person trips to vehicle trips by using auto occupancy rates. Auto occupancy factors were estimated from the 2012 Household Travel Survey. For the distribution assignment model, rates were calculated for HBW, HBC, HBSch, HBShp, HBOth, NHBW and NHBNW. The final assignment model used the more aggregate HBO and NHB rates.

Exhibit 77. Auto Occupancy Rates



Auto Occupancy Rates	
HBW	1.13
HBC	1.25
HBSch	2.82
HBShp	1.61
HBOth	1.69
NHBW	1.18
NHBNW	1.75
HBO	1.67
NHB	1.56

External and truck trips already represent vehicles, so no conversion factor is needed.

10.3 Path Building

The assignment model uses the same generalized cost functions in selecting the best route path as those used in the distribution path skimming process. Details on how the generalized costs are calculated are found in the Distribution section of this report.

10.4 Volume Delay Function

The distribution model uses a volume delay function (VDF) to develop congested speeds. The volume delay function is based on the standard Bureau of Public Roads (BPR) form:

Congested Speed = Free Flow Speed / (1 + X*(V/C)^Y)

Where:

V/C = Volume/Capacity Ratio

X = Coefficient

Y = Exponent

Highway links are assigned one of five link classes, each of which has unique VDF parameters as shown in the following figures.

Fwy = Freeway and centroid connectors (FT=1, 30-40)

Ramp = Freeway on/off ramps (FT=41-42)

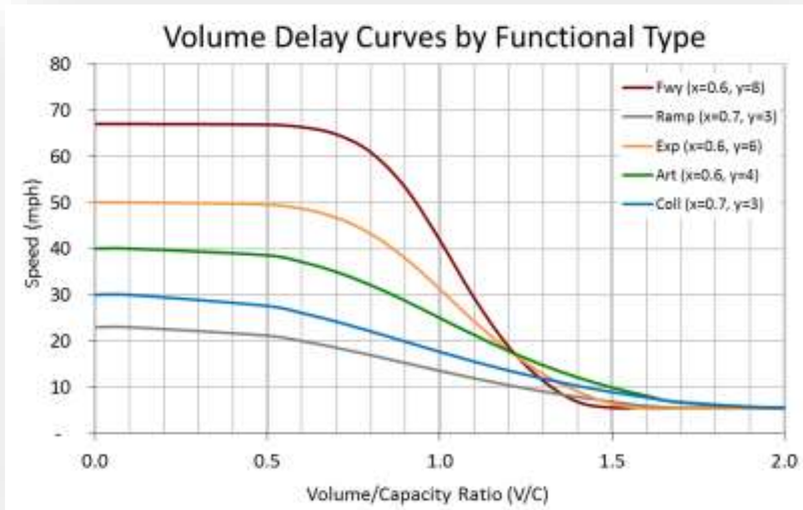
Exp = Expressway (FT=12-15)

Art = All other principal and minor arterial type roads (FT=2-3)

Coll = All major and minor collector roads and local roads (FT=4-7)

Exhibit 78. Volume Delay Function Parameters by Link Class

	Fwy	Ramp	Exp	Art	Coll
Typ FFS	67	23	50	40	30
Coeficient (x)	0.6	0.7	0.6	0.6	0.7
Exponent (y)	8	3	6	4	3
Max V/C	1.44	1.65	1.55	1.80	1.85

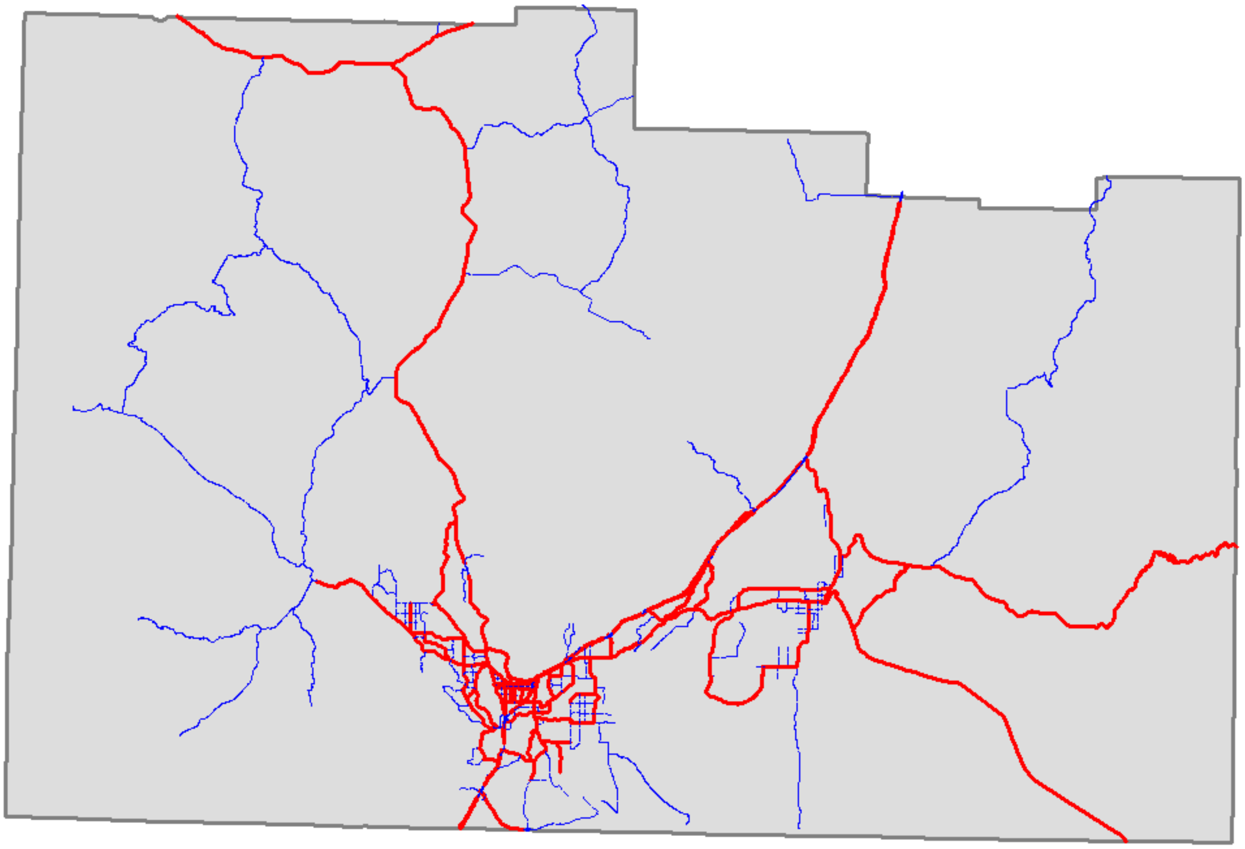


10.5 Final Assignment Validation

10.5.1 Traffic Segments

Traffic assignment for the Dixie model was validated to UDOT AADT data, 24 hour count data and truck count data. Count data and model data were analyzed based on common segments identified by the UDOT Traffic on Utah Highways (TOUH) traffic segments. A total of 145 traffic segments were identified for the Dixie model area covering a majority of the major roadways (see Exhibit79, below). A unique ID (SEGID) was created for each segment based on the route number and beginning mile post in the TOUH report in both the model network and the observed count databases to link the model and observed data together.

Exhibit 79. Links with Segment ID's in Dixie Model



10.5.2 Volume Validation

Travel model link data was summarized at the segment level for validating to the UDOT count data. Segment summaries used a weighted average (weighted based on distance) of the modeled volumes for both directions of the roadway to match the scale of the observed data. The averaged volumes were then compared to the UDOT count data (AADT data was converted to AWDT before making the comparison).

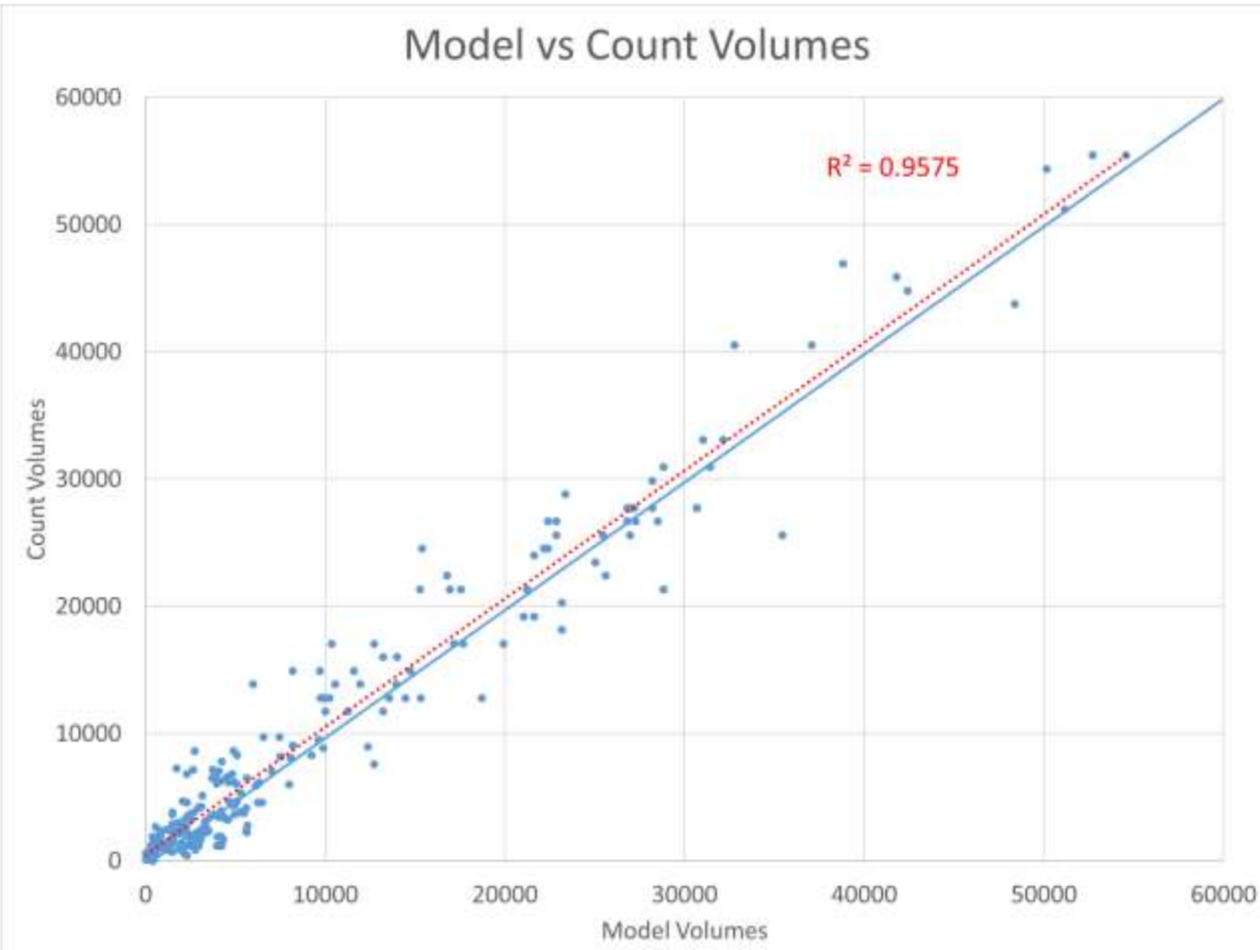
The modeled and observed data were averaged by volume class. The comparison of these averages can be found in the following exhibit.

Exhibit 80. Auto Occupancy Rates

Volume Range	# of Segments	Model Volume	Count Volume	Diff.	% Diff.	RMSE	% RMSE
0 - 2,500	75	1,779	1,397	382	27%	1282	92%
2,500 - 5,000	38	3,590	3,679	-90	-2%	1377	37%
5,000 - 10,000	36	5,881	7,348	-1,466	-20%	2724	37%
10,000 - 25,000	41	16,093	17,207	-1,113	-6%	3758	22%
25,000 - 50,000	28	30,570	31,384	-814	-3%	3750	12%
>50,000	5	52,258	54,389	-2,131	-4%	2602	5%
All	223	10,128	10,606	478	5%	2598	24%

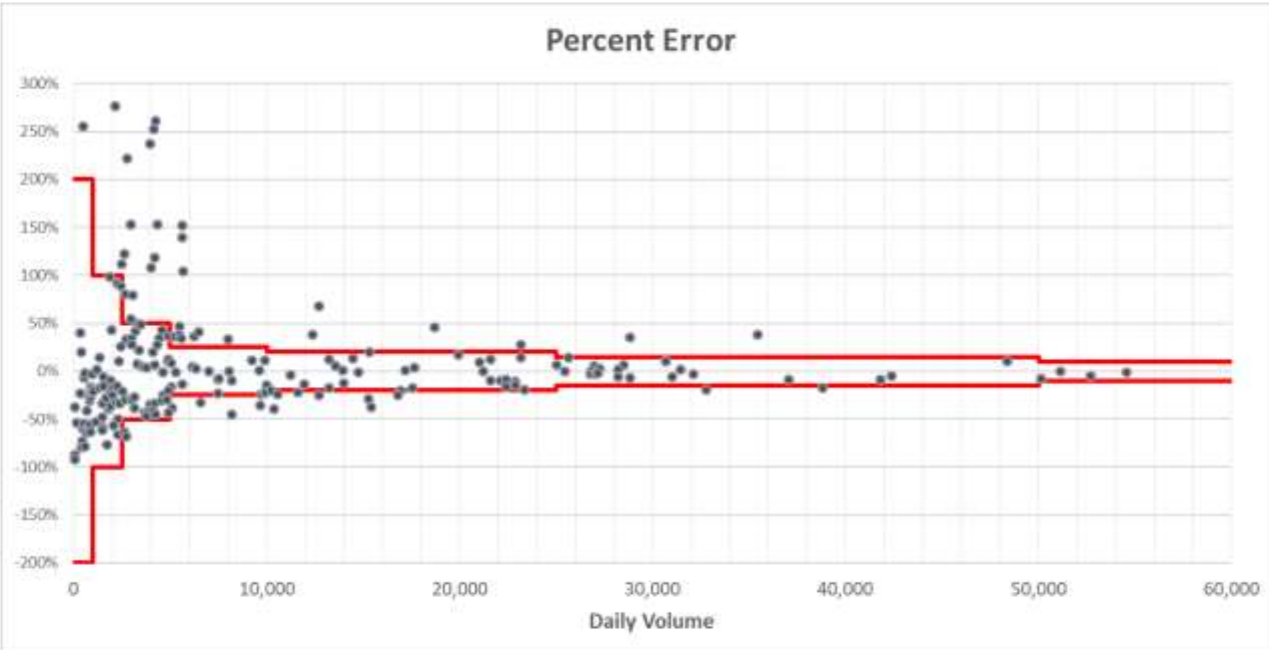
When compared to the count data, the model performed reasonably well. In general the model was slightly higher than the count data. In addition, the modeled daily volume and observed volume were plotted together and an R square test was used for validation. Several references in modeling literature recommend a minimum R squared value of 0. 77. The following exhibit shows the modeled to count volumes and the resulting linear regression line, which has an R squared value of 0. 91.

Exhibit 81. Base Year Volume Validation



The following exhibit plots the percentage error, which is (Model volume – Observed Volume) / Observed Volume. This exhibit compares the percentage error to general target values (represented by the red line). Travel models are expected to be more accurate for higher volume roadways and as such have a tighter error tolerance than minor roads. In the majority of the cases, the model met the target values.

Exhibit 82. Percent Error by Volume



10.5.3 VMT Validation

Vehicle Miles Traveled (VMT) comparisons are a good indicator of how well traffic is regionally assigned to the highway network. UDOT's Highway Performance Monitoring System (HPMS) reports annual VMT by functional type for each county. The percent share of VMT by facility type was used for validation. The comparison of VMT by facility type is shown below. The Dixie model VMT compared well to the observed data.

Exhibit 83. Base Year VMT Validation

	Freeway	Arterial	Freeway + Arterial	% Arterial	% Freeway	Total
2016 Observed	1,368,186	1,805,344	3,173,530	57%	43%	100%
2016 Modeled	1,489,430	2,183,711	3,673,141	59%	41%	100%