2050 Metropolitan Transportation Plan

TECHNICAL REPORT #1

Transportation Modeling and Forecasting

December **2023**

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1.0 Introduction

This report includes a description of the procedures used in developing the updated demographics and travel estimates used in the 2050 Metropolitan Transportation Plan for the Clarksville Urbanized Area Metropolitan Planning Organization (CUAMPO). It also describes the relationship between planning data and trip making, and the calibration and testing of the model. This report does not include how to operate the model, which is discussed in the User's Manual.

The CUAMPO Travel Demand Model (TDM) is being updated for use in the MPO's new Metropolitan Transportation Plan (MTP). The TDM used for the MTP 2050 is an update of the model used in the previous MTP. The updated model was calibrated and validated to meet the requirements established by the Tennessee Department of Transportation (TDOT) and the Federal Highway Administration (FHWA.)

The updated TDM has an established base year of 2019. Additional updates to the TDM include:

- updated master roadway network;
- updated socioeconomic data and trip rates; and
- updated turn penalties, capacity factors, and external trip data.

The CUAMPO TDM is based upon the conventional trip-based four-step modeling approach.

Broadly, the main model components fall within the following four (4) categories:

- **Trip Generation** - The process of estimating trip productions and attractions at each TAZ.
- **Trip Distribution** - The process of linking trip productions to trip attractions for each TAZ pair.
- **Mode Choice** - The process of estimating the number of trips by mode for each TAZ pair. This process allows the model to calculate transit trips.
- **Trip Assignment** - The process of assigning auto and truck trips onto specific highway facilities in the region.

The TDM's focus is on the region's highway network due to a limited number of transit trips. As a result, a transit element has not been included, eliminating the Mode Choice step. Following TDOT standards, the TDM was developed in TransCAD 9.0 Build 32725 64-bit travel demand forecasting software and the model interface was developed using GISDK macros.

2.0 Traffic Analysis Zones and Socioeconomic Data

2.1 Study Area and Traffic Analysis Zones

The accuracy necessary for generating trips from planning data requires it to be aggregated by small geographic areas. These areas are called Traffic Analysis Zones (TAZs).

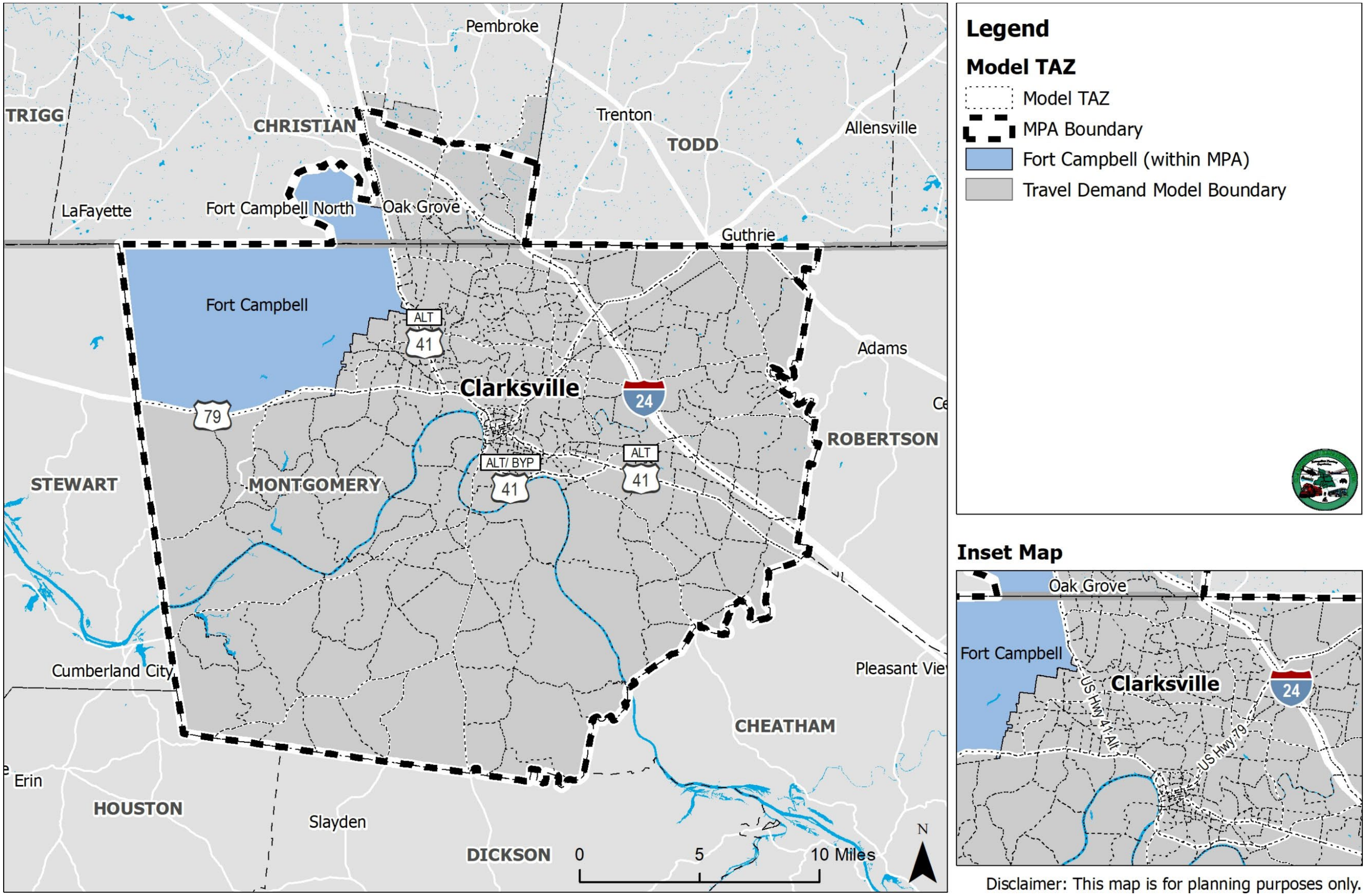
These TAZs are generally homogeneous areas and were delineated based on:

- population,
- land use,
- census geography,
- physical landmarks, and
- governmental jurisdictions.

The MTP 2050 study area and TAZ structure were updated using 2020 Census geography and based on development patterns since the last plan update. The study area is divided into 363 TAZs. There are 344 TAZs in Montgomery County, and 19 TAZs in Christian County. The study area also contains 41 external stations. A map of the TAZs is shown in **Figure 2.1**.

Except for Fort Campbell, which is responsible for its own planning efforts, the model study area is comprised of the entirety of Montgomery County, Tennessee; and the southernmost portion of Christian County, Kentucky. Local jurisdictions within the model study area include Clarksville, Tennessee; Oak Grove, Kentucky; and a portion of Hopkinsville, Kentucky.

Figure 2.1: MTP 2050 Model TAZs



Source:

2.2 Base Year (2019) Model Socioeconomic Data Update

The previous TDM had a 2016 base year that used housing, income, employment, and school attendance data as model inputs. These values were updated to reflect the new base year, 2019. This section describes the procedures used to update the model files to create the updated base year socioeconomic data.

Household Data Update

Household data for the model's TAZs were developed using:

- Census 2020 block data
- permit information obtained from the local jurisdictions

Each TAZ within the model study area is comprised of one (1) or more Census blocks. Using Geographic Information Systems (GIS) mapping, a layer stores the blocks and their information, including:

- TAZ,
- 2020 total dwelling units (DU),
- households (a.k.a. occupied dwelling units, OCCDU), and
- household population (HHPOP).

This data was aggregated to the TAZ level, resulting in 2020 DU, OCCDU, and HHPOP by TAZ and then used to develop each TAZ's percent of occupied units and average household size.

To obtain the year 2019 housing and population data:

1. Each permit received from the local jurisdictions was geocoded in GIS and assigned to its respective TAZ, along with its type and amount of units demolished or constructed.
2. Within each TAZ, any units from construction permits were subtracted from the 2020 values since they did not exist in the base year, while demolition permits were added to the 2020 values, as they existed at the time of the base year.
3. This resulted in 2019 DU values, which were multiplied by the ratio of 2020 occupied to total units to obtain the 2019 OCCDU.
4. Household population for year 2019 was then obtained by multiplying the 2019 OCCDU in each TAZ by the corresponding 2020 Average Household Size.

Table 2.1 displays the updated household data within the model study area by county. It is important to note that the model socioeconomic data will not match American Community Survey estimates for Montgomery County. This is due to the exclusion of Fort Campbell from the model study area.

Table 2.1: Study Area Households and Population, Base Year 2019

Variable	Montgomery County	Christian County	Model Study Area Total
Dwelling Units	81,778	4,761	86,539
Occupied Dwelling Units	77,135	3,301	80,436
Household Population	206,468	8,672	215,140

Source: CUAMPO, NSI, 2019

Employment Data Update

The employment values used in the model were updated using data purchased from AxleGroup and adjusted to meet the control totals derived from Quarterly Census of Employment and Wages (QCEW) data. For this effort, QCEW was used as it represents an accurate count of employees in the area with some minor exceptions and represent what has been reported to the Bureau of Labor Statistics.

It should be noted that the use of QCEW as a control total produces a significant drop in employment when compared to the Tennessee statewide model estimates for Montgomery County or MTP 2045 base year, which used Woods & Poole estimates. This may be a result of QCEW not including military personnel, which could have been included in the statewide model or Woods & Poole estimates in the MTP 2045.

The TDM used AxleGroup data for both counties to locate employment within the model study area. This data was imported into GIS and then checked for accuracy. Additional checks for larger employers were conducted to ensure they were in the right location and that their employment values match known data from the local Chambers of Commerce.

The employment by TAZ and type was calculated, then adjusted proportionately in each TAZ for each county to meet the control totals. The control totals were calculated by analyzing the QCEW employment data in each county for year 2019 and taking the proportion of employment within the model area compared to the total county, based on the 2045 MTP.

Table 2.2 displays the study area employment by type. For modeling purposes, employment variables were differentiated into the following categories:

- Retail (NAICS 44-45)
- Service (NAICS 52-55, 61-62, 71-72, 81, 92, 99)
- Basic or Non-Retail (NAICS 11, 21-23, 31-33, 42, 48-49, 51, 56)

Table 2.2: Study Area Employment Classifications, Base Year 2019

Variable	Description	Montgomery County	Christian County	Model Study Area Total
TOT_EMP	Total Employment	55,987	1,530	57,517
OTH_EMP	Other Employment	9,223	62	9,285
RET_EMP	Retail Employment	12,652	656	13,308
SE_EMP	Service Employment	34,112	812	34,924

Source: NSI, AxleGroup, Bureau of Labor Statistics, 2019

School Enrollment Data Update

The MTP 2050 TDM obtained school attendance data from the U.S. Department of Education through the National Center for Education Statistics data tool[1]. School attendance figures include:

- Public and private elementary, middle, and high schools.
- Colleges and universities.
- Vocational and business schools.

The total school attendance in the study area in 2019 was 46,194. There are currently no Kentucky TAZs within the study area that have school enrollment. For modeling purposes, the school attendance is measured by the number of students attending a school in a TAZ and not by the number of students residing in that TAZ.

[1] National Center for Education Statistics (NCES) - Data & Tools - Most Popular Tools

TAZ Data

The socioeconomic data for each TAZ are included in the TDM files. This data has been updated for the new 2019 base year. The fields used in the TAZ layer are shown **Table 2.3**.

Table 2.3: TAZ Field Attributes

Attribute Name	Description
ID	Integer (4 bytes) TAZ ID
Area	Real (8 bytes) TAZ area in Map Units
TAZ_19	Integer (4 bytes) 2019 TAZ number
TAZ_40	Integer (4 bytes) MTP 2040 TAZ Number
COUNTY	Character TAZ County location
TYPE	Integer (4 bytes) 1= Internal TAZ 2= External Station
MedInc_10	Integer (4 bytes) 2010 Median income, Census 2010
MedInc_19	Integer (4 bytes) 2019 Median income, American Community Survey 5-year Estimates
POP_19	Integer (4 bytes) 2019 Household population
HH_19	Integer (4 bytes) 2019 Occupied dwelling units/Households
AvgHHsize_19	Real (8 bytes) 2019 Average population/household
BASE_EMP_19	Integer (4 bytes) 2019 Non-Retail employment
RET_EMP_19	Integer (4 bytes) 2019 Retail employment
SER_EMP_19	Integer (4 bytes) 2019 Service employment
TOT_EMP_19	Integer (4 bytes) 2019 Total employment
SCHATT_19	Integer (4 bytes) 2019 School enrollment

Attribute Name	Description
POP_Chg_19_50	Integer (4 bytes) Change in population from 2019 to 2050
HH_Chg_19_50	Integer (4 bytes) Change in households from 2019 to 2050
EMP_Chg_19_50	Integer (4 bytes) Change in total employment from 2019 to 2050
Note: Each of the suffix "19" fields should be repeated for "30", "40", and "50" suffixes as well.	

3.0 Roadway Network

3.1 Network Line Layer

The simulation of travel patterns in a computer model requires a representation of the street and highway system in digital format. The TransCAD model creates such a network from a geographic line layer in GIS. The line layer dataview records contain descriptive information for each link and its properties. Turn prohibitions are also coded into the network at locations where certain movements are not allowed or physically cannot be made.

Adjustments were made to the model network to update it to the new base year. These adjustments included:

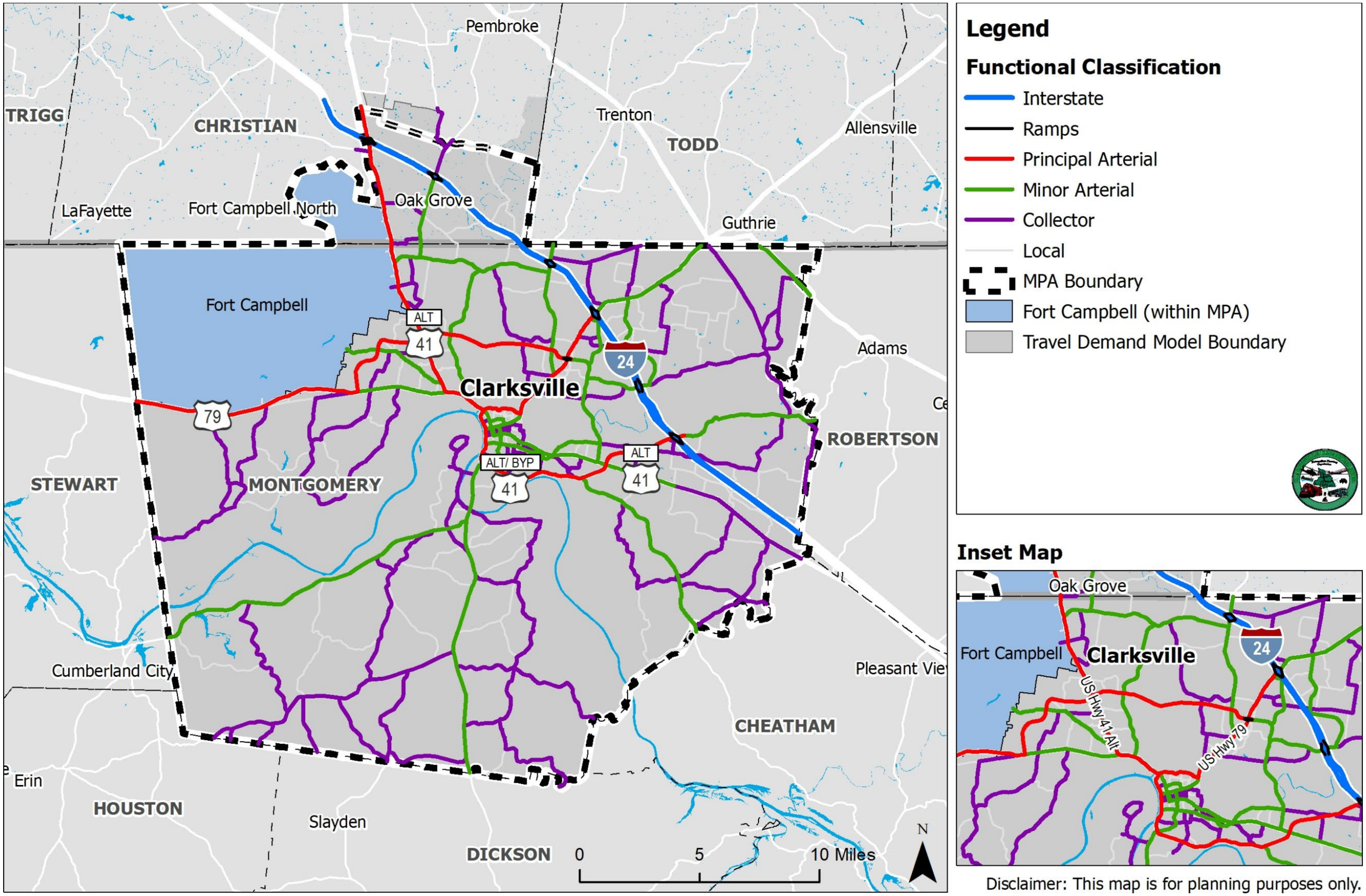
- number of lanes,
- speeds,
- functional classification,
- volume-delay function parameters (alpha and beta values), and
- daily traffic counts and traffic stations (to 2019 where possible)

In addition to the changes listed above, the updated TDM features a master network in the model's setup folder. This line layer contains the records for all roadway links used in the TDM process. The master network contains the data for the base year, Existing Plus Committed network, and all roadway test projects. **Figure 3.1** displays the 2019 base year roadway network used in the TDM.

3.2 Functional Classification

Each link in the model's roadway network was assigned a functional classification based on the federal functional classification system. This system is also maintained by TDOT and KYTC. The functional classifications used in the TDM are shown in **Table 3.1**.

Figure 3.1: 2019 Roadway Functional Classification



Disclaimer: This map is for planning purposes only.

Table 3.1: Functional Classifications Used in CUAMPO Model

FHWA Functional Classification		Description	MPO Functional Classification Number
Rural	01	Interstate	1
	02	Other Principal Arterial	2
	06	Minor Arterial	6
	07	Major Collector	7
	08	Minor Collector	8
	09	Local	9
	N/A	Ramp	10
Urban	11	Interstate	11
	12	Freeway/Expressway	12
	14	Principal Arterial	14
	16	Minor Arterial	16
	17	Collector	17
	19	Local	19
	N/A	Ramp	20
Other	N/A	Centroid Connector	99

Source: FHWA, KYTC, TDOT

3.3 Free Flow Speed and Capacity

Free flow speeds and capacities are important TDM inputs that affect the traffic assignment model. The link speed calculations are the same as those used in the previous TDM. The model uses the same capacity factors as the previous update, which are shown in **Figure 3.2**. Of note, while the capacity factors were borrowed from the Nashville model in 2018, these were deemed acceptable since Clarksville is within the same geographic region and state. These key model inputs were assigned to each individual network link. These inputs consider factors such as:

- Free Flow Speed
- Roadway posted speed
- Roadway functional classification
- Location of roadway in urban or rural area
- Link Capacity
- Roadway functional classification
- Location of roadway in an urban or rural area
- Number of lanes
- Width of travel lanes
- Presence of a median or dividing feature
- Presence and width of shoulder on roadway

Figure 3.2: Model Capacity Factors

Link Capacity (LOS D)

Vehicles per lane per hour - vphpl

Functional Class		vphpl Directional
All Interstate		
2 Lanes		2,300
>2 Lanes		2,400
Principal Arterial		
Rural	Divided	1,700
Rural	Undivided	1,500
Urban	Divided	1,500
Urban	Undivided	1,300
Minor Arterial		
Rural	Divided	1,600
Rural	Undivided	1,350
Urban	Divided	1,400
Urban	Undivided	1,150
Collector		
Rural	Divided	1,350
Rural	Undivided	1,150
Urban	Divided	1,150
Urban	Undivided	950
Local		
Rural	2 Lane	900
Rural	>2 Lane	1,000
Urban	2 Lane	800
Urban	>2 Lane	900
Ramps		1,000
Centroid Connectors		9,999

SF = c x N x Fw x Fhv x Fp x Fe x Fd x Fctl x Fpark X (V/C)i

SF = Model vphpl for desired level of service
c = Ideal vphpl
N = Number of Lanes
(V/C)I = Rate of service flow for level of service D

Adjustment Factors

Acronym	Name	Facility Type	Lane	Shoulder	Factor
Fw	Lane & Shoulder Width	Interstate & Sys Ramp	<=10'	0-<2'	0.78
		Interstate & Sys Ramp	<=10'	2'-5'	0.83
		Interstate & Sys Ramp	<=10'	>5'	0.88
		Interstate & Sys Ramp	>10'	0-<2'	0.90
		Interstate & Sys Ramp	>10'	2'-5'	0.95
		Interstate & Sys Ramp	>10'	>5'	1.00
		Principal Arterial Div	<=10'	0-<2'	0.78
		Principal Arterial Div	<=10'	2'-5'	0.83
		Principal Arterial Div	<=10'	>5'	0.88
		Principal Arterial Div	>10'	0-<2'	0.92
		Principal Arterial Div	>10'	2'-5'	0.96
		Principal Arterial Div	>10'	>5'	1.00
		Principal Arterial Undiv	<=10'	0-<2'	0.78
		Principal Arterial Undiv	<=10'	2'-5'	0.82
		Principal Arterial Undiv	<=10'	>5'	0.86
		Principal Arterial Undiv	>10'	0-<2'	0.90
		Principal Arterial Undiv	>10'	2'-5'	0.95
		Principal Arterial Undiv	>10'	>5'	1.00
		Minor Arterial Div	<=9'	0-<2'	0.81
		Minor Arterial Div	<=9'	2'-5'	0.86
		Minor Arterial Div	<=9'	>5'	0.93
		Minor Arterial Div	>9'	0-<2'	0.94
		Minor Arterial Div	>9'	2'-5'	1.00
		Minor Arterial Div	>9'	>5'	1.05
		Minor Arterial Undiv	<=9'	0-<2'	0.77
		Minor Arterial Undiv	<=9'	2'-5'	0.83
		Minor Arterial Undiv	<=9'	>5'	0.88
		Minor Arterial Undiv	>9'	0-<2'	0.89
		Minor Arterial Undiv	>9'	2'-5'	0.95
		Minor Arterial Undiv	>9'	>5'	1.00
		Collector Div	<=9'	0-<2'	0.81
		Collector Div	<=9'	2'-5'	0.86
		Collector Div	<=9'	>5'	0.93
		Collector Div	>9'	0-<2'	0.96
		Collector Div	>9'	2'-5'	1.00
		Collector Div	>9'	>5'	1.05
		Collector Undiv	<=9'	0-<2'	0.81
		Collector Undiv	<=9'	2'-5'	0.85
		Collector Undiv	<=9'	>5'	0.90
		Collector Undiv	>9'	0-<2'	0.94
		Collector Undiv	>9'	2'-5'	1.00
		Collector Undiv	>9'	>5'	1.04
		Local 2 Lane	<=9'	0-<2'	0.65
		Local 2 Lane	<=9'	2'-5'	0.78
		Local 2 Lane	<=9'	>5'	0.90
		Local 2 Lane	>9'	0-<2'	0.85
		Local 2 Lane	>9'	2'-5'	1.00
		Local 2 Lane	>9'	>5'	1.04
		Local >2 Lane	<=9'	0-<2'	0.81
		Local >2 Lane	<=9'	2'-5'	0.85
		Local >2 Lane	<=9'	>5'	0.92
		Local >2 Lane	>9'	0-<2'	0.96
		Local >2 Lane	>9'	2'-5'	1.00
		Local >2 Lane	>9'	>5'	1.10
Fhv	Heavy Vehicle	Interstate			0.88
		Principal Arterial			0.90
		Minor Arterial			0.90
		Collector			0.92
		Local			0.97
Fp	Driver Population	Rural Interstate			0.90
		Urban Interstate			0.92
		System Ramp			0.92
		Principal Arterial			0.95
		Minor Arterial			0.98
		Collector			NA
		Local			NA
Fe	Driving Environment	Interstate			NA
		Rural Prin Art	Divided		1.00
		Rural Prin Art	Undivided		0.90
		Urban Prin Art	Divided		0.90
		Urban Prin Art	Undivided		0.80
		Rural Minor Art	Divided		1.00
		Rural Minor Art	Undivided		0.90
		Urban Minor Art	Divided		0.90
		Urban Minor Art	Undivided		0.80
		Rural Collector	Divided		1.00
		Rural Collector	Undivided		0.90
		Urban Collector	Divided		0.90
		Urban Collector	Undivided		0.80
		Rural Local	2 Lane		0.90
		Rural Local	>2 Lane		0.90
		Urban Local	2 Lane		0.80
		Urban Local	>2 Lane		0.80
Fd	Directional Distribution (Local only)	2 Lane	Divided		0.94
		>2 Lane	Divided		1.16
		2 Lane	Undivided		0.94
		>2 Lane	Undivided		1.10
Fctl	Center Turn Lane	Interstate			NA
		All Other			1.08
Fpark	On Street Parking	Any			0.95

Source: Nashville Model

3.4 Network Attributes

Table 3.2 displays the network attributes used on the links in the TDM, while **Table 3.3** displays the attributes used in the node layer.

Table 3.2: CUAMPO Model Link Attributes

Attribute Name	Description	Input Type
Length	Real (8 bytes)	Automatic
Dir	Integer (2 bytes) 0 = Two-way link 1= One-way link, AB fields will be used -1= One-way link, BA fields will be used	Automatic, but user can override
State	Character State link is located within	User
NAME	Character Roadway name	User
External	Integer (4 bytes) External station of link	User
CNTStation	Character ADT count station	User
YEAR	Integer (4 bytes) ADT count year	User
ADT_19	Integer (4 bytes) 2019 Daily Traffic Count	User
Screenline	Integer (4 bytes) Screenline link is on	User
TollYear	Integer (4 bytes) Year tolls begin to apply	User
TOLL_19	Integer (4 bytes) 0= Roadway not tolled 1= Roadway is tolled	User
NO_TRK_19	Integer (1 byte) 0= No truck restrictions 1= Truck restrictions	User
NETWORK_19	Integer (2 bytes) 1= Network Road link 2= Centroid Connector 0 or null = Link will not be included in the model run	User*

Attribute Name	Description	Input Type
AB_FC_19	Integer (4 bytes) Refer to Section 6.1.1	User
BA_FC_19	Integer (4 bytes) Refer to Section 6.1.1	User
FC_DESC_19	Character General Function Class	User
MODEL_FC_19	Integer (4 bytes) Refer to Section 6.1.2	User*
MODEL_FC_DESC_19	Character Refer to Section 6.1.2	User
URB_RUR_19	Character Link area location	User
TOTAL_LANES_19	Integer (2 bytes) Number of lanes for the roadway	User*
AB_LANES_19	Integer (2 bytes) Number of lanes in AB direction	User*
BA_LANES_19	Integer (2 bytes) Number of lanes in BA direction	User*
ALPHA_19	Real (4 bytes) BPR Function Parameter	User*
BETA_19	Real (4 bytes) BPR Function Parameter	User*
POSTED_SPEED_19	Integer (4 bytes) Posted link speed (MPH)	User
AB_SPEED_19	Real (8 bytes) Link speed (MPH) in AB direction	User*
BA_SPEED_19	Real (8 bytes) Link speed (MPH) in BA direction	User*
AB_TT_19	Real (8 bytes) Link travel time in AB direction	Model
BA_TT_19	Real (8 bytes) Link travel time in BA direction	Model
AB_TT_AM_19	Real (8 bytes) Morning Link travel time in AB direction	Model
BA_TT_AM_19	Real (8 bytes) Morning Link travel time in BA direction	Model
AB_TT_MD_19	Real (8 bytes) Mid-day Link travel time in AB direction	Model

Attribute Name	Description	Input Type
BA_TT_MD_19	Real (8 bytes) Mid-day Link travel time in BA direction	Model
AB_TT_PM_19	Real (8 bytes) Afternoon Link travel time in AB direction	Model
BA_TT_PM_19	Real (8 bytes) Afternoon Link travel time in BA direction	Model
AB_TT_NT_19	Real (8 bytes) Nighttime Link travel time in AB direction	Model
BA_TT_NT_19	Real (8 bytes) Nighttime Link travel time in BA direction Link area type 1= CBD 2= Urban 3= Suburban 4= Rural	Model
Fw_19	Real (8 bytes) Capacity factor for lane and shoulder width	User
Fhv_19	Real (8 bytes) Capacity factor for heavy vehicles	User
Fp_19	Real (8 bytes) Capacity factor for driver population	User
Fe_19	Real (8 bytes) Capacity factor for driving environment	User
Fd_19	Real (8 bytes) Capacity factor for directional distribution	User
Fctl_19	Real (8 bytes) Capacity factor for center turn lanes	User
Fpark_19	Real (8 bytes) Capacity factor for on street parking	User
Fall_19	Real (8 bytes) Overall capacity factor	User
IDEAL_VPHPL_19	Real (8 bytes) Maximum capacity in vehicles/hour/lane	User
AB_VPHPL_19	Real (8 bytes) Capacity in AB direction in vehicles/hour/lane	User
BA_VPHPL_19	Real (8 bytes) Capacity in AB direction in vehicles/hour/lane	User
AB_CAPACITY_19	Integer (4 bytes)	User*

Attribute Name	Description	Input Type
	Capacity in AB direction	
BA_CAPACITY_19	Integer (4 bytes) Capacity in BA direction	User*
AB_CAP_AM_19	Integer (4 bytes) Morning capacity in AB direction	Model
BA_CAP_AM_19	Integer (4 bytes) Morning capacity in BA direction	Model
AB_CAP_MD_19	Integer (4 bytes) Mid-day capacity in AB direction	Model
BA_CAP_MD_19	Integer (4 bytes) Mid-day capacity in BA direction	Model
AB_CAP_PM_19	Integer (4 bytes) Afternoon capacity in AB direction	Model
BA_CAP_PM_19	Integer (4 bytes) Afternoon capacity in BA direction	Model
AB_CAP_NT_19	Integer (4 bytes) Nighttime capacity in AB direction	Model
BA_CAP_NT_19	Integer (4 bytes) Nighttime capacity in BA direction	Model
DAILY_FLOW	Integer (4 bytes) Total daily model volume	Model
AB_DAILY_FLOW	Integer (4 bytes) AB directional daily model volume	Model
BA_DAILY_FLOW	Integer (4 bytes) BA directional daily model volume	Model
DAILY_TRK_FLOW	Integer (4 bytes) Total daily model truck volume	Model
AB_DAILY_TRK_FLOW	Integer (4 bytes) AB directional daily model truck volume	Model
BA_DAILY_TRK_FLOW	Integer (4 bytes) AB directional daily model truck volume	Model
DAILY_TOT_VMT	Integer (4 bytes) Total daily vehicle miles travelled	Model
DAILY_AB_VMT	Integer (4 bytes) AB directional daily vehicle miles travelled	Model
DAILY_BA_VMT	Integer (4 bytes) BA directional daily vehicle miles travelled	Model
DAILY_TOT_VHT	Integer (4 bytes)	Model

Attribute Name	Description	Input Type
	Total daily vehicle hours travelled	
DAILY_AB_VHT	Integer (4 bytes) AB directional daily vehicle hours travelled	Model
DAILY_BA_VHT	Integer (4 bytes) BA directional daily vehicle hours travelled	Model
DAILY_TOT_VHD	Integer (4 bytes) Total daily vehicle hours delay	Model
DAILY_AB_VHD	Integer (4 bytes) AB directional daily vehicle hours delay	Model
DAILY_BA_VHD	Integer (4 bytes) BA directional daily vehicle hours delay	Model
DAILY_AB_VOC	Real (8 bytes) AB directional volume/capacity	Model
DAILY_BA_VOC	Real (8 bytes) BA directional volume/capacity	Model
DAILY_MAX_VOC	Real (8 bytes) Higher of AB and BA volume/capacity	Model
Note:		
1. Each of the suffix "19" fields should be repeated for EC, VIS, and SCE suffixes as well.		
2. Volume-delay function parameter fields Alpha_19 and Beta_19 are based on BPR function.		
3. In addition to the base year fields, each planned year should have a field called "PROJECT_[suffix]" of type Integer. This field should have a unique project number for each committed or planned project.		
4. * : These values are required when adding and/or modifying a roadway link.		
5. User does not need to input values of fields whose "INPUT TYPE" is 'Model'. Model interface will calculate the values of these fields.		

Table 3.3: CUAMPO Model Node Attributes

Attribute Name	Description
Exp_Node_ID	Integer (4 bytes) For centroids keep the ID the same as TAZ number.
LONGITUDE	Integer (4 bytes) TCAD automatic field
LATITUDE	Integer (4 bytes) TCAD automatic field
CENTROID	Integer (4 bytes) TAZ number for centroid

3.5 Centroid Connectors

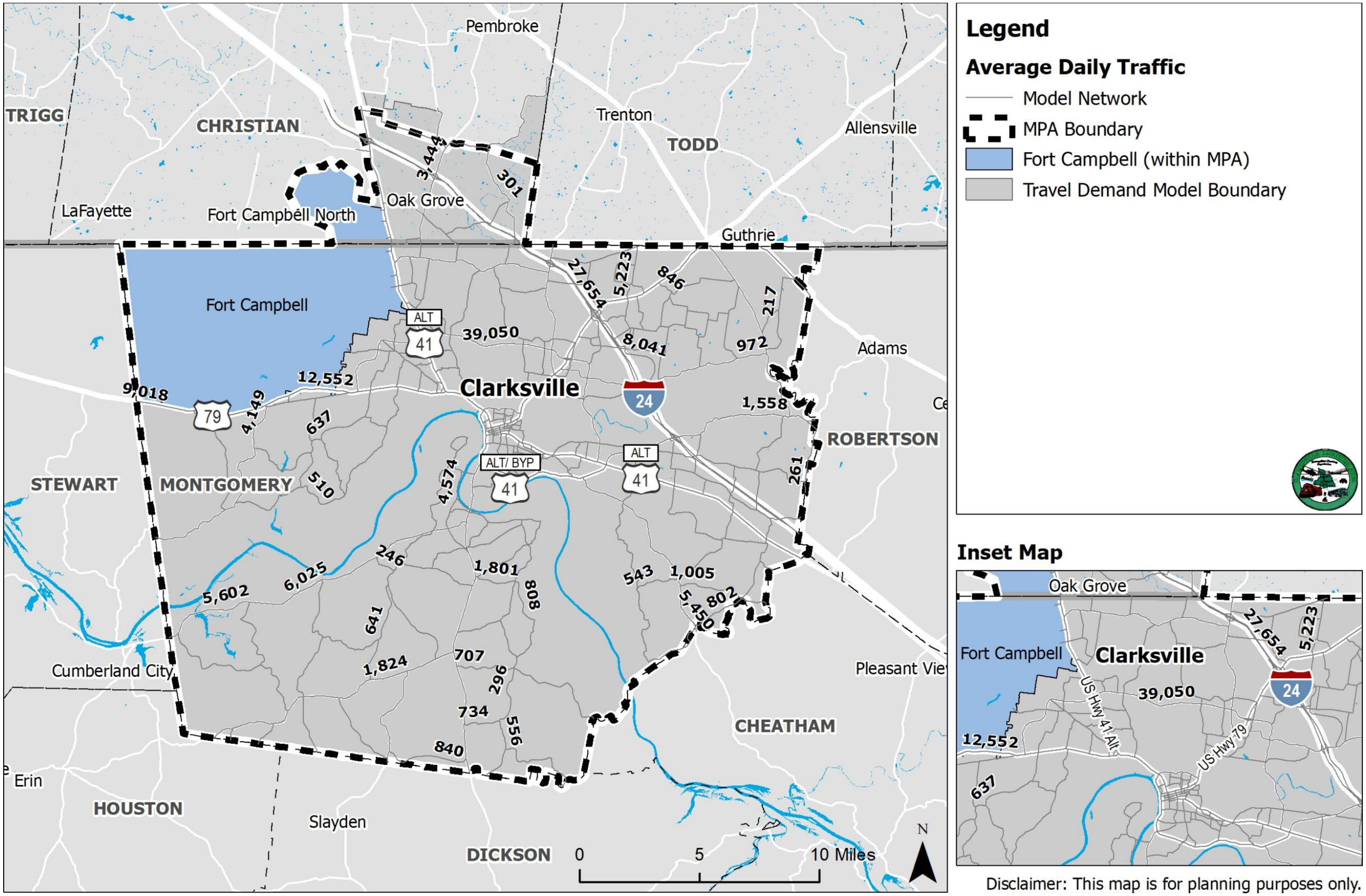
Centroid connectors are an imaginary roadway network links that connects the TAZ centroid to the adjacent roadway network at nodes. These links represent the local streets on the street and highway system that are not in the model network. Centroid connectors provide the model the ability to move trips generated from individual TAZs to the roadway network. The locations where centroid connectors access the model network are based on features such as neighborhood roadway entrances, driveways and parking lots.

During the TDM update, the centroid connectors were adjusted to match locations where traffic is most likely to access the model's roadways. This was accomplished by relocating the centroid for the TAZ to reflect the "center of mass" of developed land and/or moving the centroid connector roadway network access points to a location where trips generally enter or leave the TAZ. This changes the length of the centroid connectors and the travel times on the links to encourage modeled traffic to use certain access points to reflect the observed traffic.

3.6 Traffic Counts

The updated model also contains updated traffic counts in the roadway network. These counts come from TDOT and KYTC and are the most recent available. The update process included the verification of count stations upon the existing TDM links and ensuring that the ADTs are assigned to the correct link. Where a 2019 ADT was not available for a count station, the most recent count was factored to the base year using growth rate data from historical counts. The traffic ADTs used in the TDM are shown in **Figure 3.3**.

Figure 3.3: 2019 Roadway Traffic Counts



Disclaimer: This map is for planning purposes only.

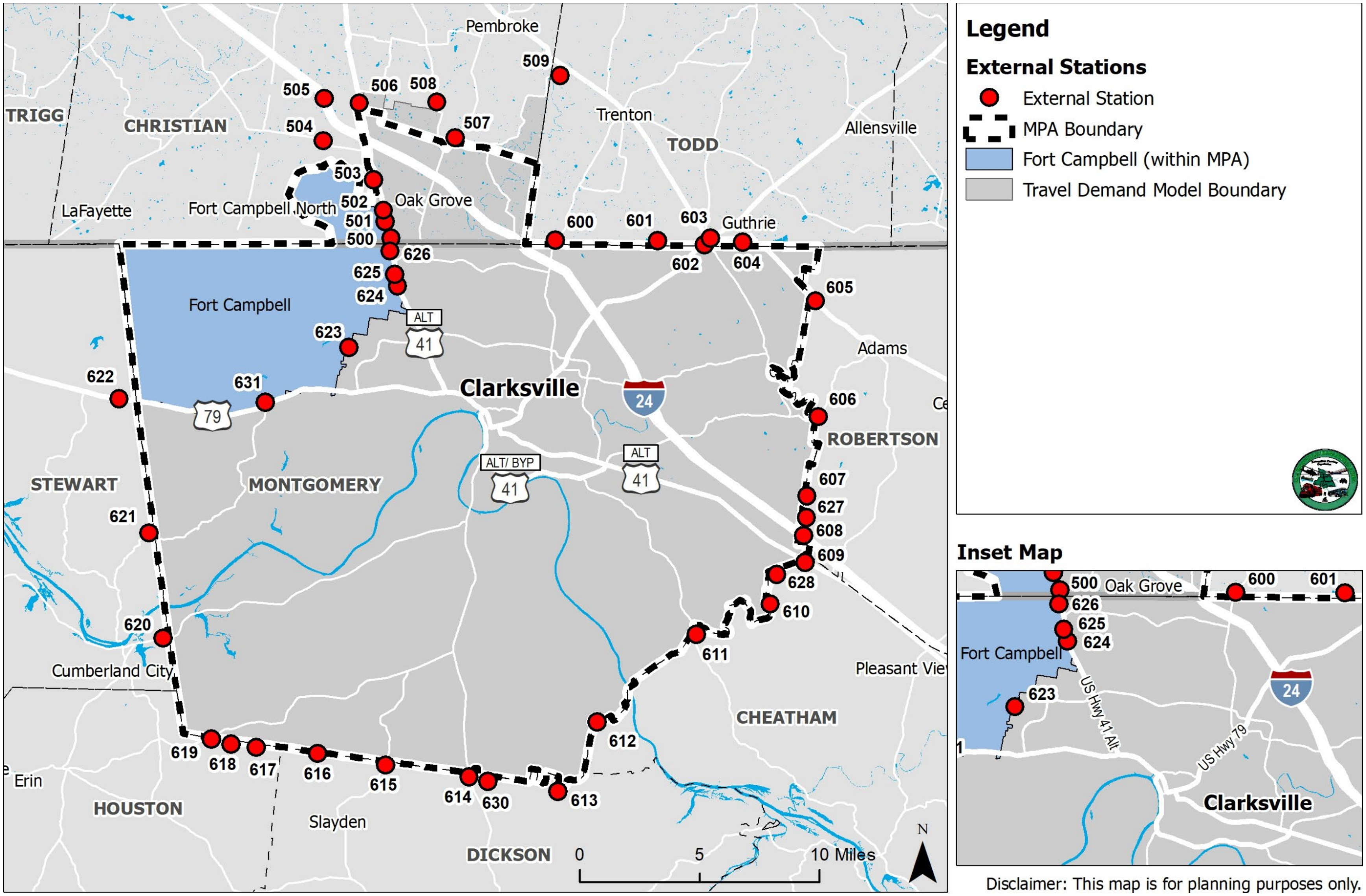
4.0 External Travel

There are two (2) types of external travel trips: external-internal (EI) trips and external-external (EE) trips.

- EI trips have one end of the trip inside the study area, and the other outside.
- This can apply to trips originating within the study area and leaving, or can be trips originating outside of the study area and stopping within.
- EE trips pass through the study area.
- They have no origin or destination within the study area itself.

Both trip types are assigned at external stations located on significant roadways that are at the periphery of the study area. These stations represent most trips that are crossing the study area boundary. Since there were no changes to the study area and no additional roadways added to the network crossing the study area boundary, the external stations are the same as the previous model. The locations of the TDM's external stations are shown in **Figure 4.1**.

Figure 4.1: MTP 2050 Model External Stations



4.1 Development of EE Trips

The EE trips that pass through the study area are represented by a matrix in the model. This matrix represents the daily vehicle trips going from one external station to the other external stations of the study area.

The percentage of EE and EI trips, as well as the auto and truck trip percentages, are the same as those used in the previous model update. However, it should be noted that the previous model EE values were derived from the 2040 MTP model update report, using Table 10 to obtain the percentage of EE and EI trips, the distribution of EE trips, and the auto and truck trip splits. This created an initial seed matrix for EE distribution. However, during the 2045 update, external matrices for auto and truck trips were updated to reflect the closure of Gate 2 and Gate 5 at Fort Campbell to public traffic, which has continued in this update. The Fratar Method was used to grow the EE trips to current ADT counts. This method has been used since a cordon study has not been conducted for the MPA since 2008.

The external travel trips at each station are shown in **Table 4.1**. The full distribution of the EE trips can be found in the model input files.

Table 4.1: Study Area External-External Trips

Station Number	Description	Station Count	Percent EE Trips	Percent EE AUTO	Percent EE TRK	EE AUTO Trips	EE TRK Trips
500	Ft Campbell Access/Gate 4	11,000	16.0%	94.0%	6.0%	1,653	106
501	Ft Campbell Access/Gate 5	0	13.2%	91.0%	9.0%	0	0
502	Ft Campbell Access/Gate 6	2,300	14.2%	90.9%	9.1%	296	30
503	Ft Campbell Access/Gate 7	5,000	13.6%	65.9%	34.1%	449	232
504	KY 117	5,028	13.6%	91.1%	8.9%	621	61
505	I-24	34,737	72.0%	70.0%	30.0%	17,270	7,731
506	Ft Campbell Blvd/US 41 A	9,355	58.0%	92.0%	8.0%	4,789	640
507	Pembroke Oak Grove Rd	2,146	0.0%	0.0%	0.0%	0	0
508	KY 109/Bradshaw Rd	669	0.0%	0.0%	0.0%	0	0
509	KY 1453	252	0.0%	0.0%	0.0%	0	0
600	Trenton Rd/SR 48	3,267	0.0%	0.0%	0.0%	0	0
601	Tylertown Rd/SR 249	1,869	13.5%	97.9%	2.1%	246	6
602	US 79/SR 13	7,278	13.3%	90.8%	9.2%	767	201
603	Port Royal Rd	1,331	10.0%	93.3%	6.7%	121	12
604	US 41	2,521	94.6%	90.0%	10.0%	2,146	238

Station Number	Description	Station Count	Percent EE Trips	Percent EE AUTO	Percent EE TRK	EE AUTO Trips	EE TRK Trips
605	US 41	2,919	88.6%	90.0%	10.0%	2,313	273
606	SR 76	830	14.6%	94.2%	5.8%	114	7
607	Harmony Church Rd	330	13.6%	90.0%	10.0%	41	5
608	I-24	60,292	47.0%	74.0%	26.0%	20,974	7,370
609	Madison St/US 41 A	6,493	13.8%	97.0%	3.0%	854	43
610	Old Clarksville PK	440	12.5%	98.0%	2.0%	54	1
611	Ashland City Rd	4,931	5.2%	94.4%	5.6%	228	26
612	Chapel Hill Rd	535	12.8%	98.0%	2.0%	67	1
613	Ryes Chapel Rd	310	11.4%	92.5%	7.5%	33	3
614	Cumberland Dr	4,250	9.8%	91.1%	8.9%	380	37
615	Marion Rd	551	12.7%	95.0%	5.0%	65	5
616	Chambers Rd	240	14.3%	90.0%	10.0%	31	3
617	Thorne Hollow Rd	272	15.0%	93.3%	6.7%	38	3
618	Ellis Mill Rd	110	14.3%	100.0%	0.0%	16	0
619	SR 13	620	13.2%	97.0%	3.0%	78	4
620	SR 149	5,798	10.2%	90.0%	10.0%	531	59
621	Lylewood Rd	1,250	13.3%	93.8%	6.3%	156	10
622	Dover Rd	9,018	15.0%	96.9%	3.1%	1,315	42
623	Lafayette Rd/101st Airborne	8,304	14.1%	100.0%	0.0%	1,167	0
624	Ft Campbell Access/Gate 1	4,500	14.3%	94.0%	6.0%	606	39
625	Ft Campbell Access/Gate 2	0	14.2%	94.4%	5.6%	0	0
626	Ft Campbell Access/Gate 3	6,000	13.9%	97.0%	3.0%	810	25
627	Sango Rd	420	0.0%	0.0%	0.0%	0	0
628	Knox Rd	210	0.0%	0.0%	0.0%	0	0
630	Old Hwy 48	105	0.0%	0.0%	0.0%	0	0
631	101st Airborne Division Rd	1,050	0.0%	0.0%	0.0%	0	0

Source: NSI, 2022

4.2 Development of EI Trips

During model development, EI trips (which include both internal-external and external-internal) were separated into auto and truck trips based on the vehicle classification counts at external stations. As with EE trips, EI trips were divided into AUTO and TRK trips based on the distributions obtained from Table 10 of the 2040 update.

However, for this update the following EI attraction equations were used in the travel demand model for EIAUTO and EITRK trips.

*EIAUTO Attractions = 0.5300 * Households + 0.8376 * RET_EMP + 1.2720 * SE_EMP + 0.8388 * OTH_EMP*

*EITRK Attractions = 0.0552 * Households + 0.1624 * RET_EMP + 0.0398 * SE_EMP + 0.1601 * OTH_EMP*

Since these equations are new for this model update, and origin-destination data was unavailable, EITRK attractions were derived from the MTP 2045 freight attractions, while EIAUTO attractions were derived from the MTP 2045 CMVEH attractions.

Table 4.2 displays the EI trips at each external station.

Table 4.2: External Station EI Data

Station Number	Description	Station Count	Percent EI Trips	Percent EI AUTO	Percent EI TRK	EI AUTO Trips	EI TRK Trips
500	Ft Campbell Access/Gate 4	11,000	84.0%	96.9%	3.1%	8,957	284
501	Ft Campbell Access/Gate 5	0	86.8%	97.0%	3.0%	0	0
502	Ft Campbell Access/Gate 6	2,300	85.8%	96.9%	3.1%	1,914	61
503	Ft Campbell Access/Gate 7	5,000	86.4%	96.8%	3.2%	4,182	138
504	KY 117	5,028	86.4%	97.0%	3.0%	4,214	132
505	I-24	34,737	28.0%	96.9%	3.1%	9,422	314
506	Ft Campbell Blvd/US 41 A	9,355	42.0%	97.0%	3.0%	3,751	175
507	Pembroke Oak Grove Rd	2,146	100.0%	96.7%	3.3%	1,972	174
508	KY 109/Bradshaw Rd	669	100.0%	97.9%	2.1%	655	14
509	KY 1453	252	100.0%	94.7%	5.3%	239	13
600	Trenton Rd/SR 48	3,267	100.0%	96.8%	3.2%	3,144	123
601	Tylertown Rd/SR 249	1,869	86.5%	96.7%	3.3%	1,561	56
602	US 79/SR 13	7,278	86.7%	96.9%	3.1%	5,864	446
603	Port Royal Rd	1,331	90.0%	97.0%	3.0%	1,149	49
604	US 41	2,521	5.4%	100.0%	0.0%	137	0

Station Number	Description	Station Count	Percent EI Trips	Percent EI AUTO	Percent EI TRK	EI AUTO Trips	EI TRK Trips
605	US 41	2,919	11.4%	96.3%	3.7%	320	13
606	SR 76	830	85.4%	97.1%	2.9%	688	20
607	Harmony Church Rd	330	86.4%	94.7%	5.3%	270	15
608	I-24	60,292	53.0%	96.9%	3.1%	30,966	982
609	Madison St/US 41 A	6,493	86.2%	96.9%	3.1%	5,316	280
610	Old Clarksville PK	440	87.5%	97.1%	2.9%	374	11
611	Ashland City Rd	4,931	94.8%	97.0%	3.0%	4,417	260
612	Chapel Hill Rd	535	87.2%	97.1%	2.9%	452	15
613	Ryes Chapel Rd	310	88.6%	96.8%	3.2%	266	9
614	Cumberland Dr	4,250	90.2%	96.9%	3.1%	3,714	119
615	Marion Rd	551	87.3%	97.1%	2.9%	460	21
616	Chambers Rd	240	85.7%	94.4%	5.6%	194	11
617	Thorne Hollow Rd	272	85.0%	94.1%	5.9%	218	14
618	Ellis Mill Rd	110	85.7%	100.0%	0.0%	94	0
619	SR 13	620	86.8%	97.0%	3.0%	514	25
620	SR 149	5,798	89.8%	97.0%	3.0%	5,052	156
621	Lylewood Rd	1,250	86.7%	97.1%	2.9%	1,052	31
622	Dover Rd	9,018	85.0%	96.9%	3.1%	7,424	238
623	Lafayette Rd/ 101st Airborne	8,304	85.9%	96.9%	3.1%	6,863	274
624	Ft Campbell Access/Gate 1	4,500	85.7%	96.8%	3.2%	3,734	122
625	Ft Campbell Access/Gate 2	0	85.8%	96.9%	3.1%	0	0
626	Ft Campbell Access/Gate 3	6,000	86.1%	96.9%	3.1%	5,007	159
627	Sango Rd	420	100.0%	97.7%	2.3%	410	10
628	Knox Rd	210	100.0%	95.0%	5.0%	200	11
630	Old Hwy 48	105	100.0%	100.0%	0.0%	105	0
631	101st Airborne Division Rd	1,050	100.0%	97.0%	3.0%	1,019	32

Source: NSI, 2022

5.0 Trip Generation

This section describes the procedures used to determine the number of trips that begin or end in a given traffic zone. Trip generation is the estimation of the amount of person trips that are produced and attracted to each TAZ. Trip rates for the various types of trips are based upon the land use properties and demographic characteristics of each TAZ.

The model considers the following internal trip purposes:

- HBW
- HBO
- NHB
- CMVEH
- FRT, a.k.a. TRK

5.1 Internal Travel Model

For home-based trips, the productions refer to the home end, and the attractions refer to the non-home end of the trip. For NHB, CMVEH, and FRT trips, productions and attractions refer to the origin and destination respectively.

The model uses cross-classification trip production models for the home-based and non-home based trip purposes. This means that trip rates that vary by household type are applied at the zonal level. The trip attraction models are linear regression equations that relate zonal employment and households to trip attractions. For the commercial vehicle and freight vehicle trip purposes, the model applies a linear regression equation that relates zonal employment and households to trip productions and attractions. These equations are based on the Quick Response Freight Manual.

The trip production and attraction models were developed from those used in the MTP 2045, which are based on the NCHRP 365 methodology and adjusted to meet the minimum calibration guidelines. These trip models were refined again for this update as needed during the calibration process and adjusted to meet the guidelines based on the updated socioeconomic data. The final trip generation production and attraction models for HBW, HBO, and NHB trips are shown **Tables 5.1** and **5.2** respectively. The trip rates for CMVEH and FRT trips are shown in **Table 5.3**.

Table 5.1: Trip Production Rates

Trip Purpose	HH Size	Vehicle Ownership (Number of Vehicles)				
		0 VEH	1 VEH	2 VEH	3 VEH	4+ VEH
HBW	1 HH	0.5713	0.6082	0.7330	0.9337	1.1142
	2 HH	0.9208	0.9208	0.9208	1.0913	1.1563
	3 HH	1.2390	1.2390	1.2390	1.4319	1.5135
	4+ HH	1.3698	1.3698	1.3698	1.6623	1.8860
HBO	1 HH	1.9621	2.1239	2.5873	3.2632	3.8708
	2 HH	3.6040	3.6040	3.6040	4.1135	4.3276
	3 HH	5.0770	5.0770	5.0770	5.7715	6.0664
	4+ HH	6.0744	6.0744	6.0744	7.3730	8.4138
NHB	1 HH	0.6922	0.7947	1.0219	1.2430	1.4472
	2 HH	1.4863	1.5657	1.6543	1.7292	1.7907
	3 HH	2.4133	2.4809	2.5815	2.6467	2.7047
	4+ HH	3.8769	4.0225	4.1153	4.1724	4.3533

Source: TDM

Table 5.2: Trip Attraction Rates

Trip Purpose	Employment Type				
	Retail	Service	Non-Retail	SCHATT	HH
HBW	1.8251	1.3583	1.6908	0.0000	0.0000
HBO	9.7958	2.1831	0.7018	0.7603	1.0991
NHB	4.4329	1.4246	0.5671	0.4611	0.5671

Source: TDM

Table 5.3: Commercial Vehicle and Freight Vehicle Trip Rates

Trip Purpose	Employment Type			
	Retail	Service	Non-Retail	HH
CMVEH	0.9800	0.4590	0.9814	0.2601
FRT	0.1900	0.0466	0.1873	0.0646

Source: TDM

5.2 Special Generators

A special generator is a land use with unusually low or high trip generation characteristics when compared to the established trip generation rates. For the CUAMPO TDM there were two (2) locations identified as special generators:

- Austin Peay State University
- Gateway Medical Center

The rates developed for the TDM's special generators are in vehicle trips. These trips were then converted to person trips using the model's vehicle occupancy rates. This makes the special generator trips consistent with the trip rates developed in the above section. Additionally, the model update splits the special generator trips at Austin Peay among the zones where parking occurs on campus, and not by being placed in the main campus TAZ.

5.3 Balancing Productions and Attractions

Productions and attractions are balanced at the study area level for all trip purposes. This means that the area-wide trip attractions match the amount of area-wide trip productions. HBW and HBO trips are balanced by holding the productions as a constant since household data is typically considered to be more accurate than employment data. The NHB trips are balanced by holding the attractions as a constant. This reflects that the trips produced at the households or trip origins must be equal to the total number of trips attracted to the non-home ends or destinations. **Table 5.4** shows the daily trips by trip purpose before and after balancing.

Table 5.4: Balanced Productions and Attractions

Trip Purpose	Before Balancing		After Balancing	
	Productions	Attractions	Productions	Attractions
HBW	89,179	88,398	89,179	89,179
HBO	361,983	351,300	361,983	361,983
NHB	188,333	189,239	189,239	189,239
CMVEH	59,104	59,104	59,104	59,104
FRT	11,089	11,089	11,089	11,089

5.4 Summary

As a member of the Tennessee Model Users Group (TNMUG), TDOT has adopted a set of guidelines that help with TDM development. These guidelines are contained in two documents. The first is the *Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee*[2], which was last updated in 2016. The second is the *Travel Model Validation and Reasonableness Checking Manual, 2nd Edition*.[3] Using these guidelines, several key statistics for trip generation were monitored, which are shown in **Table 5.5**.

Table 5.5: Modeled vs Benchmark Trip Rates

Trip Rate	Modeled	Low Benchmark	High Benchmark
Person Trips per Person	3.3	3.3	4.0
Person Trips per Household	8.8	8.0	10.0
HBW Person Trips per Employee	1.55	1.20	1.55
HBW Trips	13.9%	12.0%	24.0%
HBO Trips	56.5%	45.0%	60.0%
NHB Trips	29.6%	20.0%	33.0%

Source: Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee; NSI, 2022

These statistics are within the reasonable limits established by the TNMUG guidance. No further adjustments were made since the model was performing well within all other benchmark ranges and persons were not directly used in the trip rates.

Development of the updated TDM also included a review of the logit model used to develop the household breakdowns used in the demographic data. Using data from the "Middle Tennessee Transportation and Health Study" conducted by Westat in 2013, a comparison of the observed household sizes in Montgomery County and the modeled household percentages was conducted. Based on this data, the logit model continues to perform well in estimating the household classifications for the model. **Table 5.6** displays the household size breakdowns from Westat and the TDM.

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[2] http://tnmug.utk.edu/wp-content/uploads/sites/47/2017/06/MinimumTravelDemandModel2016.pdf

[3] Travel Model Validation and Reasonableness Checking Manual, 2nd Edition. Travel Model Improvement Program.

Table 5.6: Montgomery County Household Size Breakdown

Household Size	Percentage		
	Westat	TDM	Difference
HHS1	24%	26%	2%
HHS2	31%	29%	-2%
HHS3	19%	19%	0%
HHS4+	26%	26%	0%

6.0 Trip Distribution

The next step in travel demand modeling is the trip distribution process. This function determines the destinations of trips produced in the trip generation model, and conversely, where the attracted trips originated.

6.1 Gravity Model

Many models are available for this process; however, the CUAMPO TDM effort used the traditional gravity model.

This model employs two relationships, the first of which is indirect:

> The shorter the travel time to the destination zone, the greater the number of trips will be distributed to it from the origin zone.

The second relationship is a direct one:

> The more attractions there are in a destination zone, the more trips will be distributed to it from the origin zone.

The generalized equation for this model is:

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

Where:

T_{ij} = Trips distributed between zones i and j

P_i = Trips produced at zone i

A_j = Trips attracted to zone j

F_{ij} = Relative distribution rate (friction factors or impedance function) reflecting impedance between zone i and zone j

K_{ij} = Calibration parameter. This parameter is not used in the CUAMPO TDM

n = Total number of zones in study area

6.2 Impedance Matrix

The TDM uses a travel time impedance matrix for each zonal pairing within the study area. This matrix traced the shortest free-flow travel time path from zone i (the start of the trip) to zone j (the end of the trip). These values are placed in what is called a skim matrix. Intrazonal trips are unable to build a path for calculation purposes since i and j are the same zone in this case. When this occurred, the travel time in the skim matrix was computed by taking half of the average of travel time from zone i to its three closest zones.

6.3 Friction Factors

In a model of this type, friction factors determine the effect that spatial separation has on trip distribution between zones. This is the first relationship that was mentioned for the gravity model. These factors measure the probability of trip making at one-minute increments of travel time. Friction factors in the gravity model are an inverse function of travel time and each unique trip purpose has its own friction factors. This TDM effort uses the gamma function to derive the friction factors. Calibration of a gamma impedance function involves estimating the three parameters of the gamma function; a, b, and c. The gamma function parameter values used for each trip purpose are shown in **Table 6.1**.

The friction factors used in this effort are the same as the previous model, which were derived from NCHRP 365 guidance and adjusted to match the trip length distribution observed in 2010 NHTS data and previous TDM modeling efforts.

Table 6.1: Gamma Function Parameter Values by Trip Purpose

Trip Purpose	a	b	c
HBO	390,676.5312	0.1560	0.0866
HBW	1.1614	0.0074	0.0385
NHB	1.0016	0.0006	0.0956
CMVEH	1.0000	0.0000	0.0800
FRT	1.0000	0.0000	0.1000

Source: TDM

6.4 Terminal Times

Terminal times reflect additional travel that is associated with a trip. These can be events such as parking or walking to vehicles and/or facilities. This factor was added to the beginning and end of each trip, using a terminal time of one and a half (1.5) minutes. This value has been used in CUAMPO TDM model updates for several iterations and has not been changed for this effort.

6.5 Trip Length Frequency Distribution

As mentioned previously, the gravity model develops friction factors in one minute increments and accommodates various lengths of trips. The average trip lengths obtained from the model are displayed in **Table 6.2**. The average trip lengths that were estimated using NHTS data for 2010, and previous TDM modeling efforts, are included in the trip length table for comparison. **Figure 6.1** through **Figure 6.3** show the modeled trip length frequency distribution for HBW, HBO, and NHB trips. These curves were compared to those used in the previous model and determined to be within an acceptable level of consistency.

Table 6.2: Average Trip Length by Trip Purpose

Trip Purpose	2019 Model Average Trip Length (min)	NHTS 2010 Average Trip Length (min)	2010 Model Average Trip Length (min)	2016 Model Average Trip Length (min)
HBW	21.6	20.4	21.7	24.2
HBO	17.6	17.6	19.5	19.5
NHB	17.4	17.7	18.3	17.4

Source: TDM, CUAMPO

6.6 Auto Occupancy Rates

The trip rates calculated in the Trip Generation step for HBW, HBO, and NHB trips are in person trips. In order for the TDM to assign vehicles to the roadway network, the number of trips assigned must be in vehicle trips. This process is done using auto occupancy factors. It divides the amount of person trips by the corresponding occupancy factors shown in **Table 6.3**.

Table 6.3: Model Auto Occupancy Factors

Trip Purpose	Auto Occupancy Factor
HBW	1.08
HBO	1.65
NHBO	1.60
CMVEH	1.00
FRT	1.00

Source: TDM

Figure 6.1: Base Year 2019 Modeled HBW Trip Length Frequency Distribution

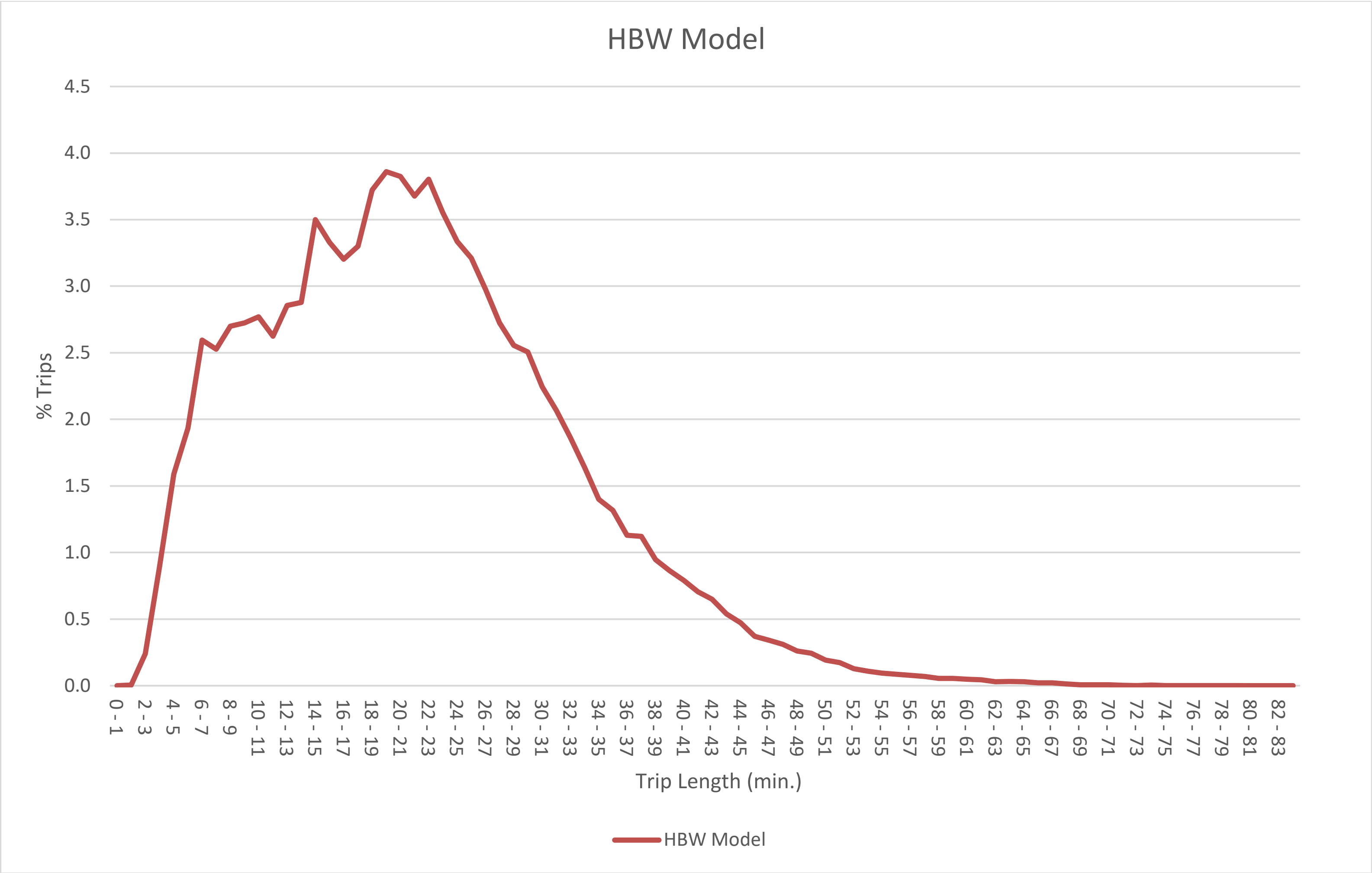


Figure 6.2: Base Year 2019 Modeled HBO Trip Length Frequency Distribution

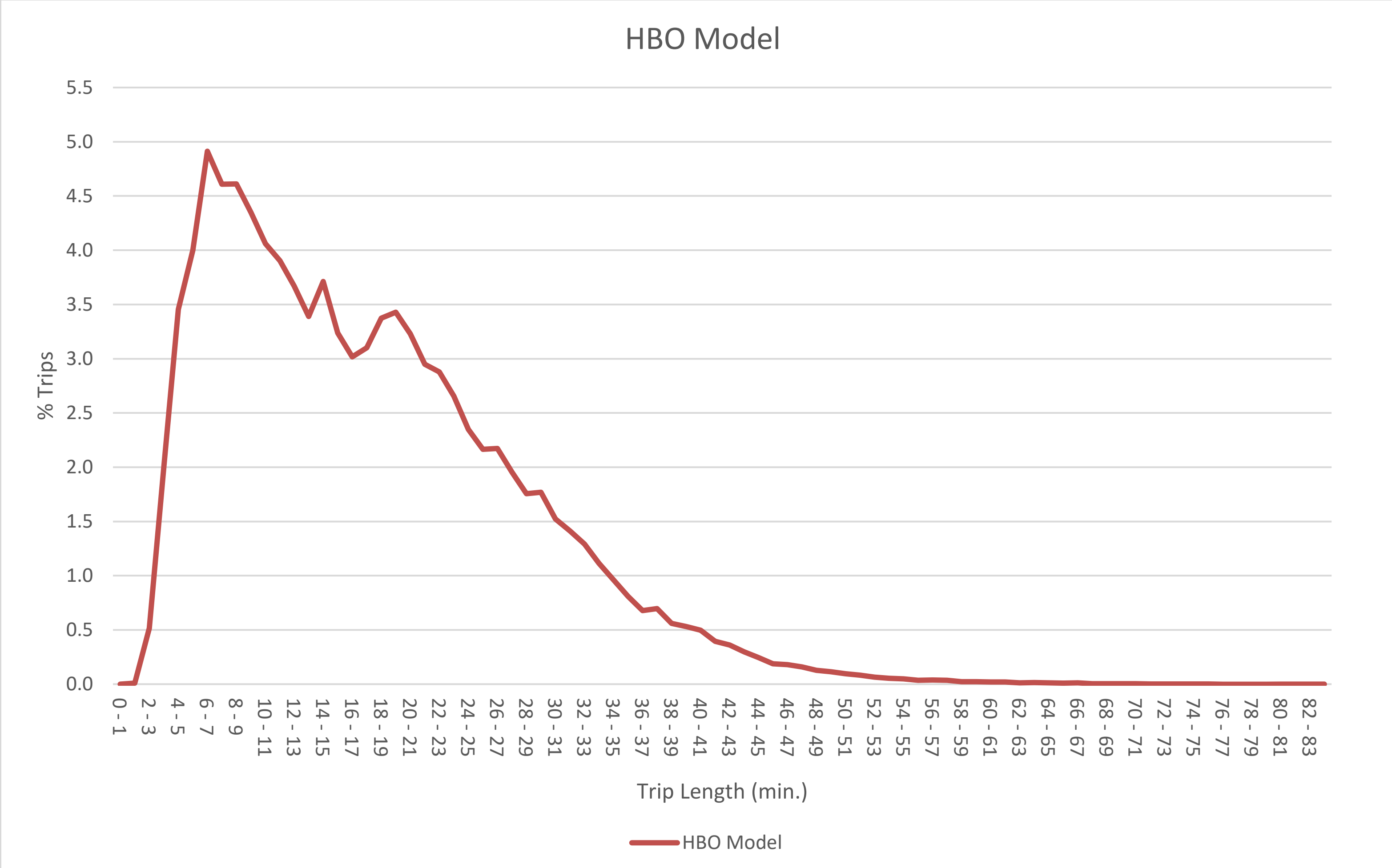
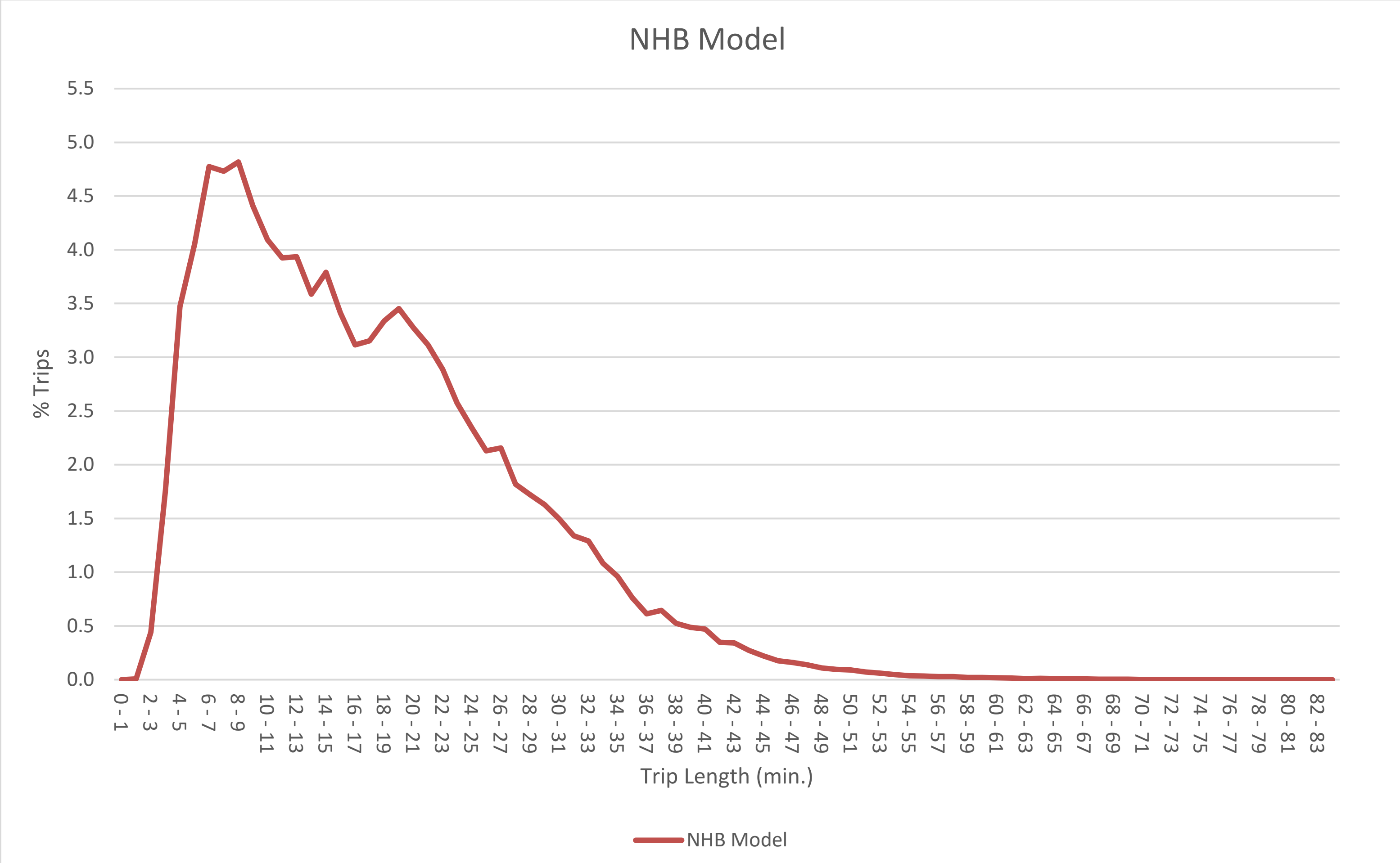


Figure 6.3: Base Year 2019 Modeled NHB Trip Length Frequency Distribution



7.0 Trip Assignment

Trip assignment is the final step in the traditional four-step planning model. Traffic assignment models are used to estimate the traffic flows on a network. The main input to these models is a matrix of flows that indicate the volume of traffic between origin-destination (O-D) pairs. The other inputs to these models are network topology, link characteristics, and link performance functions.

The trips between each O-D pair are loaded onto the network based on the travel time or impedance of the alternative paths that could carry this traffic. The 2050 MTP model is a user equilibrium model with a generalized cost assignment that uses travel time as the cost.

7.1 BPR Volume-Delay Functions

The TDM link travel time was estimated by the Bureau of Public Roads (BPR) Volume-Delay function. The values that were used in the BPR formula are determined by facility type. The TDM has updated alpha and beta values which are assigned by a roadway's functional classification. The assignment process used in the TDM analyzes link and intersection delay. For segments, as traffic volume increases on a roadway and approaches its maximum capacity, the average speed on the roadway declines. After a point, the roadway speed declines past that of the free flow speed and indicates congestion. The intersection delay is calculated using intersection volume/capacity (VOC) ratios and intersection capacities on the intersection links.

The generalized equation for the BPR formula is:

$$T = T_0 * (1 + \alpha * (\frac{v}{c})^{\beta})$$

Where: T = Congested travel time

T_0 = Free flow travel time

v = Assigned link volume

c = Capacity

α, β= BRP coefficients

This allows for the calculation of the roadway's peak hour travel:

$$\text{Peak Hour Travel Speed} = (\text{Free Flow Speed})/\left(1+\alpha*\left(\frac{v}{c}\right)^{\beta}\right.$$

The BPR coefficients used in the TDM are shown in **Table 7.1**.

Table 7.1: BPR Volume-Delay Function Parameters

Model Functional Class	Alpha	Beta
Rural Interstate	0.83	5.50
Rural Principal Arterial	0.71	2.10
Rural Minor Arterial	0.71	2.10
Rural Major Collector	0.60	1.60
Rural Minor Collector	0.60	1.60
Rural Local	0.60	1.60
Rural Other	0.60	1.60
Rural On/Off Ramp	0.71	2.10
Urban Interstate	0.83	5.50
Urban Expressway	0.71	2.10
Urban Principal Arterial	0.71	2.10
Urban Minor Arterial	0.71	2.10
Urban Collector	0.60	1.60
Urban Local	0.60	1.60
Urban Other	0.60	1.60
Urban On/Off Ramp	0.71	2.10
Centroid Connector	0.15	4.00

Source: TDM

8.0 Model Validation

The purpose of model validation is to make the adjustments necessary to replicate the base-year traffic conditions as closely as possible. In practice, this means making the link assignment volumes approximate the traffic estimates, based on actual counts, within acceptable limits of deviation. Generally speaking, the lower the volume, the greater the relative deviation that is acceptable. Conversely, the greater the amount of traffic, the greater the degree of accuracy required. This is because the ultimate purpose of the model is to determine whether additional vehicular capacity will be needed on any given roadway at a designated future date.

Where existing volumes are low, the model assignment may deviate from actual conditions by 40 or 50 percent without affecting the projected need for additional capacity. On the other hand, in the case of a heavily traveled interstate route, a deviation of 20 percent may be significant (i.e., alter the projection of required capacity). The validation process is intended to ensure that the model is performing within the limits that define acceptable ranges of deviation from observed "real-world" values.

As stated previously, the TNMUG uses the *Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee* and the *Travel Model Validation and Reasonableness Checking Manual, 2nd Edition,* as guidelines for the validation of TDMs. The following criteria were used to validate the CUAMPO TDM:

- Vehicle Miles Travelled (VMT) by Region and Facility Type
- Percent Root Mean Square Error (RMSE) by Functional Class
- Percent RMSE by Volume Group
- Percent Error/Deviation by Roadway Facility
- Coefficient of Determination (R^2)
- Screenlines and Cutlines
- Cordon Lines

8.1 VMT by Region and Facility Type

The VMT of a roadway link is calculated by multiplying the vehicle volume on a link by its length in miles. The validation of the TDM looks at the VMT of the entire study area, as well as the individual functional classification of roadways in the study area that classified as a collector or higher. **Table 8.1** displays the VMT of the study area as well as the VMT that was calculated using data obtained from the 2015 Highway Performance Monitoring System (HPMS), adjusted to match 2019 county values since 2019 HPMS is not available at this time.

Table 8.1: VMT by Functional Classification

Functional Classification	Model VMT	HPMS 2019 VMT**	Difference	Percent Difference	Percent Difference Limit
Regional*	4,731,346	4,739,521	-8,175	-0.17%	+/- 2-5
Freeways/Expressways	1,429,232	1,479,105	-49,873	-3.37%	+/- 6-7
Principal Arterials	1,313,127	1,329,253	-16,126	-1.21%	+/- 10-15
Minor Arterials	1,363,887	1,353,229	10,658	0.79%	+/- 10-15
Collectors	625,100	577,933	47,167	8.16%	+/- 20-25

*Values do not include Local streets
**Values are estimated based on HPMS 2015 VMT and County Level 2015/2019 HPMS VMT
Source: NSI, HPMS

8.2 Percent RMSE

The RMSE measure was chosen because when comparing model flows versus counts, sometimes a straight aggregate sum by link group can be misleading. The sum of all traffic counts for a particular link group may be close to the sum of the corresponding traffic flows, but individual link flows may still be very different than their corresponding link count. However, the RMSE statistic does not convey information about the magnitude of the error relative to that of the counts. Therefore, the Percent Root Mean Square Error (Percent RMSE or % RMSE) is often computed. This measure expresses the RMSE as a percentage of the average count value. The Percent RMSE is defined below:

$$\%RMSE = \frac{\sqrt{\sum_j (Model_j - Count_j)^2 / (Numberofcounts)}}{\left(\sum_j Count_j \middle/ Numberofcounts\right)} * 100$$

Validation results by ADT group and functional class are shown in **Table 8.2** and **Table 8.3** respectively.

Table 8.2: RMSE by ADT Group

ADT Range	Number of Observations	Total Count[1]	Total Model Volume[2]	% RMSE	% RMSE Limit[3]
ADT<5,000	101	162,317	196,326	65.2	45.0 - 100.0
5,000 <= ADT < 10,000	53	364,095	373,942	22.5	35.0 - 45.0
10,000 < =ADT < 15,000	20	247,149	255,353	24.0	27.0 - 35.0
15,000 < =ADT < 20,000	12	214,402	211,637	22.6	25.0 – 30.0
20,000 < =ADT < 30,000	22	539,504	541,322	10.1	15.0 – 27.0
30,000 < =ADT <50,000	16	570,704	556,585	10.0	15.0 – 25.0
Areawide	**225**	**2,158,463**	**2,195,455**	**21.4**	**35.0 – 45.0**

Source: Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee; NSI, 2022

Table 8.3: RMSE by Roadway Functional Class

Functional Class	Number of Observations	Total Count[1]	Total Model Volume[2]	% RMSE	% RMSE Limit[3]
Freeway/Interstate	14	403,567	404,229	7.7	20.0
Principal Arterial	27	692,363	680,781	15.8	30.0
Minor Arterial	65	726,400	733,769	16.3	40.0
Collector	103	300,755	340,774	49.9	70.0
Areawide	**225**	**2,158,463**	**2,195,455**	**21.4**	**35.0-45.0**

Source: Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee; NSI, 2022

(1) Total Count represents the sum of average daily traffic estimates for all KYTC and TDOT count locations (area wide), all count locations on principal arterials, all locations on minor arterials, all on major/minor collectors.
(2) Total Model Volume is the sum of model-generated traffic volumes for all network links associated with KYTC and TDOT count locations (area wide), all links associated with count locations on principal arterials, all links associated with locations on minor arterials, and all links associated with count locations on collectors.
(3) % RMSE Limit is the maximum acceptable magnitude of the error relative to that of the counts conducted by KYTC and TDOT.

8.3 Percent Error

The next measure of model validation is the percent error, or percent deviation, of the model's assigned traffic volumes to the observed traffic counts. **Table 8.4** and **Table 8.5** display the validation results by ADT group, ADT and lane group, and by facility category respectively.

Table 8.4: Percent Deviation by ADT Group

ADT Range	Number of Observations	Total Count[1]	Total Model Volume[2]	% Dev	% Dev Limit[3]
ADT<1,000	44	21,148	31,509	49.0	+/- 200.0
1,000 < =ADT < 2,500	33	53,595	65,852	22.9	+/- 100.0
2,500 <= ADT < 5,000	24	87,574	99,549	13.7	+/- 50.0
5,000 <= ADT < 10,000	53	364,095	373,388	2.6	+/- 25.0
10,000 < =ADT <25,000	44	722,638	732,268	1.3	+/- 20.0
25,000 < =ADT < 50,000	26	849,121	832,629	-1.9	+/- 15.0
Areawide	**225**	**2,158,463**	**2,195,455**	**1.7**	**+/- 5.0**

Source: Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee; NSI, 2022

Table 8.5: Percent Deviation by Facility Type

Facility Type	Number of Observations	Total Count[1]	Total Model Volume[2]	% Dev	% Dev Limit[3]
Freeway/Interstate	14	403,567	404,229	0.2	+/- 6-7
Principal Arterial	27	692,363	680,781	-1.7	+/- 10-15
Minor Arterial	65	726,400	733,769	1.0	+/- 10-15
Collector	103	300,755	340,774	13.3	+/- 20-25
Areawide	**225**	**2,158,463**	**2,195,455**	**1.7**	**+/- 5**

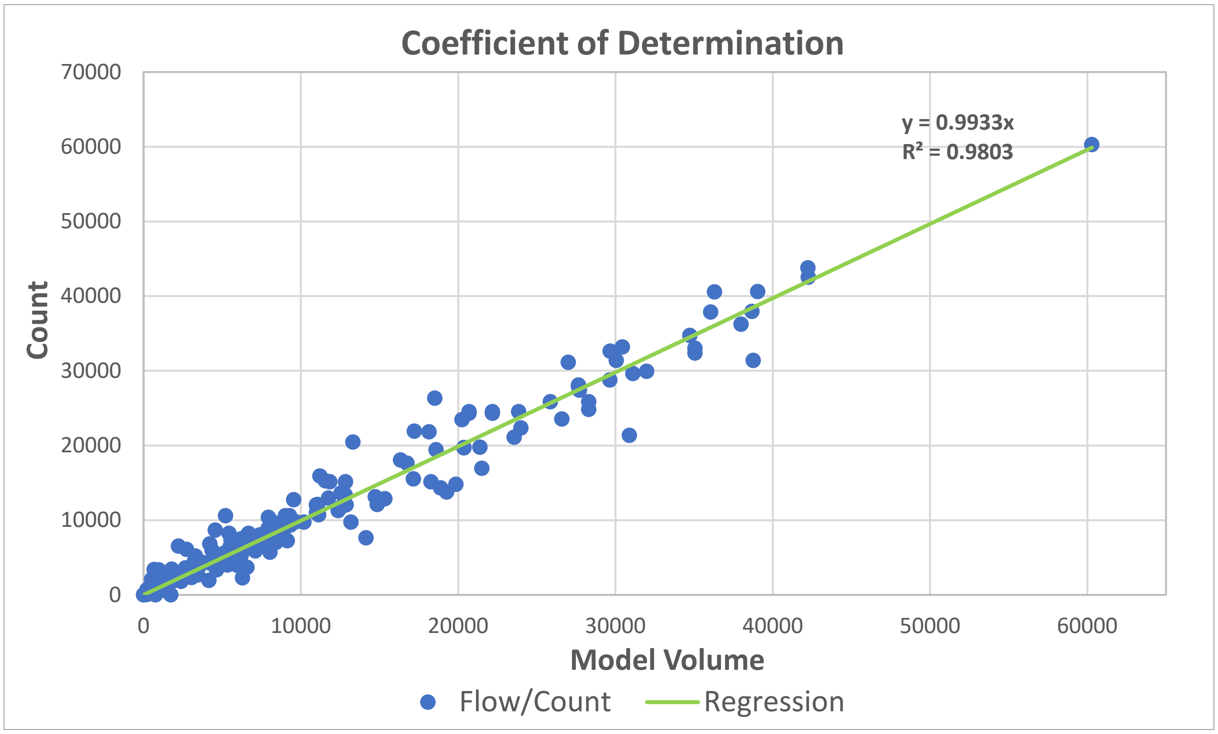
Source: Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee; NSI, 2022

(1) Total Count represents the sum of average daily traffic estimates for all KYTC and TDOT count locations (area wide), all count locations on principal arterials, all locations on minor arterials, all on major/minor collectors.
(2) Total Model Volume is the sum of model-generated traffic volumes for all network links associated with KYTC and TDOT count locations (area wide), all links associated with count locations on principal arterials, all links associated with locations on minor arterials, and all links associated with count locations on collectors.
(3) % Dev Limit is the maximum acceptable plus/minus percentage deviation from estimated base-year (2019) average daily traffic (ADT) based on counts conducted by KYTC and TDOT.

8.4 Coefficient of Determination

The coefficient of determination (R^2) provides a correlation between the observed traffic volumes from KYTC and TDOT and the estimated TDM volumes. The TNMUG guidelines recommend a minimum R^2 of 0.88. The areawide coefficient of this TDM effort was 0.96 and a scatter plot of the results is shown in **Figure 8.1**.

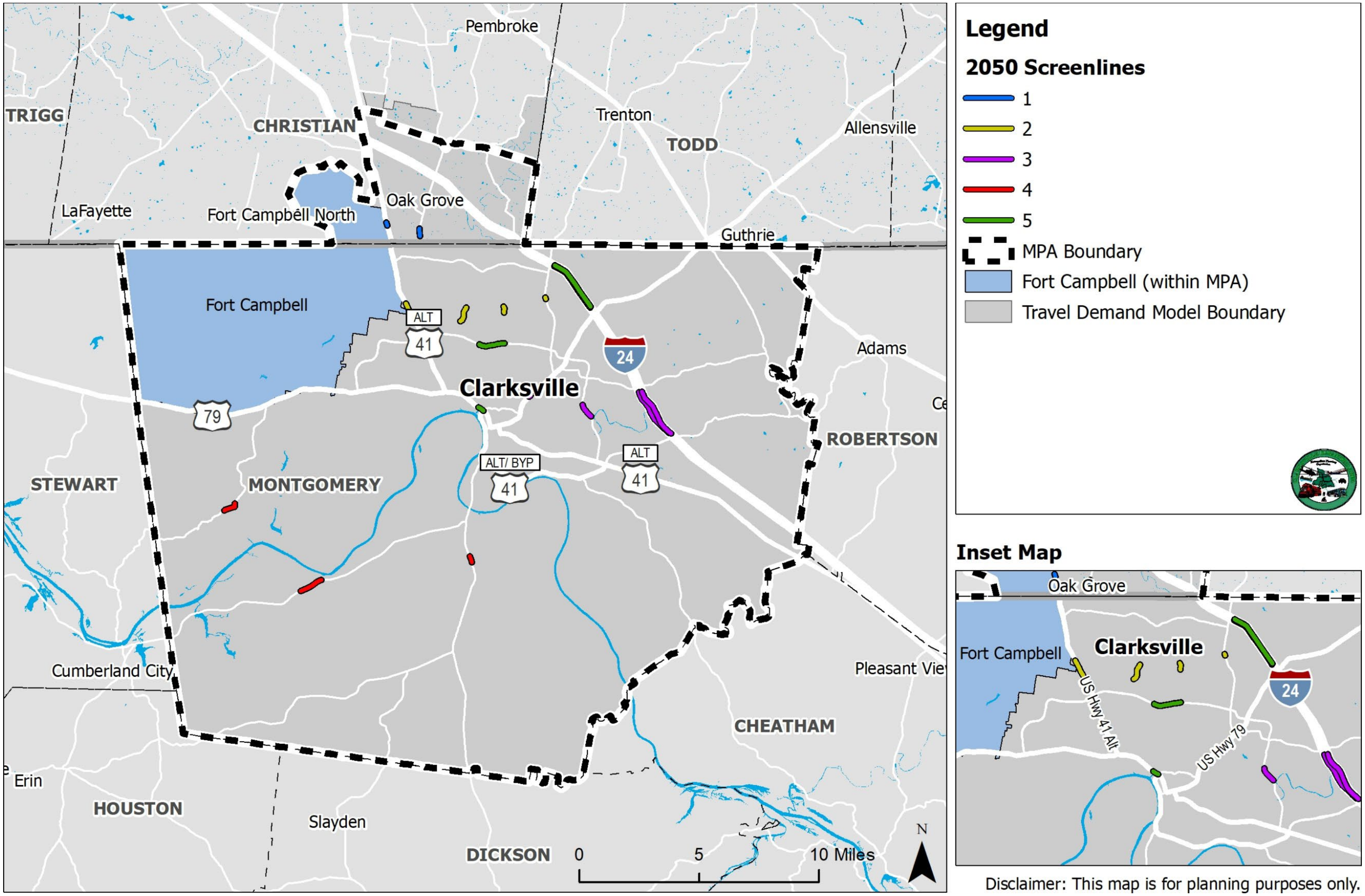
Figure 8.1: Base Year 2019 Modeled Volume vs Traffic Count Plot



8.5 Screenlines, Cutlines, and Cordon Lines

In travel demand modeling, screenlines and cutlines are used to assess how well the model replicates major trip movements and travel between different subareas of the study area. Screenlines often go from boundary cordon to boundary cordon within a study area and are usually a significant physical feature within the study area such as rail lines, rivers, etc. Cutlines extend across corridors and contain multiple facilities and assist with validation of corridor flows within the TDM. **Figure 8.2** shows the screenlines and cutlines used in the model validation, which have been used in previous modeling efforts, while **Table 8.6** displays the results of the screenline analysis.

Figure 8.2: MTP 2050 Screenlines



Disclaimer: This map is for planning purposes only.

Table 8.6: Screenline and Cutline Analysis

Line Number	Type	Number of Observations	Total Count[1]	Total Model Volume[2]	% Dev	Allowable % Dev
1	Screenline	2	32,174	31,805	-1.1	+/-20.0
2	Screenline	4	85,045	86,794	2.1	+/-10.0
3	Screenline	4	131,658	122,725	-6.8	+/-10.0
4	Screenline	3	20,226	22,205	9.8	+/-20.0
5	Screenline	4	136,611	139,149	1.9	+/-10.0

Source: Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee; NSI, 2022

(1) Total Count represents the sum of average daily traffic estimates for all KYTC and TDOT count locations (area wide), all count locations on principal arterials, all locations on minor arterials, all on major/minor collectors.
(2) Total Model Volume is the sum of model-generated traffic volumes for all network links associated with KYTC and TDOT count locations (area wide), all links associated with count locations on principal arterials, all links associated with locations on minor arterials, and all links associated with count locations on collectors.

An analysis of the study area boundary's cordon lines was also conducted in order to determine if the external station TDM volumes matched those of the traffic counts. Based on the TNMUG guidance, all external station link model volumes should be within +/- one (1) percent of the observed traffic counts. The results of the cordon analysis are shown in **Table 8.7**.

Table 8.7: Cordon Analysis

External Station	Description	Model Volume	Count Volume	Volume/Count
500	Ft Campbell	10,998	11,000	1.00
501	Ft Campbell	0	0	1.00
502	Ft Campbell	2,299	2,300	1.00
503	Ft Campbell	4,997	5,000	1.00
504	KY 117	5,026	5,028	1.00
505	I-24	34,734	34,737	1.00
506	Ft Campbell	9,353	9,355	1.00
507	Pembroke Oak	2,144	2,146	1.00
508	KY 109/Bradshaw	667	669	1.00
509	KY 1453	250	252	0.99
600	Trenton Rd/SR 48	3,265	3,267	1.00
601	Tylertown Rd/SR	1,867	1,869	1.00
602	US 79/SR 13	7,276	7,278	1.00
603	Port Royal Rd	1,329	1,331	1.00
604	US 41	2,519	2,521	1.00
605	US 41	2,917	2,919	1.00
606	SR 76	827	830	1.00

External Station	Description	Model Volume	Count Volume	Volume/Count
607	Harmony Church	328	330	0.99
608	I-24	60,290	60,292	1.00
609	Madison St/US 41	6,491	6,493	1.00
610	Old Clarksville PK	437	440	0.99
611	Ashland City Rd	4,929	4,931	1.00
612	Chapel Hill Rd	533	535	1.00
613	Ryes Chapel Rd	308	310	0.99
614	Cumberland Dr	4,248	4,250	1.00
615	Marion Rd	548	551	0.99
616	Chambers Rd	238	240	0.99
617	Thorne Hollow Rd	270	272	0.99
618	Ellis Mill Rd	108	110	0.98
619	SR 13	618	620	1.00
620	SR 149	5,796	5,798	1.00
621	Lylewood Rd	1,248	1,250	1.00
622	Dover Rd	9,016	9,018	1.00
623	Lafayette Rd/101st	8,302	8,304	1.00
624	Ft Campbell	4,497	4,500	1.00
625	Ft Campbell	0	0	1.00
626	Ft Campbell	5,997	6,000	1.00
627	Sango Rd	419	420	1.00
628	Knox Rd	207	210	0.99
630	Old Hwy 48	103	105	0.98
631	101st Airborne	1049	1050	1.00

The validation effort concluded that the CUAMPO study area travel demand forecasting model performs within the established limits of acceptable deviation from base-year estimated volumes.

9.0 Future Year Model Development

Future year models were developed to forecast traffic that the study area will experience based on its anticipated growth. This includes forecast socioeconomic data, external travel, and special generator data. Forecast models also require updates to the roadway network based on projects that are expected to occur or have allocated funding in the near future.

9.1 Future Year Socioeconomic Data Development

To adequately forecast future transportation system needs, future projections of demographic variables were developed for each Traffic Analysis Zone (TAZ).

Population and Employment Growth

County-level growth rates and study area-level population and employment control totals for the year 2050 were developed in consultation with CUAMPO. These forecasts were developed based on a comparison of the previous MTP, historical trends, state projections, and third-party projections to determine the potential growth rates for the planning area. The potential growth rates are shown in **Table 9.1**.

Table 9.1: Population and Employment Growth Rates

Forecast Population Annual Growth Rates		
Source	Christian County	Montgomery County
MTP 2045	0.43%	1.96%
State Data Center Projections	-0.58%	1.63%
Woods & Poole	-0.14%	1.36%
Historical Census (2010-2020)	-0.16%	2.48%
Forecast Employment Annual Growth Rates		
Source	Christian County	Montgomery County
MTP 2045	1.52%	2.23%
State Data Center Projections	N/A	N/A
Woods & Poole	0.51%	1.78%
POP/EMP Ratio (2019 Base)	5.67	3.69

Each of the growth rates was then applied to the base year population and employment to develop year 2050 data. From these, it was determined that the most reasonable population estimates came from the State Data Center projections, while Woods & Pool projections provided the most reasonable employment estimates. Interim control totals were derived using growth rates from the same data sources to determine Year 2030 and Year 2040 control totals. The interim and final horizon year control totals are displayed in **Table 9.2**.

Table 9.2: Planning Area Population and Employment Control Totals

Population					
County	Year				Total Change in Persons
	2019	2030	2040	2050	
Christian County	8,672	8,288	7,758	7,240	-1,432
Montgomery County	206,468	251,313	294,080	340,843	134,375
Employment					
County	Year				Total Change in Employees
	2019	2030	2040	2050	
Christian County	1,530	1,637	1,715	1,792	262
Montgomery County	55,987	69,346	82,555	96,784	40,797

Using these control totals, both population and employment growth were sub-allocated to each TAZ in the travel demand model. **Figure 9.1** displays the total population change by TAZ, while **Figure 9.2** displays the percent change of population. **Figure 9.3** displays the total employment change by TAZ, while **Figure 9.4** displays the percent change of employment.

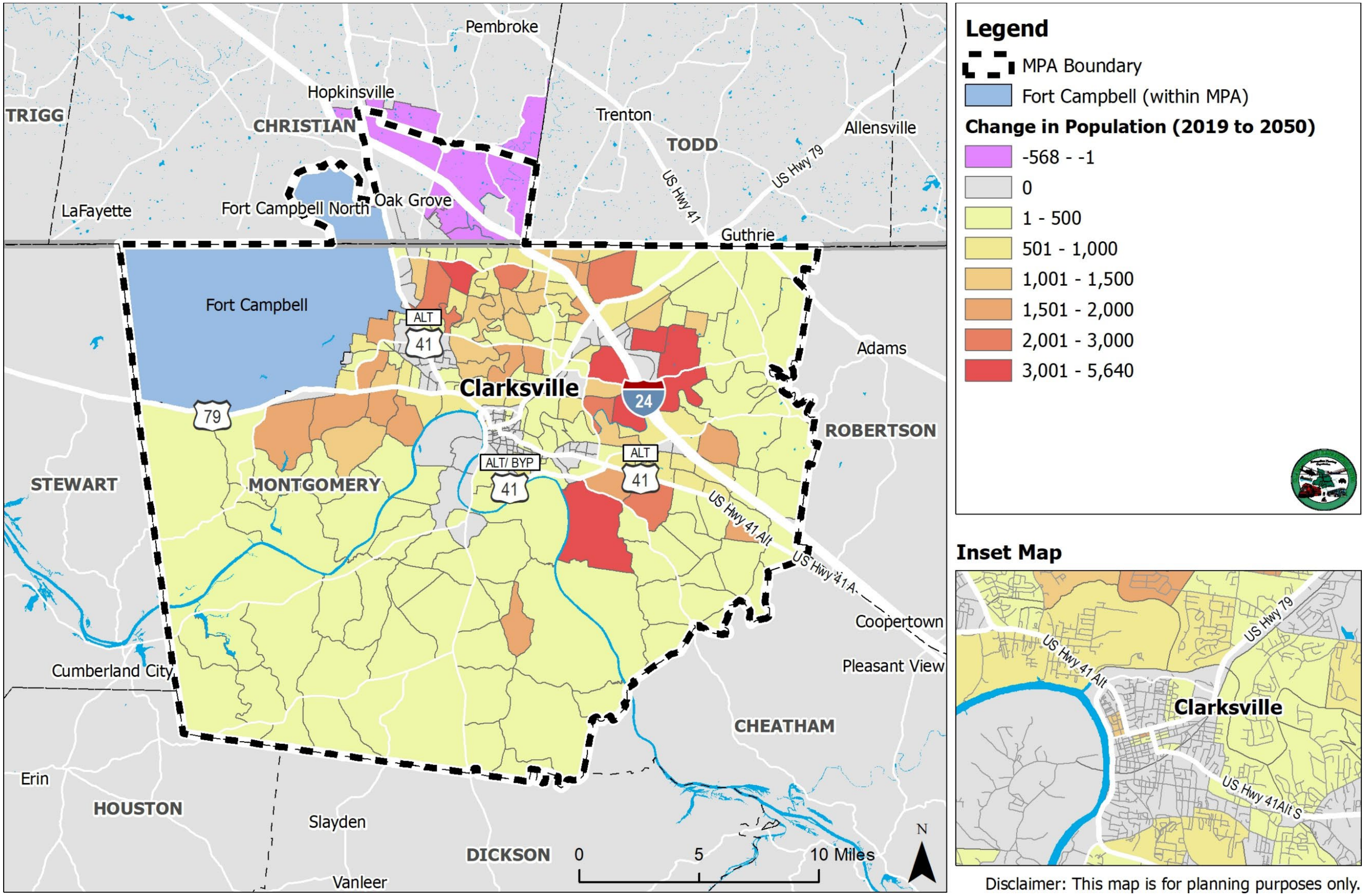
- First, growth that has occurred since the base year was added, based upon local and MPO staff knowledge of recent or approved developments.
- The remaining available growth was allocated through 2050, with an emphasis on areas that were identified as growth areas in the MTP 2045.
    - The first growth to be allocated was that closer to the urban core, near Downtown Clarksville, reflecting the philosophy of currently growing areas continuing to grow until they have been built out.

- Since the new control totals resulted in less population and employment than the MTP 2045, growth to the remaining TAZs was proportionately allocated.
- Following that, some growth was "moved" and instead allocated to nearby zones that had not previously received it so as to produce more reasonable results.
- After approval of the year 2050 TAZ data, data for years 2030 and 2040 were created.

School Enrollment Growth

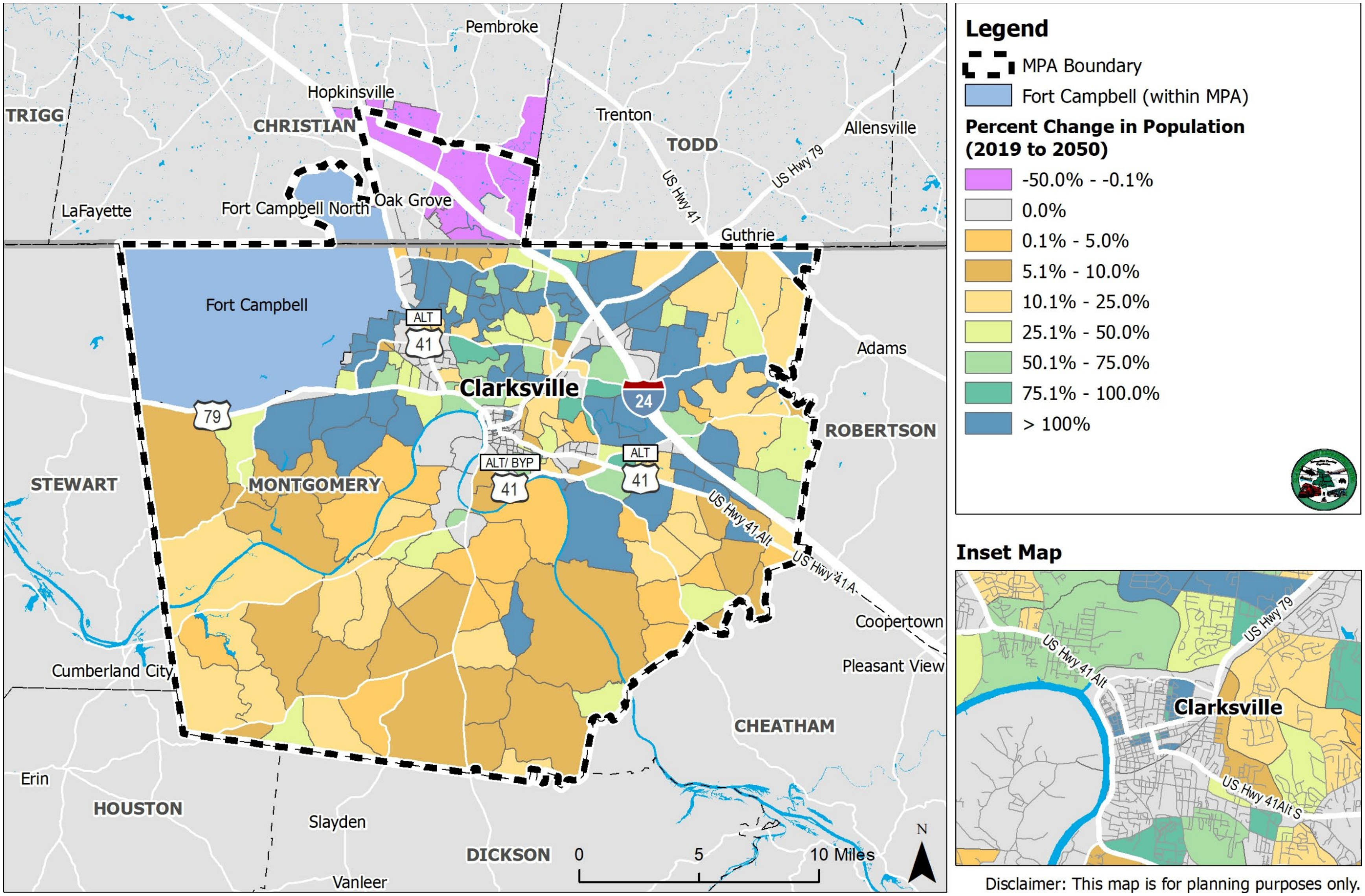
School enrollment growth was projected to grow at the same rate as the total population of the County it is located within until it reached the maximum school enrollment established by the Clarksville-Montgomery County School System. Then, further growth was added to other TAZs to reflect new schools, based on the MTP 2045 locations.

Figure 9.1: Population Growth, 2019-2050



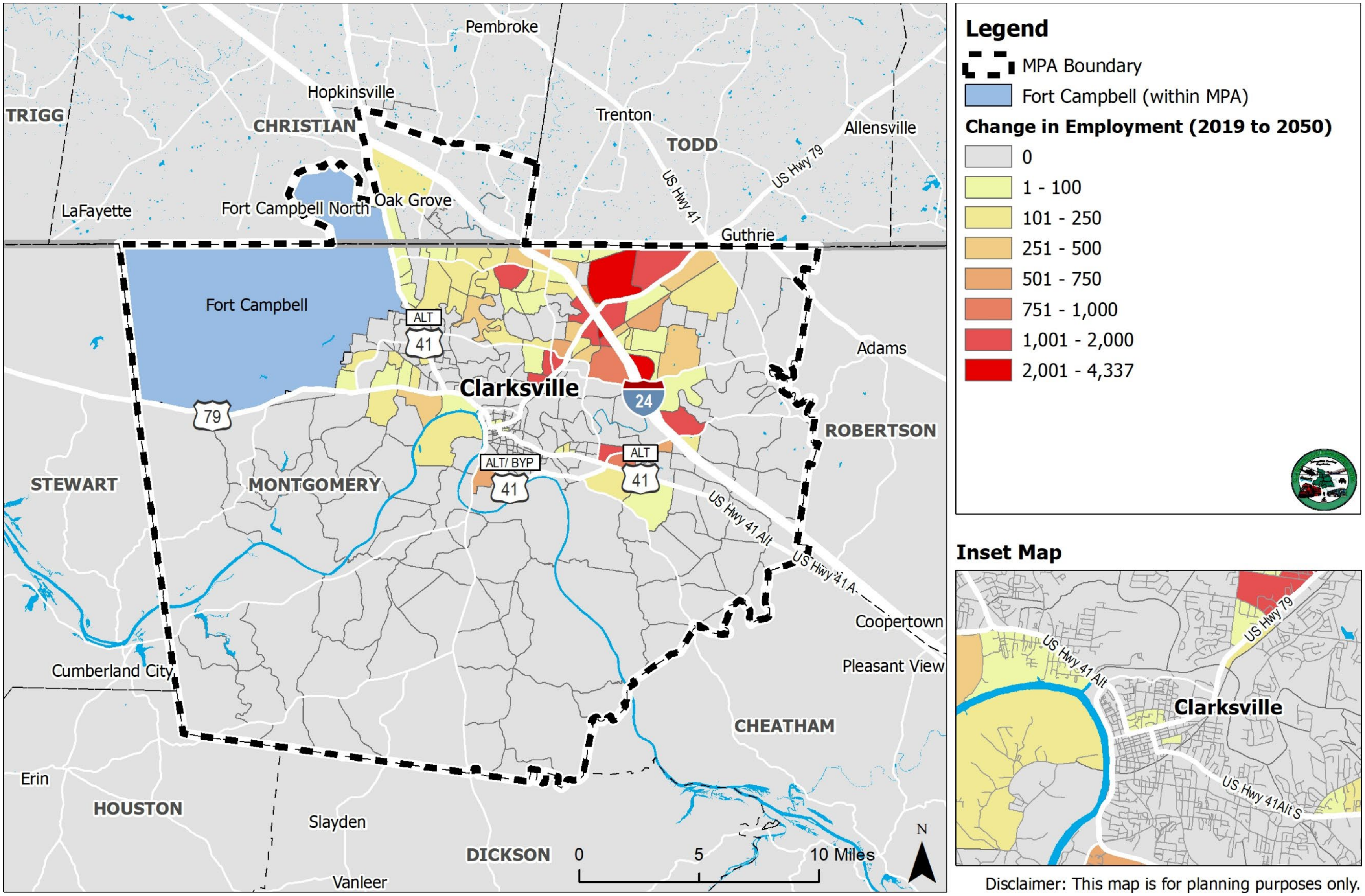
Disclaimer: This map is for planning purposes only.

Figure 9.2: Percent Change in Population, 2019-2050



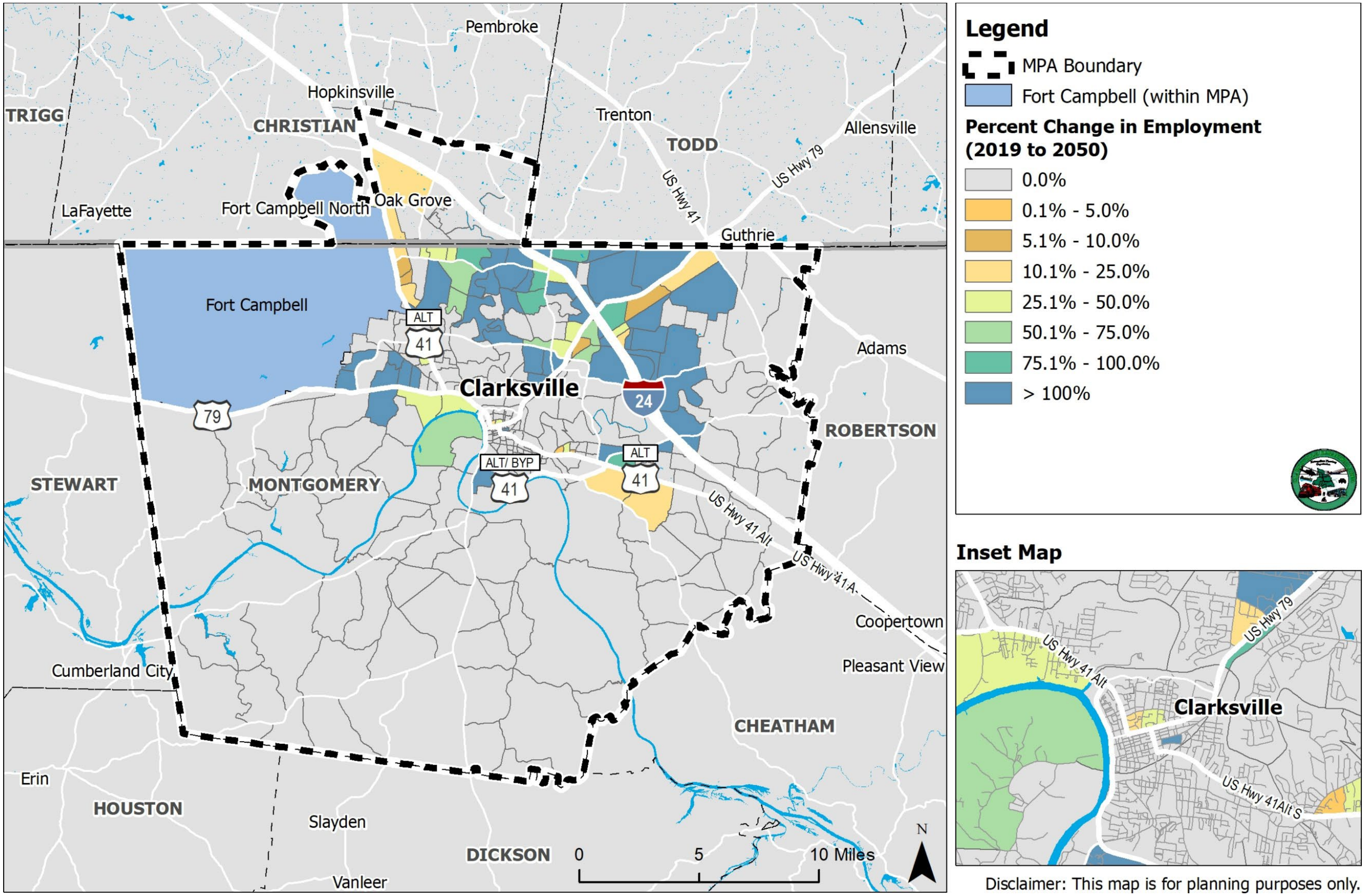
Disclaimer: This map is for planning purposes only.

Figure 9.3: Employment Growth, 2019-2050



Disclaimer: This map is for planning purposes only.

Figure 9.4: Percent Change in Employment, 2019-2050



Disclaimer: This map is for planning purposes only.

9.2 Existing Plus Committed (E+C) Network

The base year network was defined as the street and highway system that existed in year 2019. Once the base year network was calibrated, the E+C network was developed, which included committed projects.

Committed projects are those improvements for which:

- construction was either completed or begun since 2020,
- a contract for construction has been awarded,
- have completed the National Environmental Policy Act (NEPA) phase, or
- have funding for right-of-way and/or construction programmed in the MPO's Transportation Improvement Program.

Committed projects were added to the base network using the following procedure:

- New routes were coded with the proposed number of lanes, and with the posted speed and volume-delay function attributes that reflect the project's functional classification.
- Widened roadways change the number of lanes to the appropriate amount in each direction as well as the lane configuration field required by the network.
- All E+C projects were flagged in the 'PROJECT_EC' field using a unique project ID.

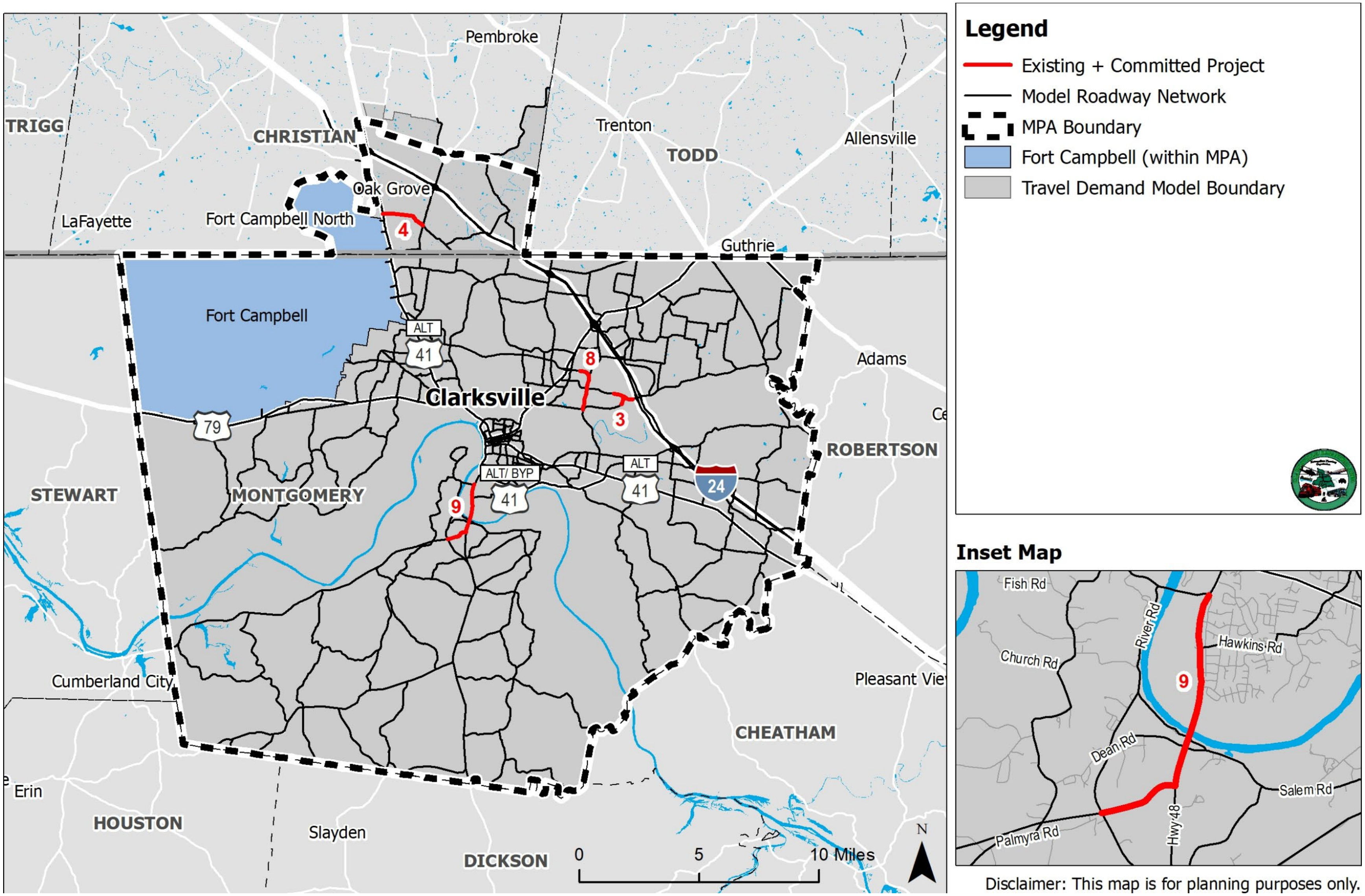
The committed projects are listed in **Table 9.3** and shown in **Figure 9.5**.

Table 9.3: Existing + Committed Projects

Project ID	Roadway	Location	Improvement	Opening Year
3	Dunbar Cave Rd	0.07 mile south of Moss Rd to Rossview Rd	Realignment	2026
	Rossview Rd	Before Keysburg Rd to Cardinal Ln Cardinal Ln to Powell Rd	Widen from 2 to 3 Lanes Widen from 2 to 5 Lanes	2026
4	KY-911	US 41A to KY- 115	Widen from 2 to 5 Lanes	2025
8	SR-374	South of Dunbar Cave Rd to West of Stokes Rd	Widen from 2 to 5 Lanes	Complete
9	SR-149/SR-13	SR-149 from River Rd to SR-13 SR-13 from SR-149 to Zinc Plant Rd	Widen from 2 to 5 Lanes	2023

Source: CUAMPO

Figure 9.5: Existing + Committed Projects



Disclaimer: This map is for planning purposes only.

9.3 External Station Growth

The base year traffic counts at each external station were projected to 2030, 2040, and 2050 using growth factors developed based on historic traffic counts at the external stations. Development of the growth rates used the following methodology:

- Used current ADT counts at the external stations as well as historical ADT counts to determine the nine-year growth rate, six-year growth rate, and three-year growth rate of traffic at each external station.
- Obtained the average of the growth rates and established that rate as the initial external station growth rate.
- If the external station rate exceeded three (3) percent annually, the growth rate was adjusted to three (3) percent.
    - External station growth above three (3) percent annually is often indicative of short-term, explosive growth due to major developments or temporary changes in traffic patterns due to construction.
    - These growth rates are generally not sustainable in the long-term and often produce unreasonable results unless there is a known major development or roadway project expected in the future.
    - There are no known major developments or roadway projects at these external stations, therefore, annual growth rates have been capped to 3 percent.
- If the external station growth rate was less than one (1) percent, including negative growth rates, the external growth rate was adjusted to one (1) percent.
- For some stations, the average annual growth rate produced unrealistic results or reflects recent explosive growth that is not expected to continue into the future.
    - Stations where this occurred further had the growth rate adjusted to reflect more reasonable expected growth.

The final forecast growth rates for each external station and comparison of external travel forecast for the base year and target years is shown in **Table 9.4**.

The total traffic at each station was then divided into EI and EE trips with the assumption that there would not be a significant change in the distribution from the base year. In addition, both EI and EE forecast trips were also separated into auto and truck trips.

Table 9.4: External Station Forecast Growth

Station No.	Station Description	Forecast Growth Rate	2019 Volume	2030 Volume	2040 Volume	2050 Volume
500	Ft Campbell Access/Gate 4	0.0%	11,000	11,000	11,000	11,000
501	Ft Campbell Access/Gate 5	0.0%	0	0	0	0
502	Ft Campbell Access/Gate 6	0.0%	2,300	2,300	2,300	2,300
503	Ft Campbell Access/Gate 7	1.0%	5,000	5,578	6,162	6,673
504	KY 117	1.0%	5,028	5,610	6,196	6,710
505	I-24	1.6%	34,737	41,364	48,480	55,044
506	Ft Campbell Blvd/US 41 A	1.6%	9,355	11,107	12,983	14,709
507	Pembroke Oak Grove Rd	1.0%	2,146	2,394	2,645	2,864
508	KY 109/Bradshaw Rd	3.0%	669	926	1,245	1,577
509	KY 1453	3.0%	252	349	469	594
600	Trenton Rd/SR 48	2.0%	3,267	4,062	4,952	5,802
601	Tylertown Rd/SR 249	3.0%	1,869	2,587	3,477	4,404
602	US 79/SR 13	1.0%	7,278	8,120	8,969	9,713
603	Port Royal Rd	2.1%	1,331	1,680	2,077	2,460
604	US 41	2.4%	2,521	3,277	4,160	5,034
605	US 41	2.3%	2,919	3,762	4,737	5,697
606	SR 76	1.0%	830	926	1,023	1,108
607	Harmony Church Rd	3.0%	330	457	614	778
608	I-24	1.1%	60,292	68,002	75,864	82,802
609	Madison St/US 41 A	1.5%	6,493	7,640	8,858	9,970
610	Old Clarksvile PK	1.0%	440	491	542	587
611	Ashland City Rd	2.0%	4,931	6,131	7,474	8,757
612	Chapel Hill Rd	2.0%	535	663	805	941
613	Ryes Chapel Rd	1.0%	310	346	382	414
614	Cumberland Dr	1.9%	4,250	5,227	6,309	7,334
615	Marion Rd	1.0%	551	615	679	735
616	Chambers Rd	2.5%	240	314	401	488
617	Thorne Hollow Rd	3.0%	272	377	506	641
618	Ellis Mill Rd	3.0%	110	152	205	259

619	SR 13	1.0%	620	692	764	827
620	SR 149	1.2%	5,798	6,615	7,458	8,208
621	Lylewood Rd	1.0%	1,250	1,395	1,540	1,668
622	Dover Rd	1.9%	9,018	11,151	13,525	15,783
623	Lafayette Rd/101st Airbourne	1.3%	8,304	9,560	10,866	12,039
624	Ft Campbell Access/Gate 1	1.0%	4,500	5,021	5,546	6,005
625	Ft Campbell Access/Gate 2	0.0%	0	0	0	0
626	Ft Campbell Access/Gate 3	0.0%	6,000	6,000	6,000	6,000
627	Sango Rd	1.0%	420	469	518	560
628	Knox Rd	1.0%	210	234	259	280
630	Old Hwy 48	1.0%	105	117	129	140
631	101st Airbourne Divison Rd	1.0%	1,050	1,171	1,294	1,401

Source: NSI, 2023

9.4 Future Year Model Runs

The TDM was used to forecast traffic for the future years using the E+C network and forecast socioeconomic, external station, and special generator data. Interpolation was used where necessary to obtain a future year scenario that occurred between the base year (2019), interim years (2030 and 2040), or the horizon year (2050).