Cleveland Metropolitan Planning Organization
2016 Travel Demand Model

Model Development

and Calibration Report

FINAL DRAFT

March 8, 2016

1. INTRODUCTION / HISTORY OF CLEVELAND MODEL

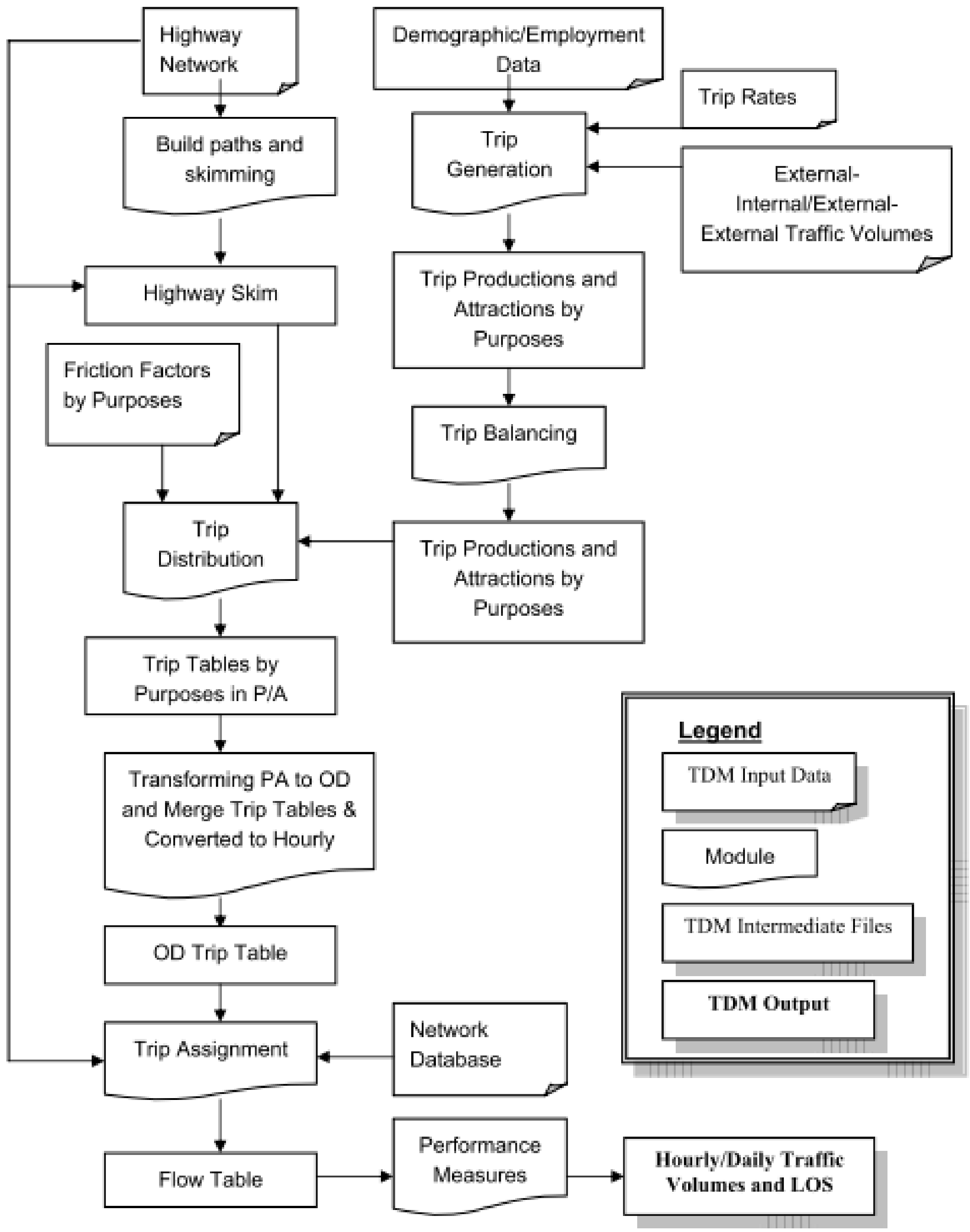
- In 2004 the City of Cleveland and portions of Bradley County were officially designated as a metropolitan planning organization (MPO) as a result of the 2000 United States Census. With this designation came the responsibility of developing and maintaining a regional TDM capable of assisting the MPO in accurately assessing current and future transportation travel demands within the MPO area. Using an older QRS II model as a base, a TransCAD TDM was developed with a base year of 2000.
- 2005: The model was updated to a base year of 2003 which included updated forecasts along I-75 in the future year model.
- 2010: As part of the MPO's 2035 Regional Transportation Plan (RTP), the 2003 base TransCAD Model was updated to a base year of 2008.
- 2015 / 2016: As part of the MPO's 2040 Regional Transportation Plan (RTP), the 2008 base TransCAD Model was updated to a base year of 2013, the most recent year for which traffic counts were available when model development began. Improvements were made to the user interface, including the addition of model reporting for all steps of the model. The new 2016 model also includes a time-of-day component, more detailed breakout of employment types compared to the 2008 model, and an expanded set of network attributes.

2. MODEL OVERVIEW

Consistent with TDOT standards, the model was developed using the TransCAD travel demand forecasting software. The MPO TDM can be executed by running a GISDK macro.

The MPO TDM follows the traditional four-step planning process. However, the focus of the model is on the highway network; thus, the mode of transit is not included in the model and the mode choice step is excluded. The structure of the model is illustrated by the flow chart diagram shown in **Figure 1**.

Figure 1: Model Structure



3. NETWORK AND DATABASE DEVELOPMENT

Introduction

The spatial representation of the transportation system is one of the most important aspects of travel demand modeling. The transportation system elements include the basic roadway system in the study area along with their key attributes as well as a system of traffic analysis zones.

Study Area / Planning Area Boundary Considerations

One of the first steps in the development of a travel forecasting model is the determination of the geographic area of analysis, or study area. The 2010 Cleveland model already included the entirety of Bradley County. For the 2016 model, the model boundary was expanded to include a portion of McMinn County since the MPO planning area has undergone a similar expansion.

Zone System Definition

Traffic Analysis Zones (TAZs) are geographic areas dividing the transportation study area into homogeneous areas of land use, land activity, and aggregate travel demand. TAZs are geographic polygons representing areas of trip production and attraction activity within the study area. To develop the TAZs for the Cleveland TN MPO model, the previous version of the TAZ system was used as a starting point. US Census Block geography was aggregated to these larger geographical areas. The proposed roadway network served as the boundary for many of these zones. Known railroad lines served as a boundary as well. In addition, natural / geographical features also provided boundaries to the zones. New zones were created in locations where growth had occurred or was expected to occur. Consultation with the Tennessee Statewide Model was also made.

External Zones/Stations

External zones, commonly referred to as external stations, are similar to traffic analysis zones in that they represent travel activity. For external zones, this travel activity has an origin and / or destination outside of the study area. Unlike TAZs, they are not represented by a geographic polygon and demographic data, but are represented as a node in the highway network with an associated traffic count. The Cleveland model has twenty-three external stations.

Land Use Data

Land use at the TAZ level is a primary input to the modeling process. **Table 1** lists the land use and demographic variables used for the Cleveland model. Land use data for the base year model development, calibration, and validation work was obtained from the US Census Bureau as well as InfoUSA data. The US Census Bureau data included population, household, and vehicles per household while the InfoUSA Development provided employment data. The employment data was geocoded and then reviewed by MPO staff for validation.

Table 1: Land Use and Demographic Data Variables

Variable	Description (where needed)	Data Input (I) or Model Generated (M)
Population		I
Households		I
Vehicles		I
Students	K-12 student enrollment data	I
Industry	Number of employees by each employment type	I
Retail		
HwyRet		
Service		
Office		
TotEmp	Total number of employees	I
CV*IND	Commercial autos (1), pickups (2) or trucks (3) at an industrial site (IND), retail site (RET), high retail site (HWY), service site (SER), or office site (OFF)	I
CV*RET		
CV*HWY		
CV*SER		
CV*OFF		
hhp*a#	Household by size and auto ownership where * = 1, 2, 3, 4, or 5; and # = 0, 1, 2, or 3	M

Highway Network Development

Representation of transportation infrastructure in the form of a computerized network is mechanically implemented within TransCAD using a GIS data layer. The highway network serves several purposes in the analysis of transportation systems. First, it is an inventory of the existing road system of interest represented in a GIS data layer, serving as a catalogue of facilities. Basic information such as length of roadway, roadway configurations and cross-section, capacity, and volume can be stored in the highway network GIS database. Second, the network is used in demand analysis to estimate the highway impedance between TAZs in the region. The third major use of the network is in estimating auto travel volumes and their associated impacts.

Each link in the GIS network database has several attributes associated with it. The coded roadway attributes defined for the Cleveland model are described in **Table 2**. **Table 3** provides values for facility type.

The 2008 model network was updated by identifying new roadways or roadway improvements that had been constructed since the last update, as well as new traffic signals. Significant changes included the addition of the state industrial access road serving Wacker Chemie in northern Bradley County, as well as the widenings of SR 60 (Dalton Pike) and McGrady Drive. Lower River Road NW was also added to the network due to the probability of changes in traffic patterns since the opening of Wacker and a new Amazon distribution center in the area. Appropriate roads in McMinn County were also added as part of the model area expansion.

Table 2: Roadway Link Attributes

Attribute	Type	Description
ID	Integer (4 bytes)	TransCAD generated, required fields
Length	Real (8 bytes)	
DIR	Integer (2 bytes)	
Posted Speed	Integer (2 bytes)	
Facility Type	Character 23	See Table 3 and Figure 4
Divided	Character 14	See Table 4
AB Lanes	Integer (4 bytes)	Number of lanes by direction
BA Lanes	Integer (4 bytes)	
Terrain	Integer (4 bytes)	3: Rolling/Standard 4: Mountainous/Challenging 5: Flat/Ideal
Initial Time	Real (4 bytes)	Initial link travel time, calculated from Posted Speed. See Table 5
Alpha	Real (4 bytes)	Parameter used in the Volume Delay Function See Table 6
AB Capacity	Integer (4 bytes)	See Table 7
BA Capacity	Integer (4 bytes)	

Table 3: Model Values for Facility Type

Value	FACTYPE_CD	Definition
Freeway	1	Roads with uninterrupted flow and fully restricted access including interstate facilities, freeways, and expressways.
Multi-lane Highway	2	Partial access control two-way facility. No traffic signals or with traffic signals spaced at least 2 miles apart. Directional traffic is divided or with a continuous turn lane.
Two-lane Highway	3	Rural, undivided, two-way highways. Intercity or commuting route serving longer trips in rural areas.
Urban Arterial I	4	Principal arterials of high speed design.
Urban Arterial II	5	Most suburban designs, and intermediate designs for principal arterials.
Urban Arterial III	6	Generally urban design for principal arterials, intermediate design for minors.
Urban Arterial IV	7	Minor arterials of intermediate or urban design.
Collector	8	Urban suburban locations with lower speeds than arterials. Can be rural roadways with low free-flow speed or frequent interruptions.
Local Road	9	Low speed collectors coded to provide connectivity.
Diamond Ramp	10	
Loop Ramp	11	
Centroid Connector	12	

A facility is determined to be divided if it generally operates as if there is no opposing traffic that would affect operational capacity. Facilities with a median and center turn lane are considered divided as are all ramps. Roadways with a 3-lane or 5-lane cross section where the center lane is a continuous left turn lane (CLTL) are treated as a divided highway.

Table 4: Values for Divided Facilities

Definition	DIVIDED_CD
Undivided	0
Divided	1

The free-flow speed and initial travel time is calculated based on the posted speed, facility type, and terrain. Free-flow is the speed at which a vehicle would travel if there were no other vehicles on the road. This calculation is done with a lookup table, which is shown in **Table 5**. The speed adjustment column is the miles per hour added to the posted speed.

Table 5: Initial Link Travel Time Calculation Criteria

Facility Type	Terrain	Speed Adjustment
Freeway	Flat/Ideal	5
Freeway	Rolling/Standard	5
Freeway	Mountainous/Challenging	2
Multi-lane Highway	Flat/Ideal	3
Multi-lane Highway	Rolling/Standard	3
Multi-lane Highway	Mountainous/Challenging	1
Two-lane Highway	Flat/Ideal	3
Two-lane Highway	Rolling/Standard	3
Two-lane Highway	Mountainous/Challenging	-2
Urban Arterial I	Flat/Ideal	-1
Urban Arterial I	Rolling/Standard	-1
Urban Arterial I	Mountainous/Challenging	-3
Urban Arterial II	Flat/Ideal	-2
Urban Arterial II	Rolling/Standard	-2
Urban Arterial II	Mountainous/Challenging	-4
Urban Arterial III	Flat/Ideal	-3
Urban Arterial III	Rolling/Standard	-3
Urban Arterial III	Mountainous/Challenging	-5
Urban Arterial IV	Flat/Ideal	-3
Urban Arterial IV	Rolling/Standard	-3
Urban Arterial IV	Mountainous/Challenging	-5
Collector	Flat/Ideal	-5
Collector	Rolling/Standard	-5
Collector	Mountainous/Challenging	-7
Local Road	Flat/Ideal	-5
Local Road	Rolling/Standard	-5
Local Road	Mountainous/Challenging	-7
Diamond Ramp	Flat/Ideal	0
Diamond Ramp	Rolling/Standard	0
Diamond Ramp	Mountainous/Challenging	0
Loop Ramp	Flat/Ideal	0
Loop Ramp	Rolling/Standard	0
Loop Ramp	Mountainous/Challenging	0
Centroid Connector	Flat/Ideal	0
Centroid Connector	Rolling/Standard	0
Centroid Connector	Mountainous/Challenging	0

The application of a facility type specific volume delay function (VDF) during highway assignment requires that the function parameters be coded as a data attribute in the highway line layer. The VDF parameter controls the level of speed sensitivity to changes in congestion. The VDF parameter is coded in the attribute table based on the value in field Facility Type. Any links that are not coded with a valid Facility Type will not be coded with the essential parameter value. **Table 6** shows the Alpha parameter lookup table values for the Cleveland model.

Table 6: Alpha Values for Conical Delay Function

Facility Type	Alpha
Freeway	10
Multi-Lane Highway	8
Two-lane Highway	6
Urban Arterial I	6
Urban Arterial II	6
Urban Arterial III	6
Urban Arterial IV	6
Collector	4
Local Road	4
Diamond Ramp	8
Loop Ramp	8
Freeway to Freeway Ramp	8
Centroid Connector	NA

Network Link Capacity

The specification of highway network capacity in a travel demand model relates the supply characteristics of the urban roadway system to the network representation used by travel demand models and application software. An accurate portrayal of highway system supply is very important as it is related to the highway travel demand through a feedback or equilibration process resulting in a well understood and accepted model of individual route choice behavior. For the Cleveland model, a capacity lookup table is used to assign per hour per lane capacity values to each roadway link using a combination of facility type, posted speed, terrain, and whether the facility is divided or undivided. An example is shown below in **Table 7**.

Table 7: Cleveland Model Capacity Lookup Table - Example

FACTYPE_CD	SPEED	TERRAIN_CD	DIVIDED_CD	Capacity (Hourly/Lane)
1	55	5	1	1750
1	55	3	1	1650
1	55	4	1	1550
2	65	5	1	1550
2	65	3	1	1475
2	65	4	1	1400
2	55	5	0	1400
2	55	3	0	1325
2	55	4	0	1250

4. TRIP GENERATION

Introduction

Trip generation is step one in the traditional 4-step model approach. A trip generation model estimates the number of trip-ends generated for each zone in the model. Only trips with both ends in the modeled area are counted. A separate external model is used to account for trips external to and through the modeled area. The number of trips estimated is based on socioeconomic characteristics such as the number of persons, households, autos, and the employment for each zone. This estimate is based on an average weekday trips. A trip rate is applied to these socioeconomic values to calculate trip ends by trip purpose.

Model Form

The model form for trip productions is a cross-classification model. The cross-classification model uses a simple trip rate per household, but classifies the households according to discrete characteristics. The Cleveland model uses a 2-variable cross-classification model of household size and auto ownership. Household size varies from 1 to 5+ persons (5 categories), while auto ownership varies from 0 to 3+ autos (4 categories). This model provides a trip rate for 20 separate household types. The trip rates (by purpose) are applied to the number of households in each household type, by zone. A cross-classification model does not assume a linear relationship between the classification variables and trips, and is therefore able to reflect the non-linear nature of trip production behavior.

The trip attraction model is a regression model using a linear equation to estimate trip attractions based on employment by employment type for each zone.

Model Application

The trip generation cross-classification model was applied for five internal trip purposes: Home-Based Work (HBW), Home-Based Other (HBO), Home-Based School (HBSCH), Non-Home-Based Work (NHBW), and Non-Home-Based Other (NHBO). The final trip production rates based on final model validation are shown in **Table 8**. The trip attraction regression model was applied for the same five internal trip purposes. The final trip attraction rates used in the regression model are shown in **Table 9**.

Table 8: Person Trip Production Rates

Field Name	Description	HBW	HBO	HBSCH	NHBW	NHBO
hhp1a0	1 person, 0 auto households	0.318	1.533	0.081	0.593	0.005
hhp1a1	1 person, 1 auto households	1.114	2.010	0.483	0.938	0.017
hhp1a2	1 person, 2 auto households	1.114	2.010	0.558	0.938	0.017
hhp1a3	1 person, 3+ auto households	1.114	2.010	0.558	0.938	0.017
hhp2a0	2 person, 0 auto households	0.873	2.378	0.136	0.867	0.145
hhp2a1	2 person, 1 auto households	1.148	3.621	0.483	1.478	0.145
hhp2a2	2 person, 2 auto households	2.208	3.621	0.734	1.478	0.044
hhp2a3	2 person, 3+ auto households	2.208	3.621	0.858	1.478	0.022
hhp3a0	3 person, 0 auto households	1.392	2.474	0.254	0.867	0.562
hhp3a1	3 person, 1 auto households	1.544	4.653	0.744	1.876	0.562
hhp3a2	3 person, 2 auto households	2.362	4.653	1.103	1.876	0.392
hhp3a3	3 person, 3+ auto households	3.171	4.653	1.181	1.876	0.392
hhp4a0	4 person, 0 auto households	1.392	2.474	0.254	0.867	0.896
hhp4a1	4 person, 1 auto households	2.063	5.614	0.744	1.950	0.896
hhp4a2	4 person, 2 auto households	2.362	6.665	1.103	2.72	0.896
hhp4a3	4 person, 3+ auto households	3.171	6.665	1.181	2.72	1.006
hhp5a0	5+ person, 0 auto households	1.392	4.536	0.254	0.867	1.424
hhp5a1	5+ person, 1 auto households	2.063	5.614	0.744	1.950	1.424
hhp5a2	5+ person, 2 auto households	2.362	8.597	1.103	3.297	1.424
hhp5a3	5+ person, 3+ auto households	3.171	8.597	1.181	3.297	1.424

Table 9: Person Trip Attraction Rates

Employment Type	HBW	HBO	HBSCH	NHBW	NHBO
Total Employment	1.56				
Industry		0.60		0.36	0.20
Retail		6.02		1.67	2.90
Highway Retail		6.02		1.67	2.90
Service		0.50		0.29	0.12
Office		0.34		0.23	0.10
Households		1.96			0.72
Student Enrollment			0.94		

Trips made within the study area by non-residents are called non-home-based non-resident trips (NHB-NR). These trips were estimated as a percentage of External-Internal (EI) trips. The typical assumption is that non-residents will make NHB trips at a similar rate as residents of the region. The following parameters and assumptions were made in the estimation of these trips:

- The proportion of Internal/External (IX) trips categorized as Internal-External (IE) trips was 0.90
- The factor applied to the EI trips to get the number of NHBW-NR trips was 11% and the factor applied to the EI trips to get the number of NHBO-NR trips was 21%

The EI trips were estimated using the following formula:

$$EI = (IXP - (IX\text{-}ATTR_{hh} * 0.90))$$

Where: IXP = External station productions

$IX\text{-}ATTR_{hh}$ = External station attractions for households only

NHBW-NR trips were estimated by multiplying 0.11 times the EI trips and NHBO-NR trips were estimated by multiplying 0.21 times the EI trips. The resulting trips were proportionally allocated to each zone for the NHBW and NHBO trip purposes respectively.

Model Results

This section summarizes the model results for the final application of the trip generation model. **Table 10** is a tabulation of the internal trip generation statistics including the number of productions and attractions by trip purpose and the normalization, or production to attraction ratio (P/A ratio). The normalization factor for the P/A ratio should ideally be between 0.9 and 1.1. This factor is within an acceptable range for all trip purposes in the Cleveland model. The other statistic summarized in this table is the percent of trips by trip purpose. The typical ranges for trips by trip purpose as recommended in the literature are displayed in **Table 11** along with the model estimated percentages. All percentages are within the expected range.

Table 10: Internal Trip Generation Statistics

Trip Purpose	Productions	Attractions	Normalization Factor (P/A ratio)	% by Trip Purpose
HBW	77,041	77,037	1.00	21.9%
HBO	163,663	163,505	1.00	46.5%
HBSCH	14,551	14,557	1.00	4.1%
NHBW	30,386	30,362	1.00	8.6%
NHBO	66,063	66,030	1.00	18.8%
TOTAL	351,704	351,491	1.00	100.0%

Table 11: Percentage of Trips by Trip Purpose

Trip Purpose	Typical Range	Model Estimated
HBW	18 – 25%	21.9%
HBO	45 – 55%	50.6%
NHB	20 – 30%	27.4%

5. TRIP DISTRIBUTION

Introduction

The trip distribution model pairs or connects estimated productions and attractions by TAZ to each other. The resulting output is a trip table or matrix of trips from every zone to every other zone for each of the trip purposes specified in the model. In addition to productions and attractions by zone, the trip distribution model uses a generalized cost value for the distribution of trips. As noted in a previous section, the advantage of this approach is that distance is considered as part of the perceived cost of travel.

Model Form

The trip distribution model structure applied for the Cleveland model is the standard gravity model. In general, the “gravity” model suggests that the number of trips from one TAZ to another is proportional to attractions at the attraction TAZ and inversely proportional to the travel impedance between the two TAZs.

The general formulation of the model can be described as follows:

$$T_{ij} = P_i * \frac{A_j * F_{ij} * K_{ij}}{\sum_{k=1}^{zones}(A_k * F_{ik} * K_{ik})}$$

where:

T_{ij} = the number of trips from zone i to zone j
P_i = the number of trip productions in zone i
A_j = the number of trip attractions in zone j
F_{ij} = the friction factor associated with the travel impedance from zone i to zone j
K_{ij} = the socioeconomic or physically related factor for all movements between zone i and zone j

In general, proper model specification attempts to avoid the use of K-Factors as the validity of these factors may be questionable when applied in a future year. K-Factors should only be considered when an underlying physical or geographic barrier can be associated with the error in estimation (e.g., river crossing) or when a distinct socioeconomic or land use characteristic introduces the error (e.g., mismatch between worker and job features). K-Factors were not needed for the Cleveland model.
The friction factors for the trip distribution model are estimated using the gamma function. The final gamma coefficients for the Cleveland model are shown in **Table 13**.

Table 13: Gamma Coefficients

Trip Purpose	a	b	c
HBW	93.27	0.3952	0.0616
HBO	811.02	0.2661	0.0832
HBSCH	354.08	0.1469	0.1291
NHBW	470.40	0.9334	0.0678
NHBO	2983.17	1.0461	0.0782

Model Application

The trip distribution model was applied using the balanced productions and attractions, the zone to zone impedance measures, and the gamma coefficients listed in Table 13 for five internal trip purposes: Home-Based Work (HBW), Home-Based Other (HBO), Home-Based School (HBSCH), Non-Home-Based Work (NHBW), and Non-Home-Based Other (NHBO).

Model Results

The results from the final application of the trip distribution model are shown in **Table 14**. This trip length values follow a logical trend with the HBW trip purpose having the longest travel time.

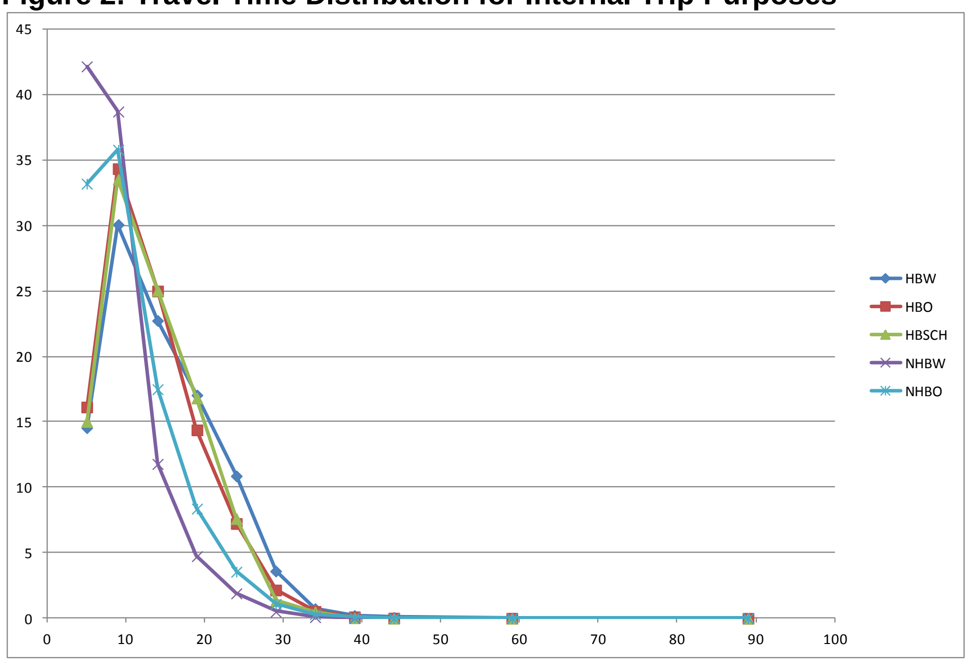
Table 14: Trip Distribution Results

Purpose	Generalized Cost	Travel Time	Distance	% Intrazonal
HBW	18.69	12.22	6.12	2.80
HBO	21.56	11.03	5.00	9.75
HBSCH	20.91	11.01	4.69	10.00
NHBW	11.43	6.93	3.19	15.11
NHBO	13.73	8.44	4.22	16.88

Trip Length Distributions

The trip length distributions by trip purpose resulting from the final application of the trip distribution are shown in **Figure 2** below.

Figure 2: Travel Time Distribution for Internal Trip Purposes



6. MODE SPLIT

Introduction

The Cleveland trip generation model estimates person trips, not auto trips. Before these trips can be assigned to the highway network, factors must be applied to convert the person trips to auto trips. This conversion is accomplished through the application of mode split factors.

Mode Split Factors

A simple mode split approach involves applying mode share factors to the person trip tables for the internal trip purposes (HBW, HBO, HBSCH, NHBW, and NHBO) in order to convert the person trips to person auto trips. The conversion from person trips to person auto trips uses uniform mode share values by trip purpose. Mode split values were asserted based on previous experience with travel surveys from similar sized communities. These values are summarized in **Table 15**.

Table 15: Cleveland Applied Mode Split

Purpose	Auto	Non-Auto
HBW	96.4	3.6
HBO	93.7	6.3
HBSCH	93.7	6.3
NHBW	94.6	5.4
NHBO	95.2	4.8

Auto and non-auto trips by trip purpose are shown in **Table 16**.

Table 16: Auto and Non-Auto Trips by Trip Purpose

Purpose	Auto	Non-Auto	Total
HBW	72,881	4,160	77,041
HBO	153,353	10,311	163,664
HBSCH	13,641	917	14,558
NHBW + NR	33,591	1,917	35,509
NHBO + NR	71,989	3,630	75,618

Vehicle Occupancy Factors

During the time of day procedure average auto occupancy factors by time of day and trip purpose are applied to the HBW, HBO, HBSCH, NHBW, and NHBO trip tables to convert auto person trip tables to auto vehicle trip tables. The vehicle occupancy factors used for this purpose and are shown in **Table 17**. These factors were asserted based on previous experience with travel surveys from similar sized communities.

Table 17: Vehicle Occupancy Factors by Trip Purpose

Purpose	AM	MD	PM	OP
HBW	1.05	1.07	1.05	1.05
HBO	1.48	1.31	1.52	1.52
HBSCH	2.07	1.58	1.99	1.23
NHBW	1.09	1.18	1.09	1.10
NHBO	1.57	1.39	1.61	1.73

7. COMMERCIAL VEHICLES

Commercial Vehicle Trip Generation

The commercial vehicle trip generation model uses a regression model for both trip productions and trip attractions. Trip productions and attractions are based on employment by employment type. The final trip production and attraction rates for the Cleveland model are shown in **Tables 18** and **19**.

Table 18: Commercial Vehicle Trip Production Rates

Vehicle Type	Employment type:					
	Industry	Retail	High Traffic Retail	Service	Office	Households
Autos/Vans (CV1)	12.46	15.16	15.16	18.60	18.60	0.16
Pickups (CV2)	23.86	34.65	34.65	24.73	24.73	0.39
Trucks (CV3)	26.90	32.81	32.81	30.81	30.81	0.04

Table 19: Commercial Vehicle Trip Attraction Rates

Vehicle Type	Employment type:					
	Industry	Retail	High Traffic Retail	Service	Office	Households
Autos/Vans (CV1)	0.1203	0.1986	0.1504	0.0602	0.0722	0.0109
Pickups (CV2)	0.1746	0.2328	0.1921	0.1455	0.0757	0.0058
Trucks (CV3)	0.5438	0.4858	0.3626	0.1523	0.1668	0.0257

The production and attraction models were applied for three commercial vehicle trip purposes: autos/vans (CV1), pickups (CV2), and trucks (CV3) and the final results are summarized in **Table 20**.

Table 20: Commercial Vehicle Trip Generation Statistics

Trip Purpose	Productions	Attractions
CV1	5,644	5,642
CV2	8,259	8,254
CV3	17,296	17,281
TOTAL	31,201	31,179

Commercial Vehicle Trip Distribution

The trip distribution model for the commercial vehicle trip purpose started with the NHB trip purpose generalized cost value for the impedance measure, but these values were modified during model calibration. The final gamma coefficients for the Cleveland model are shown in **Table 21** below.

Table 21: Gamma Coefficients CV Trips

<table>
<tr><th>Trip Purpose</th><th>a</th><th>b</th><th>c</th></tr>
<tr><td>CV1</td><td rowspan="2">2983.1</td><td rowspan="2">1.3076</td><td rowspan="2">0.0782</td></tr>
<tr><td>CV2</td></tr>
<tr><td>CV3</td><td>2983.1</td><td>1.0461</td><td>0.0782</td></tr>
</table>

The trip distribution procedure was applied using the balanced productions and attractions from the trip generation step, the zone to zone impedance measures, and the gamma coefficients shown in Table 21. The results from the model are shown in **Table 22**.

Table 22: Commercial Vehicle Trip Distribution Results

Purpose	Generalized Cost	Travel Time	Distance	% Intrazonal
CV1	10.27	6.31	2.80	19.29
CV2	9.98	6.14	2.71	19.96
CV3	11.14	6.80	3.07	17.42

8. EXTERNAL TRIPS

Introduction

External travel can be defined as through traffic, external-internal travel, and internal-external travel. Through traffic is defined as having both trip ends external to the study area. External-internal or internal-external travel is defined as having one trip end external to the study area.

Through Trip Table

The through trip table for the Cleveland model was synthesized using a synthetic estimation procedure developed by Dr. David Modlin and documented in Transportation Research Record 842. The external traffic count data and roadway functional classification were provided by TDOT. The value for percent trucks was assumed based on the traffic volume and the functional classification. The station data inputs for the synthetic process are summarized in **Table 23**.

Table 23: Data Inputs for Synthetic Estimation

Station ID	Route	Functional Classification	AWDT
1001	I 75	Interstate	39,575
1002	SR 2 / US 11	Principal Arterial	7,310
1003	CR 700	Minor Collector	392
1004	CR 750	Minor Collector	2,161
1005	CR 660	Minor Collector	527
1006	SR 163 / Etowah Rd	Minor Collector	2,467
1007	Athens Rd	Minor Collector	621
1008	Upper River Rd	Minor Collector	734
1009	Bakers Bridge Rd	Minor Collector	831
1010	SR 33 / Benton Pike	Local	7,418
1011	SR 40 / Waterlevel	Principal Arterial	16,514
1012	SR 313 / Ladd Springs	Local	1,160
1013	Spring Place Road	Major Collector	1,086
1014	Keith Valley Road	Local	461
1015	SR 60 / Dalton Pike	Minor Arterial	3,996
1016	SR 317 / Weatherly Switch	Minor Collector	913
1017	US 11 / SR 2 / S Lee Hwy	Minor Arterial	5,878
1018	I 75	Interstate	59,707
1019	SR 312	Local	2,173
1020	SR 60 / Georgetown Pike	Principal Arterial	5,860
1021	SR 306 / Lower River Rd	Major Collector	2,379
1022	CR 20	Minor Collector	758
1023	CR 57	Minor Collector	74

Study area population and route continuity are both required inputs to the synthetic process. The study area population was input as 100,627 and the route continuity is shown in **Table 24**.

Table 24: Route Continuity

From Station	To Station
1001	1018
1002	1017
1017	1002
1018	1001

Final external trip statistics are provided in **Table 25**.

Table 25: Final External Station Trip Statistics

Station	AWDT	% EE	IE/EI Productions
1001	39,575	85.0%	5,936
1002	7,310	26.4%	5,382
1003	392	8.4$	359
1004	2,161	13.0%	1,880
1005	527	8.7%	481
1006	2,467	13.8%	2,127
1007	621	9.0%	565
1008	734	9.3%	666
1009	831	9.5%	752
1010	7,418	26.7%	5,441
1011	16,514	50.3%	8,207
1012	1,160	10.4%	1,040
1013	1,086	10.2%	975
1014	461	8.6%	421
1015	3,996	17.8%	3,286
1016	913	9.7%	824
1017	5,878	22.7%	4547
1018	59,707	60.0%	23,883
1019	2,173	13.0%	1890
1020	5,860	22.6%	4,536
1021	2,379	13.6%	2,057
1022	758	9.3%	687
1023	74	7.6%	68

IE/EI Trip Generation

The simplifying assumption for the Cleveland model is that all IE/EI productions are made at the external stations. Trip attractions are based on employment by employment type and total households in a zone. Including the households in the attraction equation recognizes that, even with the simplifying assumption of all productions at the external stations, some external trips are a result of trips produced by households in the region, not just employment attractions made by households outside of the region. The trip attraction rates for the external station trips are shown in **Table 26**.

Table 26: External Station Trip Production Rates

Trip Purpose	Households	Industry	Retail	Highway Retail	Service	Office
IE/EI	0.86	0.89	1.28	0.73	0.73	0.73

The final application of the external station trip generation model yields the results summarized in **Table 27**. The normalization factor for the P/A ratio is within range as expected given the reasonableness checks and model adjustments performed for the through trip analysis.

Table 27: External Station Trip Generation Statistics

Trip Purpose	Productions	Attractions	Normalization Factor (P/A ratio)
IE/EI	76,010	76,007	1.0

The trip distribution model for the external station trip purpose uses a generalized cost value for the impedance measure and the gamma function for the friction factors. The final gamma coefficients for the external trip model are documented in **Table 28** below.

Table 28: Default Gamma Coefficients

Trip Purpose	a	b	c
IE/EI	2983.1	4.184	0.156

The trip distribution procedure was iteratively applied using the balanced productions and attractions, the zone to zone impedance measures, and gamma coefficients. The final results are shown in **Table 29**.

Table 29: IE/EI Vehicle Trip Distribution Results

Purpose	Generalized Cost	Travel Time	Distance	% Intrazonal
IE/EI	29.17	14.29	10.61	0

9. TIME OF DAY ANALYSIS

Introduction

The need to participate in various activities in most, if not all, study areas varies throughout the day and as such the travel (traffic) required for participating in these activities varies throughout the day. Time-of-day factors and peak/off-peak traffic assignments are recommended for any urban area that has or will require design, capacity and level of service guidance from the planning process, regardless of its size. Daily traffic assignments cannot reflect the effect of volume delay on route choice and therefore cannot be used to forecast congested conditions or the effects of increases in highway capacity on traffic congestion.

Model Form and Application

The conversion of daily trips to trips by time of day is accomplished by applying departure and return factors by trip purpose for each hour of the day. The different departure and return factors by trip purpose capture the different peaking characteristics for the different trip purposes as well as the fact that the departures and returns by time of day vary by trip purpose. The use of departure and return factors by time of day also converts the trip tables from production/attraction (P/A) format to origin/destination (O/D) format. The only trip purpose where this is not necessary is through trips (EE) as these trips are already in O/D format. **Table 30** summarizes the departure and return factors for the internal trip purposes by time of day. These factors were derived from work performed for the North Carolina Department of Transportation on the development of a combined household travel survey database representing travel survey results from several communities across North Carolina. The commercial vehicle trip purposes and the IE/EI trip purposes use the factors for the NHBO trip purpose. The percent flow factors for the EE trips are also provided in this table.

Table 30: Time of Day Factors

	HBW		HBSCH		HBO		NHBW		NHBO		EE
Hour	Dep	Ret	Dep	Ret	Dep	Ret	Dep	Ret	Dep	Ret	%Flow
0	0.00	0.05	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02
1	0.05	0.59	0.00	0.17	0.04	0.33	0.00	0.00	0.04	0.04	0.29
2	0.00	0.20	0.00	0.00	0.00	0.03	0.02	0.00	0.02	0.02	0.07
3	0.15	0.04	0.00	0.00	0.03	0.03	0.00	0.03	0.02	0.02	0.08
4	0.32	0.03	0.00	0.00	0.07	0.04	0.00	0.06	0.02	0.02	0.13
5	1.82	0.00	0.00	0.00	0.32	0.04	0.00	0.49	0.07	0.07	0.63
6	6.54	0.08	0.88	0.00	1.00	0.11	0.14	2.01	0.12	0.12	2.23
7	15.46	0.12	18.55	0.00	3.57	0.68	0.29	7.25	1.10	1.10	7.20
8	11.94	0.26	20.29	0.00	4.70	1.78	0.89	11.42	2.88	2.88	8.77
9	4.24	0.18	3.92	0.34	4.31	1.68	1.73	4.21	2.61	2.61	5.31
10	1.62	0.28	0.90	0.41	3.56	1.57	2.31	1.82	3.43	3.43	4.61
11	0.55	0.47	0.42	0.28	3.40	2.66	3.17	2.19	4.40	4.40	5.42
12	0.85	1.59	0.49	1.80	2.71	3.08	7.78	3.94	4.70	4.70	6.72
13	1.33	1.26	0.35	2.36	2.59	2.83	4.76	7.42	4.82	4.82	6.66
14	1.17	1.52	0.52	4.48	3.00	2.87	3.29	4.52	4.56	4.56	6.23
15	0.91	4.11	0.44	15.60	3.42	3.85	4.98	1.90	5.47	5.47	8.01
16	0.59	7.13	0.96	8.63	2.91	4.49	5.77	0.94	4.20	4.20	7.73
17	0.56	14.49	0.98	4.06	3.37	4.88	8.73	0.96	3.65	3.65	9.45
18	0.71	9.75	0.88	3.89	4.49	4.80	3.82	0.43	3.37	3.37	7.94
19	0.38	3.25	0.20	1.66	4.03	4.14	1.50	0.16	1.97	1.97	4.90
20	0.05	1.30	0.25	1.88	1.57	4.26	0.45	0.13	1.55	1.55	3.40
21	0.25	1.37	0.00	2.65	0.67	3.69	0.22	0.00	0.75	0.75	2.50
22	0.38	0.83	0.00	1.82	0.18	1.58	0.17	0.11	0.23	0.23	1.12
23	0.16	1.16	0.00	0.00	0.10	0.62	0.00	0.05	0.07	0.07	0.58

10. TRIP ASSIGNMENT

The final step in the travel demand model is trip assignment. This is the process of assigning the zone to zone trips to the individual links in the highway network. This step is performed iteratively with overall model calibration and validation. When overall model calibration and validation is achieved, as measured by established performance measures, the trip assignment step provides the data needed for: 1) testing alternative transportation plans; 2) establishing priorities between different transportation investment strategies; 3) analyzing alternative locations for roadway improvements; and 4) forecasting design volumes needed to adequately design and construct new roadway facilities. The reliability of the output from this step is dependent upon the reliability of all the proceeding steps.

Highway Assignment

The algorithms used in traffic assignment attempt to replicate the process of choosing the best path between a given origin and destination. For the Cleveland Metropolitan Planning Organization (MPO) model, the algorithm used for assignment is an equilibrium assignment. This is a widely accepted, best practice approach that produces link loadings by optimally seeking user-equilibrium path loadings reflecting user path choices as influenced by congestion on the network. During the assignment process, the trip table is assigned to the highway network over multiple iterations. At the end of the iteration, link travel times are recalculated using the total link demand and compared to the link travel times of the previous iteration. The aggregate change of link travel times between the current iteration and the previous is compared against the convergence criteria. Thus, the number of iterations is determined by a user defined closure parameter (set to 0.001 for the Cleveland MPO model) or for a maximum number of iterations (set to 25 for the Cleveland MPO model). The final assignment represents an optimum combination of previous assignments using the Frank-Wolfe algorithm.

For each iteration, a volume-delay function is used to update the link speeds based on the previous iteration's vehicle demand and the link capacity. A Conical-delay function was used for the Cleveland MPO model; the formulation of this function is shown below and the corresponding alpha parameter by facility type is shown in **Table 31**.

$$\frac{t'}{t_0} = 2 + \sqrt{\alpha^2 (1 - \frac{v}{c})^2 + \beta^2} - \alpha (1 - \frac{v}{c}) - \beta$$

Where:

$$\beta = \frac{(2\alpha - 1)}{(2\alpha - 2)}$$

Table 31: Cleveland MPO Model Alpha Parameters

Facility Type	Alpha
Freeway	10
Multi-lane Highway	8
Two-lane Highway	6
Urban Arterial I	6
Urban Arterial II	6
Urban Arterial III	6
Urban Arterial IV	6
Collector	2
Local Road	2
Diamond Ramp	8
Loop Ramp	8
Freeway to Freeway Ramp	8

Highway trip assignment is performed separately for the AM peak period (6:00 AM – 9:00 AM), Midday period (9:00 AM – 3:00 PM), the PM peak period (3:00 PM – 6:00 PM), and the Off Peak period (6:00 PM – 6:00 AM). At the end of the assignment procedure, the time period assignments are summed to produce a daily traffic assignment.

Model Results

There are three basic comparisons made when comparing actual traffic counts to trip assignment results: 1) global measures of vehicle miles traveled (VMT); 2) comparisons by screenline, volume group, and facility type, and 3) link level comparisons.

Following an iterative calibration and validation process, acceptable performance measures were achieved. This section describes the final highway trip assignment results.

Vehicle Miles Traveled (VMT)

At the regional level, comparisons of VMT provide useful information on how well the model understands the magnitude and geographic distribution of travel. Typically, estimated study area VMT should be within 5% of observed VMT. **Table 32** summarizes calibrated base year VMT results for the Cleveland MPO model.

Table 32: Vehicle Miles Traveled by Facility Type

Facility Type	Estimated VMT	Observed VMT	% Deviation	TDOT Recommendations
Freeway /Expressway	553,161	550,430	0%	18-23%
Arterials	247,651	283,852	15%	25-28%
Collectors	180,927	151,286	-16%	12-15%
All	981,739	985,568	0%	5-10%

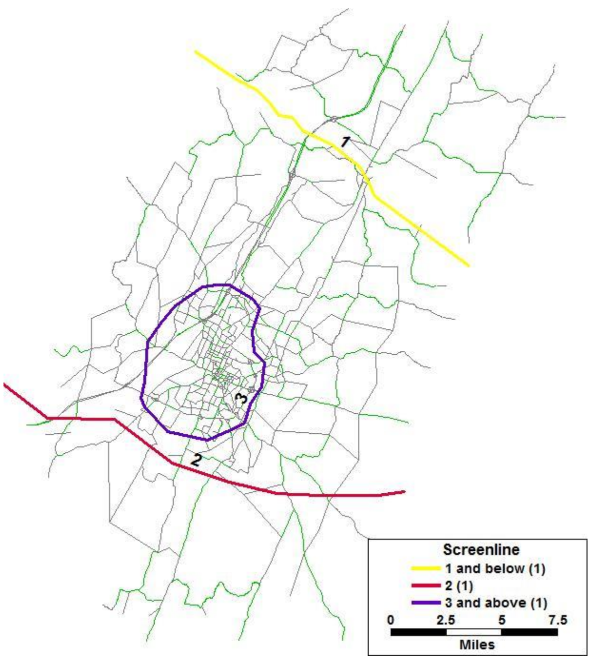
Screenline and Cutline Comparisons

The Cleveland model utilizes two screenlines and one cordon:

1. Screenline 1 runs east to west north of town and captures the north-south flow into town from the north.
2. Screenline 2 runs east to west south of town and captures the north-south flow into town from the south.
3. The cordon captures flow into and out of the core of the Cleveland community.

The screenlines and cordon are shown in **Figure 3** below.

Figure 3: Screenline and Cordon Locations



When properly developed, screenline and cutline comparisons provide a good check on the need for possible adjustments to the upper level models. If all screenlines are either high or low this may indicate a need to make global adjustments to daily trip generation. If some screenlines are high while others are low then this may be an indication that changes are needed in the trip distribution model, or may point to issues in the underlying transportation network. Both screenlines capture a fairly low volume and do not perform as well considering the percent deviation. Screenline 1 is slightly higher than the desired percent deviation, likely attributed to the fact that it is on the northern edge of the planning boundary. The Cordon on the other hand provides a better picture of overall flow into and out of the core part of the region and is well within an acceptable range.

Table 33: Screenline Results

Name	Total Observed Flow	Total Estimated Flow	% Deviation
1	49,644	59,872	20.6%
2	19,598	17,562	-10.4%
Cordon	133,010	136,995	3.0%
Total	202,252	214,429	6.0%

Volume Group and Facility Type Comparisons

At the link level, several comparisons were made including link assignment summaries by volume group and facility type and a measure of the percent root mean square error (%RMSE). The %RMSE is a measure of the variance between the observed and modeled volumes (numerator), normalized by the average of the observed data (denominator) and is expressed as a percent. The formula is as follows:

$$\%RMSE = \frac{(\Sigma_j(Model_j - Count_j)^2 / (Number\ of\ Counts - 1))^{0.5}}{(\Sigma_j Count_j\ \ / Number\ of\ Counts)} * 100$$

Since the differences between estimated and observed are squared before they are averaged, the RMSE gives a relatively high weight to large errors. This means the %RMSE is most useful when large errors are particularly undesirable. Targets for the %RMSE are in the ranges of 35-45%, depending upon the number of low-volume roadway segments included in the count sample. The %RMSE should decrease as volumes increase – thus for facility types with high volumes such as freeways, the %RMSE is expected to be lower (estimated should better match observed) than %RMSE measured on facility types with low volumes such as collectors.

The %RMSE by facility type and volume group is summarized in **Tables 34** and **35**. By facility type, all facilities are within the target range, and the overall %RMSE is between 35-45%. The volume group comparison also shows that all targets have been met, though the lower volume facilities do show more error as expected.

Table 34: Percent Root Mean Square Error by Facility Type

Classification	Observations	%RMSE	Target
Freeways	16	8.0%	20%
Arterials	84	28.4%	30%
Collectors	73	57.0%	70%
Locals	16	88.2%	NA
Total	189	29.8%	35-45%

Table 35: Percent Root Mean Square Error by Volume Group

Volume Group	Observations	%RMSE	Target Range
0 to 4,999	101	67%	45-100%
5,000 to 9,999	36	35%	35-45%
10,000 to 14,999	19	31%	27-35%
15,000 to 19,999	8	16%	25-30%
20,000 to 29,999	21	12%	15-27%
30,000 to 49,999	NA	NA	15-25%
50,000 to 59,999	NA	NA	10-20%
60,000 and greater	NA	NA	10-19%
Total	185	29%	30-40%

Count to Flow Comparisons

Table 36 provides a summary of the assignment results by comparing the daily count to the daily flow by volume group. The percent difference is calculated and compared to recommended target values. As the volume increases the calculated percent difference should decrease as recommended by the target values.

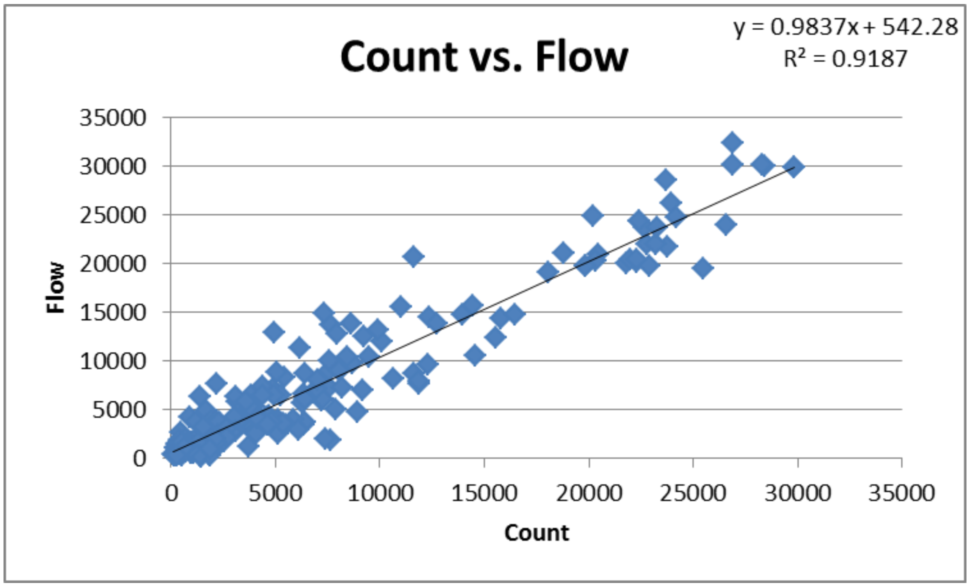
Table 36: Assignment Summary by Volume Group

Volume Group	Modeled Daily Flow	Count Daily Flow	Model % Error	Target % Error
Less than or equal to 1,000	12,943	19,984	54%	200%
1,001 to 2,500	56,821	65,480	15%	100%
2,501 to 5,000	153,742	152,115	-1%	50%
5,001 to 10,000	256,321	231,942	-10%	25%
10,001 to 25,000	771,654	721,680	-6%	20%
25,001 to 50,000	237,134	217,859	-8%	15%
Greater than 50,000	-	-	-	10%

Finally, the observed and estimated daily volumes by link were plotted and the r-squared value was calculated as a final indication of the degree to which the counts and estimated volumes match. The r-squared value is, in part, a function of the number of observations and therefore it is difficult to establish a guideline for acceptable values of r-squared. In general, a high r-squared value is desirable.

Figure 4 shows a scatter plot of observed versus estimated volumes by link. The diagonal line on the graph is defined by the set of points where the estimated count equals the observed count. If all counts fell along this line the r-squared value would be equal to one. The highway traffic assignment for the Cleveland model shows a tight fit between the observed and estimated values.

Figure 4: Scatter Plot of Observed Count and Estimated Flow



Summary of Trip Assignment

The results reported in this technical memorandum indicate that the model is performing within acceptable standards, indicating that the model is representing base year travel demand within the Cleveland MPO model region.

11. FUTURE YEAR MODEL DEVELOPMENT

Upon completion of the calibration and validation of the base year TDM, the model was then developed for future year 2040. Two versions of the future year model were developed:

- Existing plus Committed (E+C): Includes routes that currently exist, in addition to any projects that are committed with construction funds between 2013 and 2040.

- Regional Transportation Plan (Plan): Includes routes and other improvements that are recommended in the MPO's 2040 RTP.

The traffic analysis zones were not changed for the future year models. Future socioeconomic data was developed and approved by the MPO based on identified areas that are anticipated to experience growth in population, households and employment.

As with the TAZs, the model network was updated to reflect future year conditions. Two different networks were created, one for each version of the future year model as noted above. **Tables 37** and **38** show the specific roadway improvements included in the E+C and Plan networks, respectively.

Table 37: Committed Projects Included in 2040 E+C Network

Route	Termini	Miles	Description
US 64/74 (SR 311, APD-40)	Between I-75 Exit 20 and S. Lee Highway (US 11/SR 2)	-	New interchange
I-75	At Exit 20 (SR 311/US 74/ APD-40)	-	Interchange improvements
I-75	At Exit 25 (SR 60 / 25th Street)	-	Interchange improvements
Adkisson Drive	Norman Chapel Rd to Paul Huff Pkwy	1.1	Widen from 2 to 3 lanes
SR 60 (Georgetown Rd)	Westlake Dr to SR 306 (Freewill Rd)	2.5	Widen from 4 to 5 lanes

Table 38: Projects Included in 2040 Plan Network

Roadway	Termini	Description
Paul Huff Parkway Extension	Freewill Rd to SR 60	Construct new 3-lane road
Midtown Connector	3rd and 6th Street area	Construct bridge over railroad in downtown Cleveland
SR 308 Extension	SR 2/US 11 to Chatata Valley Dr	Extend as 3-lane roadway, including RR overpass. Eastern terminus aligns with Upper River Rd N.E.
I-75	Hamilton Co. line to APD 40	Widen from 4 to 6 lanes
I-75	APD-40 (SR 311) to Bradley/McMinn Co line	Widen from 4 to 6 lanes
Georgetown Road (SR 60)	Eureka Rd to Rabbit Valley Rd	Widen from 2 to 5 lanes
N. Lee Highway (US 11/SR 2)	Near Anatole Ln to SR 308	Widen from 2 to 5 lanes