Appendix D

Regional Travel Demand Forecast Model Technical Report

GRAND FORKS EAST GRAND FORKS 2015 TRAVEL DEMAND MODEL UPDATE

FINAL REPORT

To the Grand Forks East Grand Forks MPO

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TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

The Grand Forks East Grand Forks MPO's (The GF-EGF MPO) Travel Demand Model (TDM) is updated every five years to reflect new ground truths/data and the advancements in the state-of-the-art in transportation modeling techniques and methods. The current update reflects base year 2015 data. The model is a four-step TDM including trip generations, trip distributions, modal split and trip assignment. The update process involves calibrating the model input parameters and validating the model output with ground truths. The model calibration is a cyclical process as shown in Figure 1.

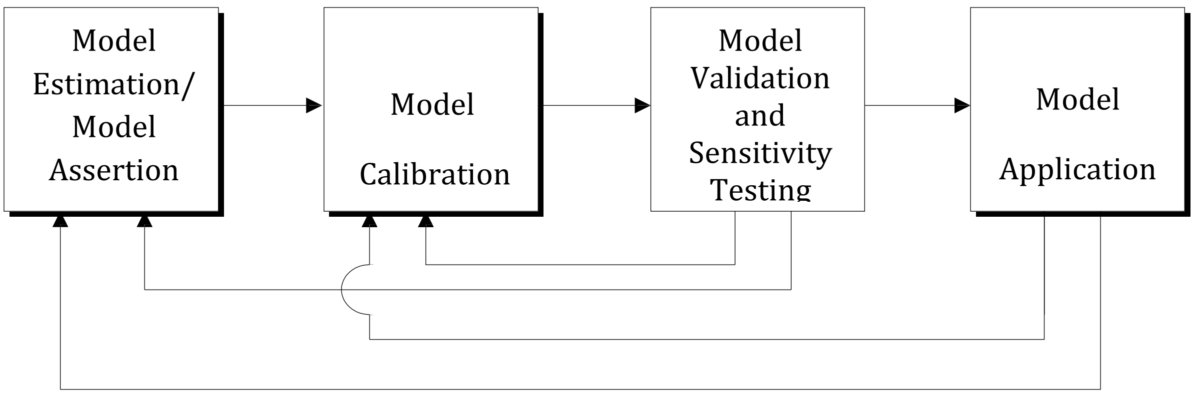


Figure 1 GF-EGF TDM Calibration Flow Chart

The rest of this document describes the model update process including the data, methods and models that were used to update the model. Chapter 2 discusses the improvements made to the 2015 TDM; Chapter 3 discusses the capacity calculation methodology; Chapter 4 discusses the input data used in the model; Chapter 5 summarizes the trip generation models and methods; Chapter 6 discusses the trip distribution step; Chapter 7 discusses the trip assignment step; Chapter 8 discusses the model calibration, validation and output.

2. IMPROVEMENTS TO THE 2015 TDM

For the 2015 base year model, several updates were made to the model to reflect the availability of new and improved data, new and advanced methods in modeling software and the inclusion of long-haul freight movements as part of the model. New data that was used for 2015 model update included: Origin Destination Data (Obtained from Airsage), the traffic analysis tool data, incorporation of truck counts and FAF data to model freights.

2.1. Origin Destination Data Obtained from Airsage

Origin-destination (OD) data were obtained from a commercial vendor Airsage. Airsage is a company that aggregates cell phone cellular-signal data points anonymously in partnership with the nation's largest wireless carriers. Origin Destination data were collected for the entire North Dakota and external locations rather than for the GF/EGF MPO area only. Overall, a total of 301 OD TAZs were used. OD TAZs are defined as TAZS that were used in the OD survey data collection. Of the 301 OD TAZs, 61 were TAZs internal to the GF/EGF MPO area. The internal OD TAZs were an aggregation of the TAZs in the GF/EGF TDM which had a total of 584 TAZs. Figure 2 shows the overall OD TAZs and the GF/EGF MPO TAZs geographies.

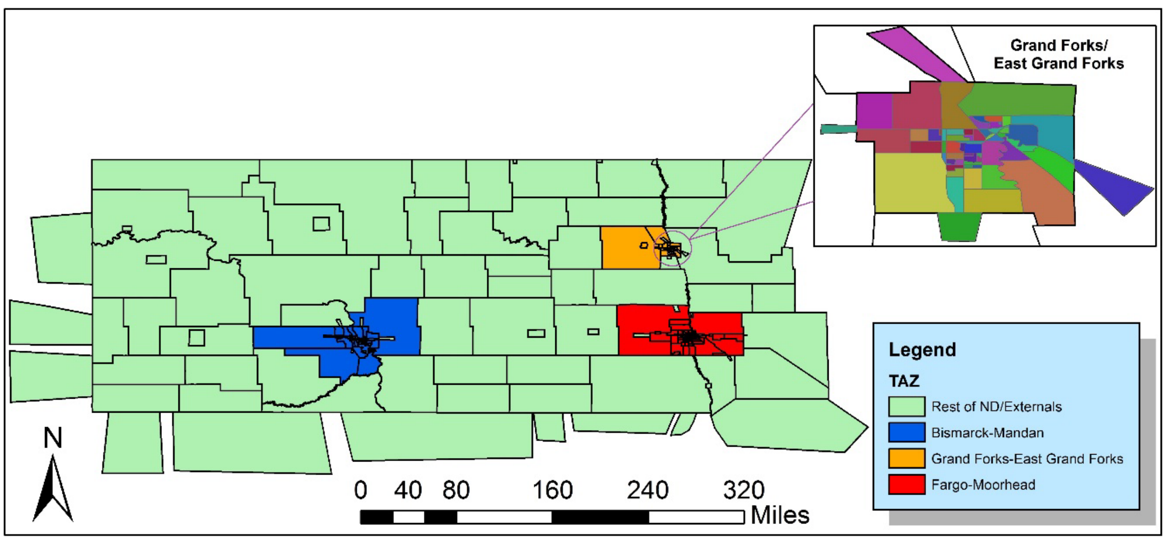


Figure 2 OD TAZs

Different datasets were provided by Airsage reflecting temporal, socioeconomic and weekday/weekend data and included the following tables:

Average Weekday 24 Hour trip matrix reflecting the total 24-hour Origin-Destination by trip purposes (HBW, HBO, NHB). Three Matrices were provided for different socioeconomic variables including age (5 year cohorts), income ($10,000 increments), and vehicle attributes (0->5 for rent/owner households).

Average Weekday Peak Hour matrices (7:00AM-10:00AM, 10:00AM-4:00PM, 4:00PM-7:00PM) by trip purposes. Three Matrices were provided for different socioeconomic variables including age (5 year cohorts), income ($10,000 increments), and vehicle attributes (0->5 for rent/owner households).

1. Weekend matrices for each of the weekends of October 2015 by trip purposes (HBW, HBO, NHB). Three Matrices were provided for different socioeconomic variables including age (5 year cohorts), income ($10,000 increments), and vehicle attributes (0->5 for rent/owner households) for each weekend.
2. Long Distance ODs, showing external-external trips for the full day for both weekday averages and each weekend for HBW, HBO and NBH trips. No socioeconomic data were provided for these matrices.

The OD data is very useful in differentiating trips that are internal to the GF-EGF MPO area: internal-internal (II) trips, trips that pass through the GF-EGF MPO area: external-external (E-E) trips, and trips that start/end in the MPO area with the other end outside the MPO area: internal-external/external-internal (IE/EI) trips.

2.1.1. Internal-Internal OD Trip Summary

Table 1 summarizes the OD data by trip purpose and by time periods. For HBW trips for the GF/EGF MPO TAZs, the late-morning to early-evening period had the highest proportion of trips (30%) followed by the AM Peak and Night periods (25% each) and the PM Peak period (20%). The late-morning to early-evening period had the highest proportion of HBO trips (36%), followed by the Night period (27%), PM peak (21%) and AM Peak (17%). This is expected and possibly because fewer non-work trips originate from homes during the morning peak period. Trip activity locations such as malls, schools, walk-in hospitals, banks, typically open after 8:00AM. For NHB trips, the late-morning to early-evening period again has the highest proportion of trips (45%), followed by the PM Peak (23%), AM Peak (17%) and the Night period (16%).

The % overall column reflects the percentage of trips that had at least one end in the Grand Forks East Grand Forks MPO area with respect to the entire dataset. 23% of HBW, 14 % of HBO, and 9% of NHB, of total trips in the overall North Dakota data had trip ends in the GF-EGF MPO area. The data shows the trip purposes by time of day, Peak AM, Peak Afternoon, Peak PM and Night trips.

Table 1 Summary of Internal-Internal OD Data from Airsage

Grand Forks/East Grand Forks MPO TAZ OD Trips						
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**	**% of Overall**
HBW	11,206	13,594	8,938	10,965	44,703	23%
HBO	18,554	38,865	22,485	28,979	108,883	14%
NHB	16,482	43,878	22,195	15,373	97,928	9%
Total	46,242	96,337	53,618	55,317	251,514	12%

Proportions by Trip Purpose and Time of Day, GF/EGF MPO TAZs Only						
	7-10AM	10AM-4PM	4-7PM	Night	Total	% of Overall
HBW	25%	30%	20%	25%	100%	23%
HBO	17%	36%	21%	27%	100%	14%
NHB	17%	45%	23%	16%	100%	9%
NHCRP 718 Time-of-day Distributions by Purpose						
	7-10AM	10AM-4PM	4-7PM	Night	Total	
HBW	25%	22%	26%	27%	100%	
HBO	15%	38%	26%	21%	100%	
NHB	15%	53%	21%	11%	100%	

2.1.2. Internal-External/External-Internal Origin Destination Data

The data were further disaggregated to reflect the different proportions of trips by purpose and type for different external locations. The external locations were distinguished as North, South, East and West with Interstate 94 and U.S. Highway 2 are the main highway trips used for entry/exit to the GF/EGF MPO area. This was done to evaluate whether trips from the North (which included trips from Canada) had different Peak AM proportions for HBW for example.

Table 2 shows the IE and EI trip data and the proportions of IE/EI trips to the total trips for each trip purpose and time period. The table shows OD trips that had at least one trip end in the study area. IE/EI trips made up 15% of the total trips. For HBW trip purpose, the proportion of EI/IE is 12% of the total trips and ranged from 10% to 15% for the different time periods. For HBO trips, the IE/EI made up 13% of total trips and ranged from 11% to 15% for the different time periods. The NHB trips for IE/EI where 18% of the total GF/EGF NHB trips and ranged from 17% to 22% for the different time periods.

Table 2 IE and EI Trips from OD Data for the GF-EGF MPO Area

Total IE Trips					
	7-10AM	10AM-4PM	4-7PM	Night	Total
HBW	1,313	1,384	984	1,627	5,308
HBO	2,316	4,465	2,793	4,484	14,058
NHB	3,556	7,549	3,687	2,767	17,559
Total	7,185	13,398	7,464	8,878	36,925
Percentage of IE Trips to Total Trips for GF/EGF Data					
	7-10AM	10AM-4PM	4-7PM	Night	Total
HBW	12%	10%	11%	15%	12%
HBO	12%	11%	12%	15%	13%
NHB	22%	17%	17%	18%	18%
Total	16%	14%	14%	16%	15%

2.1.3. External-External OD Data

External-External (EE) OD data shows the trips that pass through the GF/EGF MPO area without stopping. Transient locations were not included in the OD dataset provided by Airsage which would have simplified the task of obtaining EE trips. The data itself does not inform us if a trip between two OD pairs possibly passed through the GF/EGF MPO area. The implication was that EE data had to be estimated using an algorithm that took into account the possibility that trips between OD pairs passed through the GF/EGF MPO area. The methodology developed incorporated the use of real time travel data between OD pairs and was developed using an online mapping application APIs. The method assumed that trips between OD pairs will use the shortest travel time path between the OD pairs. The methodology to estimate EE OD pairs that passed through the GF/EGF MPO is as follows

1. Select all OD pairs that are not part of the internal GF/EGF MPO OD TAZs i.e. not part of the 61 GF/EGF OD TAZs. Remaining 240 OD TAZs fit this category.
2. Calculate average shortest travel path between all OD pairs using API algorithm developed for online mapping application for each time period.
3. Evaluate whether any portion of the route between each OD pair included a spatial location point within the GF/EGF MPO area (longitude/latitude).
4. If yes to 3, trips between those OD pairs were considered as EE trips for the GF/EGF MPO area.

Table 3 shows the percentages of EE trips that pass through the GF/EGF MPO area by trip type and by trip purpose. Table 3 also shows the proportion of each EE trip type as the overall proportion of EE and EI trips. Overall, EE trips made up about 17% of total EE and EI/IE trips. This was a lot higher than the typically used 10-12% through trip percentages.

The percentage of EE only trips ranged from 21% for the AM Peak period to 37% for the late-morning to early-afternoon period. For HBW, the majority of trips occurred during the Night period (30%) with the least amount of trips occurring during the PM Peak period (17%). This could be because this time period includes the early morning (6:00AM to 7:00 AM) and late evening (7:00PM to 9:00PM) trips. Trips passing through the GF/EGF MPO area for work may typically leave early and arrive later due to comparatively longer travel times. For HBO trips, the pattern is similar to the HBW trips with 35% of trips occurring at night and 17% of trips occurring during the AM Peak period. For NHB trips, the late-morning to early-afternoon period had the highest percentage of trips (43%) followed by the AM Peak period (23%), and the Peak PM and Night periods (17% each).

Table 3 EE Trips from OD Data

EE Trips passing through GF-EGF MPO					
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**
HBW	148	186	110	194	638
HBO	351	571	380	708	2,010
NHB	814	1,540	613	595	3,562
Total	1,313	2,297	1,103	1,497	6,210
Percentage of EE Trips passing through GF-EGF MPO					
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**
HBW	23%	29%	17%	30%	100%
HBO	17%	28%	19%	35%	100%
NHB	23%	43%	17%	17%	100%
Total	21%	37%	18%	24%	100%
Percentage of EE Trips to Total EE/EI Trips					
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**
HBW	11%	13%	11%	12%	12%
HBO	15%	13%	14%	16%	14%
NHB	23%	20%	17%	21%	20%
Total	18%	17%	15%	17%	17%

2.1.4. Use of Airsage OD Data in the TDM

The OD data were used to calibrate and validate the trip generation and trip distribution steps of the model. Prior models could not distinguish between EE trips for HBW and HBO trips for the AM Peak period for example. Ultimately, it leads to more precise and accurate models.

2.1.4.1. Trip Generation

For trip generation, the data were used primarily to disaggregate daily trips into peak and off peak periods for the different trip purposes and for different trip types (II/IE/EI and EE trips). UND trips were also enhanced and developed using the OD data. This created a more refined and more accurate output that was used for later parts of the model. The refinement greatly enhanced the ability of the model to replicate ground truths.

2.1.4.2. Trip Distribution

Trip distribution assigns trips generated in the trip generation step between origin and destination pairs. The typical output of the trip distribution step in TDMs is a matrix showing the origin and destination of each trip. For the GF/EGF MPO TDM, the gravity model was used to distribute trips. The gravity model uses the trip generation outputs (productions and attractions by trip purpose for each zone), a measure of travel impedance between each zonal pair (travel time), and socioeconomic/area characteristic variables ("K-factor") variables as input. The K-factor is used to account for the effects of variables other than travel impedance in the model. The OD data were used to develop K-factor matrices imputed in the gravity model that were used for distributing trips for each time period and purpose.

2.1.5. Evaluating the OD Data for Major Trip Generators

UND, Columbia Mall and the Altru Hospital are some of the "Special" trip generators within the GF-EGF MPO area. An analysis of the OD data for trips attracted to these TAZS was performed to show how the data can be used to visually show the OD data. Figures 3, 4 and 5 show trip attractions to UND, the mall and the Altru Hospital.

Figure 3 shows the weekday trip attractions to UND for 18-24 year olds. It shows that most trips that end up in UND for this age group originate from within the UND TAZs (10-25%). TAZs South of Demers, East of Washington, North of 32nd Ave S and East of the River produced between 5-10% of trips made by 18-24 year olds that end in the UND TAZs. The Grand Forks Air force base (TAZ) to the West of the Metro area produces between 1 and 3 % of trips that were attracted to UND. Figure 4 shows the percentage of trips attracted to the mall for the different TAZs. TAZs around UND generates the highest percentage of trips that end up in the mall (5-10%). TAZs South of Demers, East of Washington, North of 32nd Ave S and East of the River again generate a good proportion of trips that end up at the Columbia Mall (3-5%). The rest of the trips are fairly evenly distributed amongst the other TAZs. Figure 5 shows the trips that are attracted to the zone that includes the Altru Hospital. Zones around UND provide the highest number of trips to the Altru hospital. The Grand Forks Air Force Base generates a good proportion of trips that end up in the Hospital. TAZs South of Demers, East of Washington, North of 32nd Ave S and East of the River produced between 0.5 and 1% of trips that ended at the Altru Hospital. Overall, the data shows some interesting trends with respect to where trips originate and terminate for some of the major trip generators in the area.

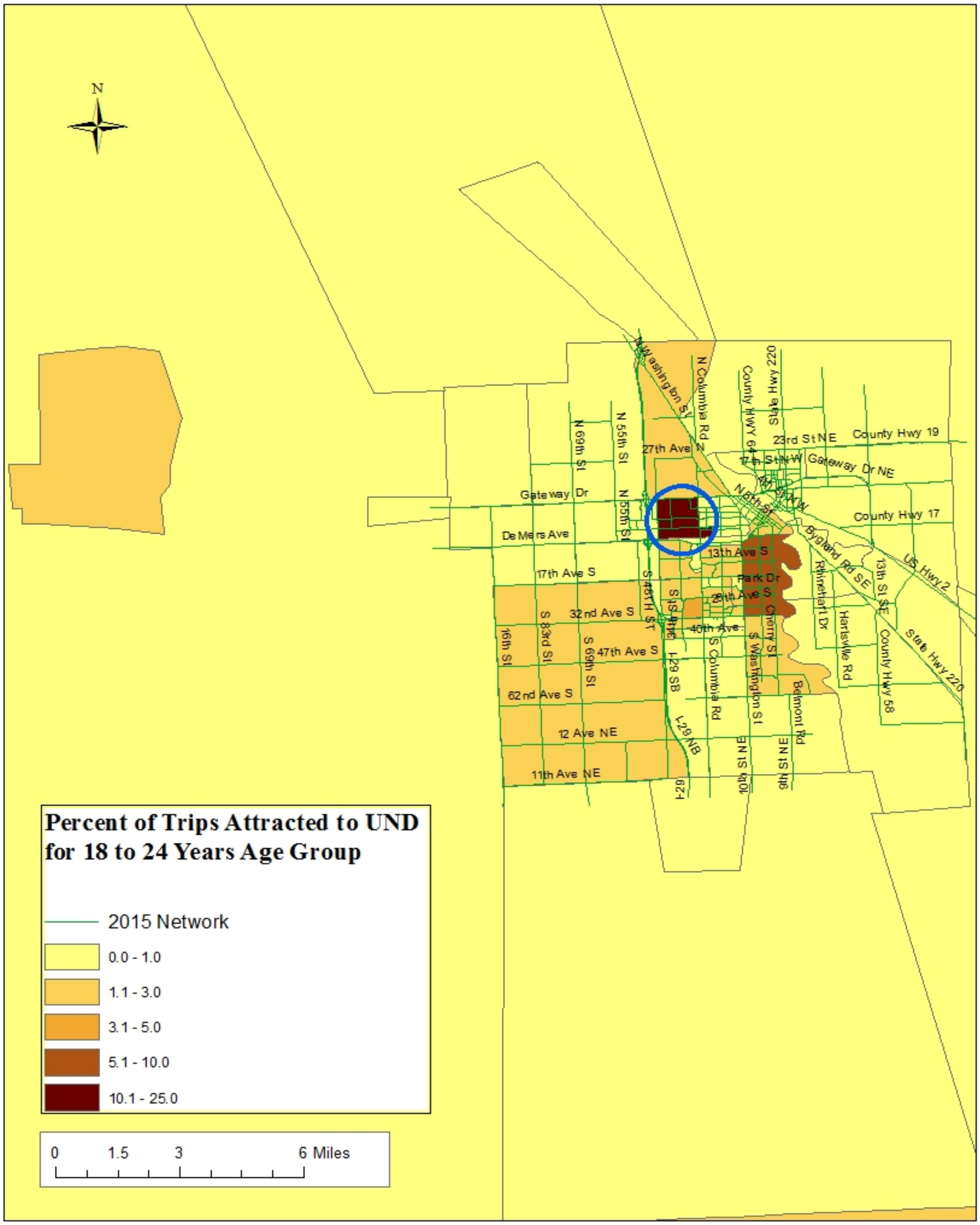


Figure 3 Origin Percent of Trips Attracted to UND for 18-24 Year Olds from Airsage OD Data

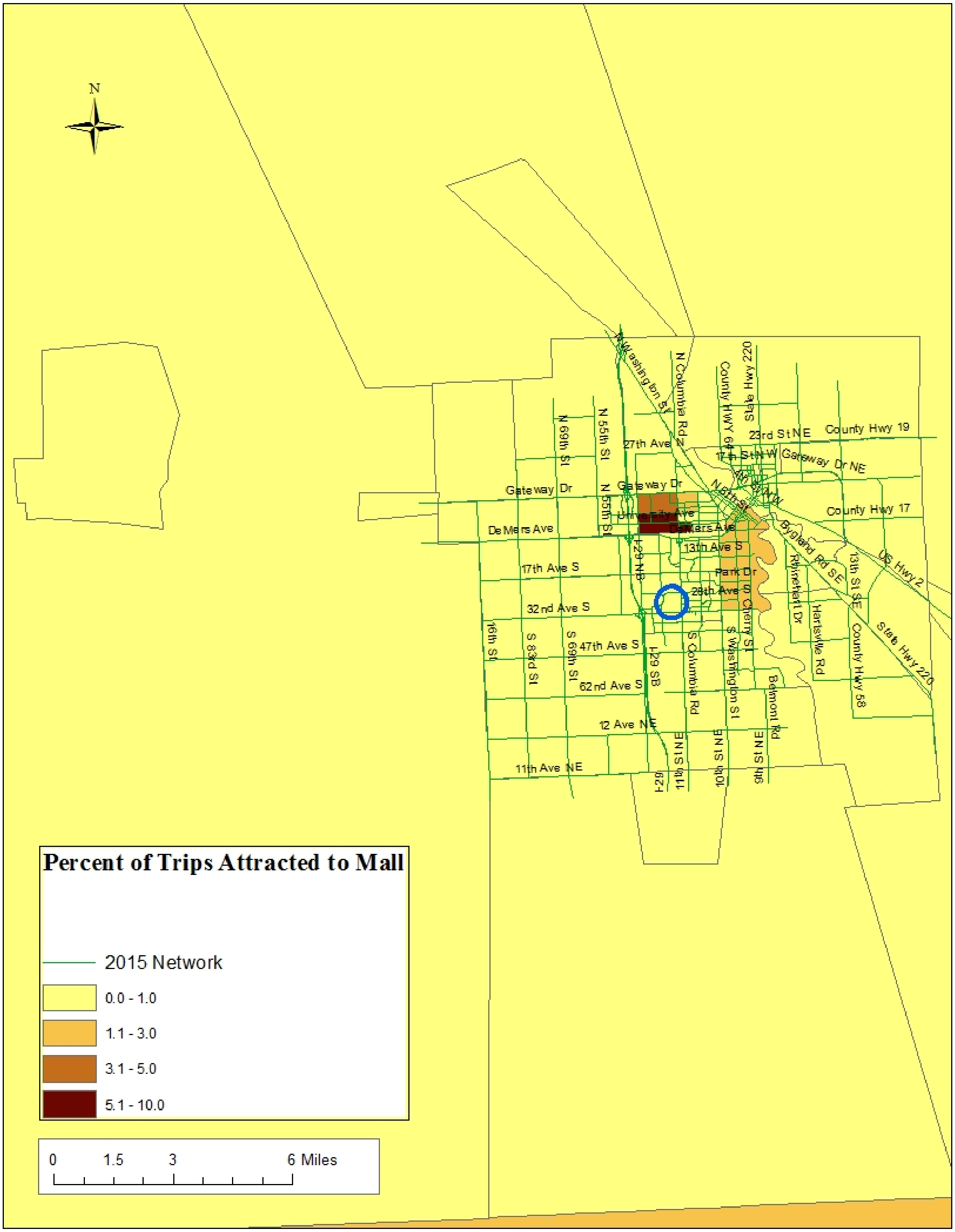


Figure 4 Origin Percent of Trips Attracted to the Columbia Mall from Airsage OD Data

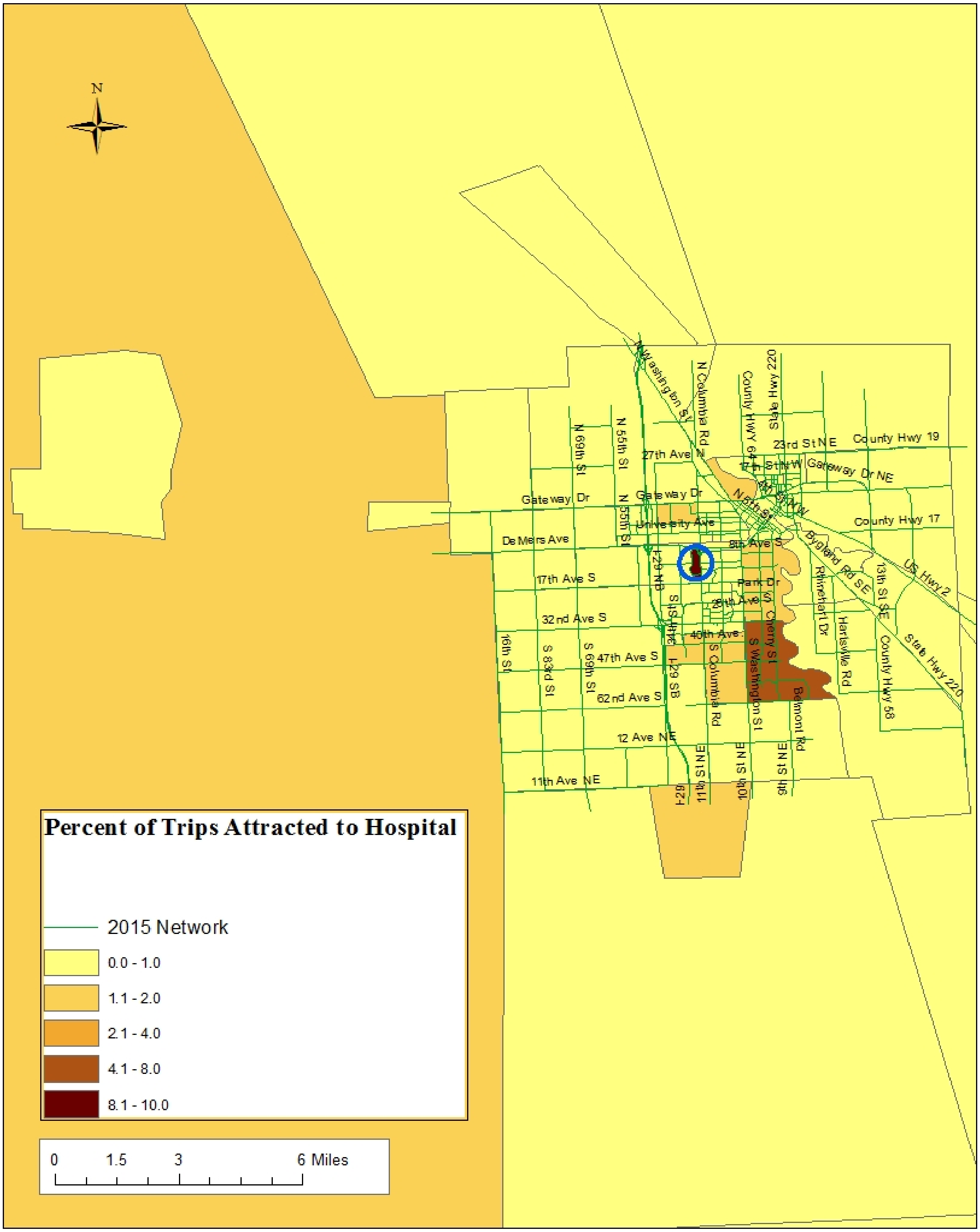


Figure 5 Origin Percent of Trips Attracted to the Altru Hospital TAZ from Airsage OD Data

2.1.6. Comparing Peak AM and Peak PM Data to the Traffic Data Analysis Tool

To validate the OD data with locally collected data it was compared to the Traffic Data Analysis tool which collect traffic volumes for several intersections in the City of Grand Forks. Table 1 shows the percentage of AM, Afternoon, PM and Night periods for the OD data and the traffic data analysis intersection tool data from October 2010. The difference ranged from -3% for the Afternoon and PM Peak periods to 3.3% for the AM peak period. Overall, the OD data seems to fairly reflect observed data.

Table 4 Comparison of Temporal Airsage OD Data and Traffic Analysis Intersection Data

	7AM-10AM	10AM-4PM	4PM-7PM	7PM-7AM	Total
Airsage OD	18.5%	39.0%	21.8%	20.7%	100%
Intersection Tool Data	15.2%	42.0%	24.7%	18.0%	100%
Difference	3.3%	-3.0%	-3.0%	2.6%	0%

For visualization purposes, Figure 6 shows the comparison of the Airsage OD data and the Traffic Analysis Intersection Data. The percentage differences are very small and the OD data is representative of the intersection data. The only difference is that the OD data can be differentiated into trip purposes whereas the intersection data contains overall trips. The OD data can be used to however differentiate the intersection data into different trip purposes.

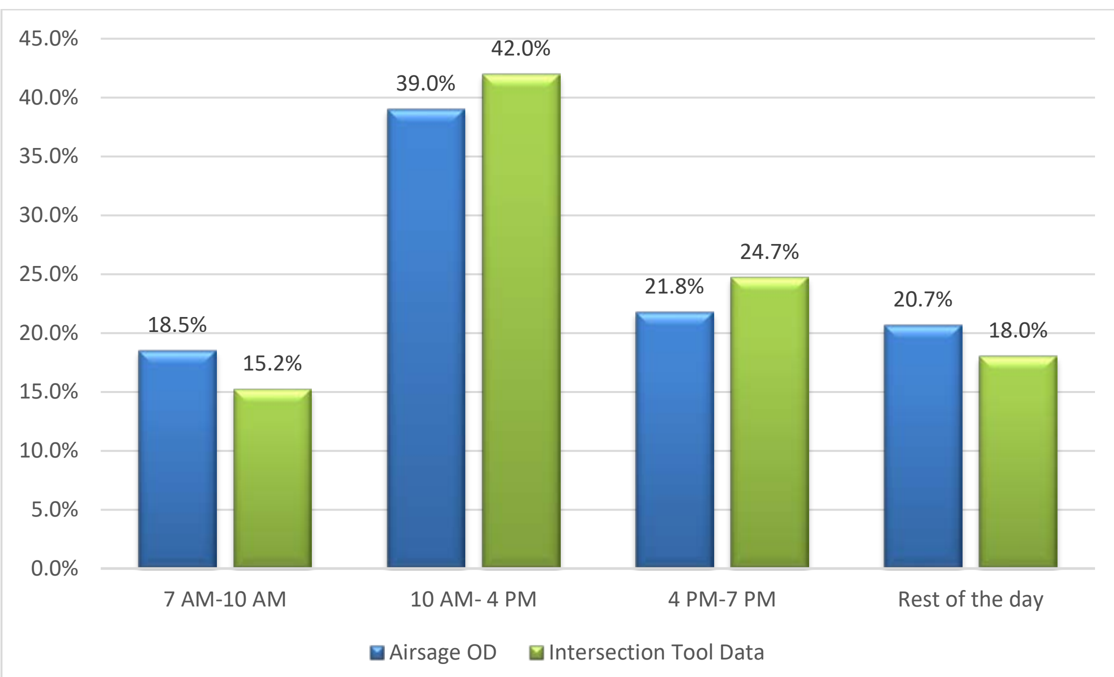


Figure 6 Comparison of Temporal Airsage OD Data and Traffic Analysis Intersection Data

2.1.7. Potential Shortcomings of the OD Data

Although the OD data provides unique opportunities to improve on the TDM, there were some deficiencies in the data.

1. By nature of the data being collected on cell phone tower pings, some zones did not show any ODs. For example, the Grand Forks Airport did not attract or produce any trips. This is because all of the trips to the Grand Forks Airport were shown in the TAZ East and Adjacent to the airport.
2. The data did not show transient locations between Origins and Destinations. Paths between OD pairs can be estimated using network data.
3. The data does not include all cell phone networks and could suffer from cell phone provide biases. For example, low income earners might use different networks from the major networks for cost savings.
4. The raw data collected is anonymous and does not contain the demographic data that is provided with the dataset. The provider uses an algorithm to create the profile for average users (age, gender etc) based on their socioeconomic data. We cannot verify the veracity of the algorithm or the socioeconomic data that was used for this process.
5. The data does not distinguish between truck and passenger vehicles.

2.2. Freight Analysis Framework Data

The Freight Analysis Framework (FAF) data integrates data from various sources to create a comprehensive freight movement data among states and major metropolitan areas for all transportation modes. The data provides estimates for tonnage (thousand tons) and value (million dollars) by regions of origins and destinations, commodity type, and mode. Data are available for the 2012 base years, years 2012-2015, and forecasts from 2020 to 2045 in five-year increments.

The FAF data for North Dakota is aggregated for the entire state. For Minnesota, the data is aggregated into two zones: The twin Cities Metropolitan area and the rest of the state. A methodology was necessary to disaggregate the data to the MPO level. Data for Grand Forks came from the North Dakota FAF aggregate data while data for East Grand Forks came from the aggregate Minnesota FAF Data. A regression model was developed to disaggregate the statewide data to the MPO level. The model used the employments as the explanatory variable. Overall, the model had very good fit with R-square ranges from 65-95 %.

The output of the regression models were the tonnage of freight produced and attracted to each of the Cities in the MPO (Grand Forks and East Grand Forks respectively). The Tonnage was then distributed to each TAZ proportionally based on the employment for that TAZ. Tonnages were then converted to truck trips using the commodity type characteristics (typical weight and size).

2.3. Traffic Analysis Intersection Data Archival

The Grand Forks-East Grand Forks MPO (MPO) and the City of Grand Forks (City) intend to utilize the already existing traffic detection cameras for traffic data collection. The intersection turning movement counts when collected over significant amount of time (e.g. a year) can be then used in various traffic operations, transportation planning, and highway design applications. This data is being used as an additional tool to validate AM and PM model output and turning movement output of the model.

3. CAPACITY CALCULATIONS

Capacities play a critical role in TDM as they are not only used to measure the Level of Service but are also critical in the assignment step. Traffic is assigned based on the saturation (Volume to Capacity) of each link, which will result in traffic being moved to other links as this value increases. The Transportation Research Board 2010 defined capacity as follows: "The capacity of a system element is the maximum sustainable hourly flow rate which persons or vehicles reasonably can be expected to travers a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, environmental, traffic, and control conditions. Capacity analysis examine roadway elements under uniform traffic, roadway, and control conditions."

NCHRP 716 on the other hand define the "Capacity" in a traffic engineering sense is not necessarily the same as the capacity variable used in travel demand model networks. In early travel models, the capacity variable used in such volume-delay functions as the BPR formula represented the volume at Level of Service (LOS) C; whereas, in traffic engineering, the term "capacity" traditionally referred to the volume at LOS E."

Link capacities are a function of the number of lanes on a link; however, lane capacities can also be specified by facility and area type combinations. Several factors are typically used to account for the variation in per-lane capacity in a highway network, including:

- Lane and shoulder widths;
- Peak-hour factors;
- Transit stops;
- Percentage of trucks
- Median treatments (raised, two-way left turn, absent, etc.);
- Access control;
- Type of intersection control;
- Provision of turning lanes at intersections and the amount of turning traffic; and
- Signal timing and phasing at signalized intersections.

Some networks combine link capacity and node capacity to better define the characteristics of a link (Kurth et al., 1996). This approach allows for a more refined definition of capacity and speed by direction on each link based on the characteristics of the intersection being approached.

To update the model capacity calculations, first a literature review was performed among similar type of MPO outside of North Dakota-Minnesota (Lincoln-NE, Des Moines Area-IA, Syracuse Metropolitan Transportation Council-NY, Chattanooga-Hamilton County Regional Planning Agency-TN, Knoxville Regional Transportation Planning Organization-TN, Tulare County Associations of Governments-CA); larger MPO than FM Metro COG (Atlanta Regional Commission-GA, Dallas-Fort Worth-TX, Chicago Metropolitan Agency for Planning-IL, Capital Area-MO. The assumptions of similar MPOs or larger MPOs came from the population's threshold value defined by NCHRP 716. Table 5 summarizes the literature review used in different MPO planning models for capacity calculations.

Table 5 Summary of Capacity Calculations for MPO Planning Models

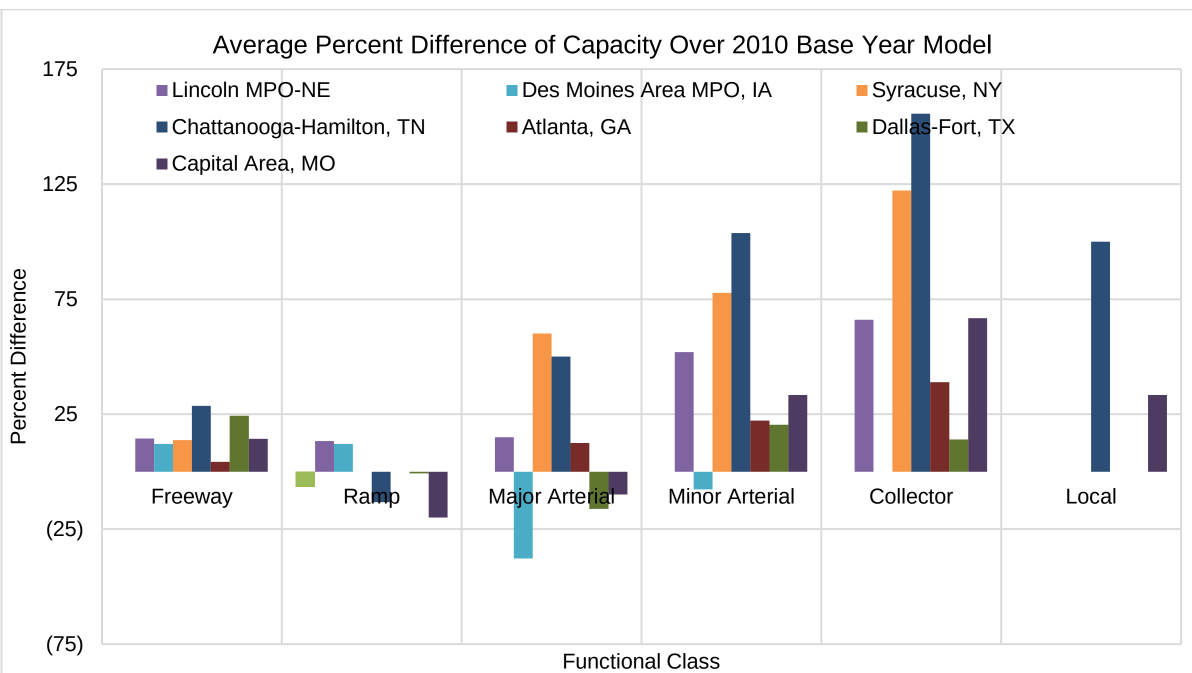
Lincoln MPO-NE, 2006	For the Lincoln MPO model, capacity at Level of Service (LOS) C was used as the threshold capacity. Highway Capacity Manual (HCM) 2000 procedures were used for estimating the capacity for each combination of functional class and area type. First, peak hour lane capacity was calculated after the effects of percent green time, and peak hour factor. Second, the 24 hour lane capacity was calculated using peak hour lane capacity and percent of traffic in the peak hour. Finally, threshold capacity at LOS C was assumed to be 75% of the 24 hour lane capacity. Reference: LIMA & Associates, 2006 http://www.princeton.edu/~alaink/Orf467F12/LincolnTravelDemandModel.pdf
VDOT, 2014	For all model regions, it is acceptable practice and recommended practice to use the most recent version Highway Capacity Manual (HCM) as the basis for roadway capacities. It is not acceptable to use older versions of the HCM or arbitrary figures for roadway capacities. Based on functional class and land use/area type Tabulation process Reference: http://www.virginiadot.org/projects/resources/vtm/vtm_policy_manual.pdf
ODOT, 1995	The procedure used to estimate free flow speed and capacity is a detailed methodology that utilizes the maximum amount of information from the network and "connects" this data with information from the Highway Capacity Manual. http://www.oregon.gov/ODOT/TD/TP/docs/reports/guidex.pdf
Memphis MPO-TN	Hourly capacities were developed for the Memphis model in order to use collected street data. This provides the most accurate representation of actual capacity (levels of service A through E) on an individual link. These capacities — detailed in the Technical Memorandum #8(b) – Capacity Development — are implemented using an equation which takes into account functional classification, speed limit, lanes, signal density, median treatment, area type, average lane width, and average shoulder width. The capacity equations are built into the model process as a TransCAD lookup table, so modifications to network attributes automatically update the capacity in subsequent runs Since the model is based on four multi-hour time periods, a conversion factor must be used to create a time period capacity for each of the four time periods. The capacity factors below are based on hourly traffic count data and the Memphis household travel survey http://www.memphismpo.org/sites/default/files/public/documents/lrtp/appendix-g-travel-demand-model.pdf
GDOT, 2013	Facility type and area type are used in combination to determine free-flow speeds and capacities. Link capacities for the model network are obtained from a lookup table of per-lane hourly capacities based on facility type and area type. The final link capacity is calculated by multiplying the hourly capacity per lane by the number of lanes, which is automatically added to the links during the model application. http://www.dot.ga.gov/BuildSmart/Programs/Documents/TravelDemandModel/GDOT%20Model%20Users%20Gude_050813.pdf
MassDOT, 2013	The coding of the EMME/2 highway network basically follows the hierarchy of the functional classification system. Expressways, other than those passing through denser urban areas, are generally coded for 60 mph speeds and hourly capacity per lane of 1,950. Higher-level arterials are coded for speeds ranging from 45 to 50 mph and corresponding capacities of 1,050 to 1,100. Lower-level arterials and major collectors range from 35 mph to 40 mph, with capacities of 950 to 1,000. Minor collectors and local streets that are not in urban centers range from 23 mph to 30 mph, with capacity generally at 800. Streets in urban centers can have substantially lower speeds and capacities. https://www.massdot.state.ma.us/theurbanring/downloads/CTPS_Travel_Demand_Modeling_Methodology.pdf

Syracuse Metropolitan Transportation Council, NY, 2012	The speed and capacity values are stored in lookup tables and automatically imported to the network each time the model runs. The main benefits of importing these data from a lookup table, as opposed to maintaining an explicit speed and capacity for every link within the highway network, are that the user has less data to manage and can easily quote values. However, there are some links in the SMTC network that warrant special attention because their actual speed or capacity is substantially different from what the lookup tables say. Therefore, the SMTC model also supports the ability to code a speed or capacity for each link by entering a value into the "TOTAL_HCAP_FIXED" or "SPEED_FIXED" fields on the network http://www.thei81challenge.org/cm/ResourceFiles/resources/SMTC%20Model%20Version%203.023%20Documentation.pdf
Atlanta Regional Commission (ARC), GA, 2011	By area type and facility type Tabulation method 20 facility type and 7 area type Total link capacity (1Hr- LOS E) http://www.atlantaregional.com/transportation/travel-demand-model
Capital Area MPO (CAMPO)-MO, 2013	The model computes link capacities at run time. Capacities are initially based on functional class and number of lanes, adjusted based on directionality, median type, and roadway slope. Capacity is expressed in terms of vehicles per day for each link by direction. http://www.jeffersoncitymo.gov/11Jan2013CAMPOTDMDocumentation.pdf
Champaign-Urbana Urbanized Area Transportation Study (CUUATS), IL	The daily capacity for each link in the Champaign County model network was calculated based on its facility type and area type. If a Two-Way Left Turn Lane (TWLTL) was present, the link capacity was increased by 30%. The lookup table was included in the model script to uniformly assign the capacity on the model network. The centroid connectors have high capacity and very low speed (15mph).
Chattanooga-Hamilton County Regional Planning Agency, TN, 2013	Using the collected street data, the proposed capacity calculation for Chattanooga model will be implemented using an equation which takes into account data such as functional classification, speed limit, lanes, median treatment, area type, average lane width, and average shoulder width. Traffic signal delays and impact of steep grades may also be considered. The equations were originally developed using the Highway Capacity Manual (HCM) and analysis performed by the Indiana Department of Transportation in 1997 for the Indiana State Highway Congestion Analysis Plan. KHA successfully applied this method in other urban area models, in conjunction with analysis performed using North Carolina DOT's Level of Service (LOS) software. http://www.chcrpa.org/2040RTP/2040RTP_Draft_Plan/Volume_III_Travel_Demand_Model.pdf
Dallas-Fort Worth (DF): North Centeral Texas COG, TX, 2009	Hourly Capacity Per Lane (Divided or One-Way Roads) – The hourly capacity per lane for divided roads is given by area type and functional class. AMFactor, PMFactor, OPFactor – These factors are used in the conversion of capacity from hourly to time period. Factors are defined by functional class 1-8 http://www.nctcog.org/trans/modeling/documentation/DFWRTMModelDescription.pdf
San Diego Association of Governments, CA, 2011	Two capacities are calculated for each direction of a hhghway link: 1. Intersection and mid-link Hourly basis Time category Factored Future ramp metering improved the capacity grow in 10 percent . See the equations http://www.sandag.org/uploads/publicationid/publicationid_1624_13779.pdf
Chicago Metropolitan Agency for Planning, IL, 2014	Zonal capacity system Capacity represented within the link travel time function is approximately the service volume at level of service C. It is calculated as 75 percent of the level of service E time period link capacity. Note that link capacity is calculated by multiplying the hourly lane capacity by the number of lanes and the number of hours in the assignment time period
Omaha-Council Bluffs Metropolitan Area Planning Agency (MAPA), NE, 2010	The daily capacity is based on the hourly ultimate capacity, that is, the point at which the Level of Service (LOS) changes from an "E" to an "F" as defined by the Highway Capacity Manual. To support the daily model, the hourly capacity is multiplied by a factor of 10, which represents a typical ratio of peak hour to daily traffic. Capacity varies by functional class, presence of turn lanes, the number of lanes, and whether the road is divided or undivided. The capacities are based on those used in Des Moines, Iowa. The capacities vary by side friction to take into account differences in driveway density. MAPA is currently comparing the capacities with other sources such as the capacity tables developed by the Florida DOT. The model does not include intersection delay separately from link delay. MAPA has attempted to represent intersection delay using downward adjustments to free flow speeds https://www.fhwa.dot.gov/planning/tmip/resources/peer_review_program/mapa/mapa_report.pdf
Des Moines Area MPO, IA, 2006	Daily directional capacity of a link Divided or undivided Number of lanes Access condition

	Facility coding http://www.ctre.iastate.edu/educweb/ce451/LABS/Lab%2012/DSM_Documentation.pdf
KYOVA Interstate Planning Commission, WV, 2013	Capacity based on area and functional class Tabulation and look up method http://www.kyovaipc.org/2040MTP/documents/KYOVA2040_ModelDocumentation_121213_withFigures.pdf
Knoxville Regional Transportation Planning Organization, TN, 2010	Peak hour capacities of the roadway network were estimated using Highway Capacity Manual 2000 procedures, which results in much more precise estimates of capacity verses traditional methods used in models that entail using a lookup table based on functional class and area type. http://www.knoxtrans.org/plans/mobilityplan/cndetern.pdf
Tulare County Association of Governments, CA, 2015	Link capacity is defined as the number of vehicles that can pass a point on a roadway at free-flow speed in an hour. One important reason for using link capacity as a model input is for congestion impact; which can be estimated as the additional vehicle -hours of delay based on the 2000 Highway Capacity Manual (2000 HCM). The capacity assumption used in the TCAG model of each road segment in the network is based on the terrain, facility type, and area type, which is consistent with the methodology suggested in the 2000 HCM http://www.arb.ca.gov/cc/sb375/tcag_scs_staff_report_final.pdf

Figure 7 shows the comparison of the base 2010 GF-EGF MPO planning model capacity calculations to reviewed capacities for several different MPOs. The capacities for freeways are very similar to the capacities for the base 2010 GF-EGF model. For ramps, the capacities for other MPO areas were typically lower in comparison to the 2010 GF-EGF model. For major arterials, minor arterials, collectors and locals, the capacity calculations were typically higher for the MPOs compared. Most of these MPOs used a Level of Service E for capacity calculations, reason why their capacities were higher.

Figure 7 Capacity Comparisons to Grand Forks East Grand Forks MPO 2010 Base Year Model



For the 2015 base year model, network-wide capacities were updated to reflect the most recent Highway Capacity Manual HCM 6th Edition and capacities estimated in other recent literature. The calculation of capacities took into account several variables including the functional classification, the number of through links, the number of turn lanes, the location of the intersection (rural, urban, CBD, suburban), the intersection control and effective green ratios, heavy vehicle adjustment factors and the speeds. The capacities used for the 2015 model were slightly different from the 2010 models and represent the state-of-the-art in capacity calculations in TDM. The next subsections discuss the capacity calculations for different types of intersections.

3.1. Capacity Calculations for Signalized intersections

For signalized intersections a step by step procedure was used to estimate the capacities.

3.1.1. Step 1: Develop Lane Groups for each Link

The first step defined the lane groups for each link. For the 2015 network, lane groups are defined by the Attribute Linkgrp1. Table 6 shows the codes for each link group. The lane group describes the geometry at the B-node of each link including the number of through lanes, the number of right turn lanes and the number of left turn lanes. The first Number in the linkgroup1 category shows the number of through lanes while the second number represents the number of turn lanes for either right or left turns as shown in Table 6. For example, if Linkgroup1 for a link was 20, it meant that link had two through lanes with no turn lanes. Similarly, if the Linkgroup1 code was 35, it means the link had three through lanes, with two right turn lanes.

Table 6 Lane Group Classification (Linkgroup 1)

Code	Lane Group Description
N0	N through lanes and no turn lane
N1	N through lanes and single exclusive left turn lane
N2	N through lanes and two exclusive left turn lanes
N3	N through lanes and continuous exclusive left turn lane from intersection to intersection
N4	N through lanes and single exclusive right turn lane
N5	N through lanes and two exclusive right turn lanes
N6	N through lanes and continuous exclusive right turn lane from intersection to intersection
N7	N through lanes, single exclusive left turn lane and single exclusive right turn lane
N8	N through lanes, two exclusive left turn lanes and single exclusive right turn lane
N9	N through lanes, two exclusive right turn lanes and single exclusive left turn lane

3.1.2. Step 2: Determining saturation flow rate (S_i) for each lane group:

Step 2 included determining the saturation flow rate *(S_i)* for each Lanegroup using Equation 1. It is important to note that not all the parameters in Equation 1 were used for the model. Some of the parameters like the lane width and approach grades are not used in calculating the saturation flow rate. If the data is however available, say for a subarea study, these paramters can potentially be used to estimate capcities. The parameters were developed from different sources including HPMS and HCM6.

Equation 1

$$\boldsymbol{S_i = S_0 \times N \times f_W \times f_{HV} \times f_g \times f_p \times f_{bb} \times f_a \times f_{LU} \times f_{LT} \times f_{RT} \times f_{Lpb} \times f_{Rpb} \times PHF}$$

Where:

S_i	=	Saturation flow rate for subject lane group, expressed as a total for all lanes in lane group (vph)
S_O	=	Base saturation flow rate per lane (pcphpln)
N	=	Number of lanes in lane group
f_W	=	Adjustment factor for lane width
f_{HV}	=	Adjustment factor for heavy vehicles in traffic stream
f_g	=	Adjustment factor for approach grade
f_p	=	Adjustment factor for existence of a parking lane and parking activity adjacent to lane group
f_{bb}	=	Adjustment factor for blocking effect of local buses that stop within intersection area
f_a	=	Adjustment factor for area type
f_{LU}	=	Adjustment factor for lane utilization
f_{LT}	=	Adjustment factor for left turns in lane group
f_{RT}	=	Adjustment factor for right turns in lane group
f_{Lpb}	=	Pedestrian-bicycle adjustment factor for left turn movements
f_{Rpb}	=	Pedestrian-bicycle adjustment factor for right turn movements
PHF	=	Peak Hour Factor

The formulas for calculating the parameters in equation 1 from the HPMS are show next:

1. *Base Saturation Flow Rate, So*

Following the HPMS procedure, the base saturation flow rate was set at 1,900 passenger car per hour per lane (pcphpl).

2. *Adjustment Factor for Lane Width, f_W*

Using HPMS lane adjustment factors, Equation 2 was used to calculate the adjustment for lane widths,

Equation 2

$$\boldsymbol{f_W = 1 + \frac{(W-12)}{30}}$$

Where:

W = Lane width, minimum of 8ft and maximum of 16ft.

3. *Heavy Vehicle Adjustment Factor, f_{HV}*

Equation 3 was used to calculate the heavy vehicle adjustment factor.

Equation 3

$$f_{HV} = \frac{100}{100 + HV(E_T - 1)}$$

Where:

HV = percent heavy vehicles

E_T = passenger car equivalent

4. *Adjustment for Grade, f_g*

Due to lack of grade information on urban minor arterials and collectors, HPMS uses f_g as 1.0.

5. *Adjustment for Parking, f_p*

For parking adjustment, Equation 4 is used to calculate the capacity adjustment.

Equation 4

$$f_p = \frac{N - 0.1 - \frac{18N_m}{3{,}600}}{N}$$

Where:

f_p = Parking adjustment factor

N = Number of lanes in group

N_m = Number of parking maneuvers per hour (6 for two-way streets with parking one side, 12 for two-way streets with parking both sides or one-way streets with parking one side, 24 for one-way streets with parking on both sides)

If no parking space or parking data is available, then f_p is set equal to 1.0.

6. Adjustment for Bus Blockage, f_{bb}

Due to non-availability of bus routes data, f_{bb} is set to 1.0. Also default values of f_{bb} used in HCM 2000 for bus routes are close to one.

7. Type of Area Adjustment, f_a

According to HCM 6, f_a is set to 0.9 for CBDs and 1 elsewhere.

8. Lane Utilization Adjustment, f_{LU}

A lane utilization adjustment factor of 1.0 was used for the model.

9. Adjustment for Left Turns, f_{LT}

Adjustment factor of 0.95 is used for left turn movements to estimate the capacities in this study.

10. Adjustment for Right Turns, f_{RT}

For right turn movements, the adjustment factor of 0.85 was used for the model.

11. Adjustment for Pedestrian-Bicycle Blockage on Left Turns, f_{Lpb}

Adjustment factor for pedestrian-bicycle blockage is set to 1.0 in HPMS procedure due to non-availability of extensive inputs.

12. Adjustment for Pedestrian-Bicycle Blockage on Right-Turns, f_{Rpb}

Similarly, the adjustment factor for pedestrian-bicycle blockage for right turns is also set to 1.

13. Peak Hour Factor (PHF)

The default values of 0.92 and 0.88 are set for urban and rural sections respectively.

14. Effective Green Ratios (g_i/C) for Lane Groups

A g_i/C value of 0.45 is used for principal and minor arterials while 0.40 is used for collectors. These values were default values suggested in HPMS. The values were evaluated based on signal timing data provided by the MPO and were found to be reasonable.

3.1.3. Step 3: Approach Capacity Calculation

After estimating the saturation flow rate for each lane group, the approach capacity for each link at the B end node of the link is calculated. This calculation is done by incorporating adjustment factors using the effective green ratio as shown in Equation 5.

Equation 5

$$C_{SI} = \sum_i S_i \times \frac{g_i}{C}$$

Where C_{SI} is signalized intersection approach capacity,

S_i represents saturation flow rate for lane group i and

$\frac{g_i}{C}$ represents effective green ratio for lane group i.

3.2. Capacities for Stop Control Intersections

The calculation for capacities for links that have stop controls at the B-node end also follow a series of steps as described next.

3.2.1. Step 1: Calculate the Potential Capacity for each Turning Movement

The potential capacity for each turning movement uses the conflicting flow rate, the critical gap, the number of lanes, follow up time for each movement, and percent heavy vehicles as input parameters. Equation 6 shows the equation used to calculate the potential capacity for stop controlled intersections for movements that are not shared.

Equation 6

$$C_{p,x} = CV_{c,x} \times \frac{e^{-V_{c,x} \times t_{c,x}/3600}}{1 - e^{-V_{c,x} \times t_{f,x}/3600}}$$

Where:

$C_{p,x}$	=	Potential Capacity of movement x (vph)
$CV_{c,x}$	=	Conflicting flow rate for each movement x (vph)
$t_{c,x}$	=	Critical gap (seconds) for each movement x $= t_{c,base} + (P_{HV} * t_{c,HV})$
$t_{c,base}$	=	Default values from Table 7
$t_{c,HV}$	=	1.0 for one or two-through lane roads 2.0 otherwise
P_{HV}	=	Percent of heavy vehicles in traffic stream, peak period, expressed as decimal
$t_{f,x}$	=	Follow-up time (seconds) for each movement x $= t_{f,base} + (P_{HV} * t_{f,HV})$
$t_{f,HV}$	=	0.9 for one or two through lane roads 1.0 otherwise

Table 7 and 8 show the default values that were used for calculating the potential capacities for stop-controlled intersections in the model.

Table 7 Default values for calculating potential capacities (Cp,x) of stop sign-controlled highways

Vehicle Movement (x)	Base Critical Gap, $t_{c,base}$	Follow-up Time, $t_{f,base}$
Right Turns	6.2	3.3
Through	6.5	4.0
Left Turns	7.1	3.5

Table 8 Default Values for Conflicting Flow Rates

Functional Class	Conflicting Flow Rate, $CV_{c,x}$
Rural Principal Arterials	100
Rural Minor Arterials	150
Other Rural	200
Urban Principal Arterials	250
Urban Minor Arterials	500
Other Urban	750

3.2.2. Step 2: Determine Potential Approach Capacity for Shared Lanes

For stop controlled intersections with shared turning lanes, Equation 7 was used to determine each approach's capacity. If turn lanes are not shared, step 2 is skipped.

Equation 7

$$C_{p,SH} = \frac{\sum_x V_x}{\sum_x \left(\frac{V_x}{C_{p,x}}\right)}$$

Where,

$C_{p,SH}$	=	Potential capacity of the shared lane (vph)
V_x	=	Flow rate of the x movement in the shared lane (vph)
$C_{p,x}$	=	Potential capacity of x movement in the shared lane (vph)

3.2.3. Step 3: Calculate Approach Capacity for each Lane Group Type

Table 9 shows the different equations that are used to calculate the approach capacity for each lane group as described previously for stop controlled intersections.

Table 9 Stop Sign Control Intersection Capacity Equations for Different Lane Groups

1	All Movements from Shared Lane	$C_A = N_T \times C_{p,SH}$
2	Shared LT + T lane; exclusive RT lane	$C_A = N_T \times C_{p,SH(LT+T)} + N_{RT} \times C_{p,RT}$
3	Shared RT + T lane; exclusive LT lane	$C_A = N_T \times C_{p,SH(RT+T)} + N_{LT} \times C_{p,LT}$
4	Exclusive lanes for all movements	$C_A = N_{LT} \times C_{p,LT} + N_T \times C_{p,T} + N_{RT} \times C_{p,RT}$
5	Consider only through volumes	$C_A = N_T \times C_{p,T}$

Where:

N_T	=	Number of peak through lanes; 1 for rural highways with two through lanes, 2 for rural highways with three through lanes
N_{LT}	=	Number of left turn lanes
N_{RT}	=	Number of right turn lanes
$C_{p,SH}$	=	Potential capacity of shared lane (vph)
$C_{p,T}$	=	Potential capacity for through movement (vph)
$C_{p,RT}$	=	Potential capacity for right turn movement (vph)
$C_{p,LT}$	=	Potential capacity for left turn movement (vph)

3.3. Freeway Capacity

For freeways, the following steps detailed the equations and procedures used to calculate their capacities.

3.3.1. Step 1: Calculate Free Flow Speed

Equation 8 shows the formula used to calculate free flow speeds. The equation utilizes the base free flow speed which is calculated using an algorithm that incorporates real time travel time data, lane width, right shoulder, number of lanes and interchange density adjustments.

Equation 8

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID}$$

Where:

BFFS	=	Base free flow speed
f_{LW}	=	Adjustment factor for lane width
f_{LC}	=	Adjustment factor for right shoulder lateral clearance
f_N	=	Adjustment factor for number of lanes
f_{ID}	=	Adjustment factor for interchange density

Table 10 shows the adjustment factors for lane width. This value is zero for 12ft wide lanes. However, if different widths exist, the values should be adjusted accordingly.

Table 10 Adjustment Factors Lane Width

Lane Width	Reduction in FFS (mph, f_{LW})
12 Ft	0.0
11 Ft	1.9
<= 10 ft	6.6

Table 11 shows the adjustment factors for right shoulder clearance. The model assumed a right shoulder clearance of greater than 6Ft. Adjustments should be made accordingly if these are different. For studies used to evaluate the construction/reconstruction impacts on freeways, this parameter will be critical in determining the reduced capacity if shoulders are closed or reduced.

Table 11 Right Shoulder Clearance Adjustment Factor

Right Shoulder Width (Ft)	Reduction in FFS (mph, f_{LC})			
	Lanes in one direction			
	2	3	4	>=5
>=6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

Table 12 shows the adjustments used for interchange densities. The distance between two nodes connecting the interchanges is used to calculate the interchange density. The values for small urban areas are used in the model. For the model, all interchange densities were greater than 1 mile. This parameter becomes important when new interchanges that increase interchange densities are being considered as they will potentially reduce freeway capacities.

Table 12 Adjustments for Interchange Density

Functional Class	Area Size	Interchange Density	Interchange Adj. Factor, (f_{ID})
Urban Interstates	Small Urban	0.7	1
	Small Urbanized	0.76	1.3
	Large Urbanized	0.83	1.7
Other Urban Highways Qualifying as Freeways	Small Urban	0.83	1.7
	Small Urbanized	0.88	1.9
	Large Urbanized	0.91	2.1

Table 13 details the adjustment factors used for adjusting freeway capacities based on the number of lanes.

Table 13 Adjustments for Number of Lanes

No of Lanes (One direction; Urban only)	Reduction in FFS (mph, f_N)
>=5	0.0
4	1.5
3	3.0
2	4.5

3.3.2. Step 2: Calculate Base Freeway Capacity

The base freeway capacity is calculated using Equation 9 for freeways with speeds less than or equal to 70mph and freeways with speeds greater than 70mph.

Equation 9

$$BaseCap = 1{,}700 + 10FFS; for\ FFS \leq 70\ mph$$

$$BaseCap = 2{,}400 + 10FFS; for\ FFS > 70\ mph$$

3.4. Ramp Capacity Calculations

The following steps were used to calculate ramp capacities:

3.4.1. Step 1: Calculate Free Flow Speed

Using Equation 10, the free flow speed for ramps were calculated as follows

Equation 10: Ramp Free Flow Speed Equation

$S_{fo} = 25.6 + 0.47 * S_{pl}$

Where S_{fo} = base free-flow speed (BFFS); and

S_{pl}= posted speed limit

3.4.2. Step 2: Calculate Maximum Saturation Flow Capacity

The Chattanooga-Hamilton model was used to develop Equation 11 to calculate ramp capacities as follows:

Equation 11: Maximum Saturation Flow Capacity

$SF = C * N * (v/c)_I * PHF$

Where SF is maximum service flow rate;

C is ideal capacity based on S_{fo};

N represents lumber of lanes;

(v/c) is rate of service flow for levels of service D or E. v/c=0.88 at LOS D, 1 at LOS E; and

PHF represents peak hour factor.

Table 28 and Table 29 in Appendix 1 shows sample Capacity calculations that are used in the model for signalized intersections.

4. MODEL INPUT DATA

The main data used as input to the model are the network and socioeconomic data. The two datasets were developed through a collaborative effort between MPO staff and ATAC. These data are discussed next.

4.1. Transportation Network Data

The transportation network is an abstract representation of the transportation system that has essential data describing the available transportation supply. The network is maintained in GIS as a geodatabase that contains four feature classes. These feature classes included: links which represent the roadway, nodes which represent intersections, centroids which are the trip origin/destination points for transportation analysis zones (TAZ) and external centroids which are external loading trip points. The network was updated by ATAC and the MPO to represent 2015 base year conditions.

The main attributes of the network that are used in the model include the network geometries (number of lanes and turn lanes), posted and Free Flow Speeds, functional classification, length of links, link ADTs (passenger and truck counts), link location area type and the intersection controls.

4.1.1. Distribution of Modeled Network by Functional Classifications

Table 14 shows the percentage of centerline miles by functional class.

Table 14 Centerline Miles Distribution by Functional Classification

Roadway Type	Interstate	Major Arterials	Ramps	Minor Arterials	Collectors	Locals	Rural Paved	Rural Unpaved
% of Total Roadway	8%	11%	2%	18%	16%	8%	10%	25%
Miles	23	32	7	51	47	24	29	72

Figure 8 shows the distribution of centerline miles for the links within each functional classification used in the model. As expected, ramps made up the lowest percentage of centerline miles comprising only 2%, while Rural Unpaved roadways made up the highest percentage comprising 25% of the network. Rural Unpaved roadways typically occurred in the outskirts of the model network and carried very little volumes in the assigned network. Minor arterials and collectors made up 18 and 16% of the roadway network. Major arterials made up 11% and interstate roadways made up 8% of the modeled network.

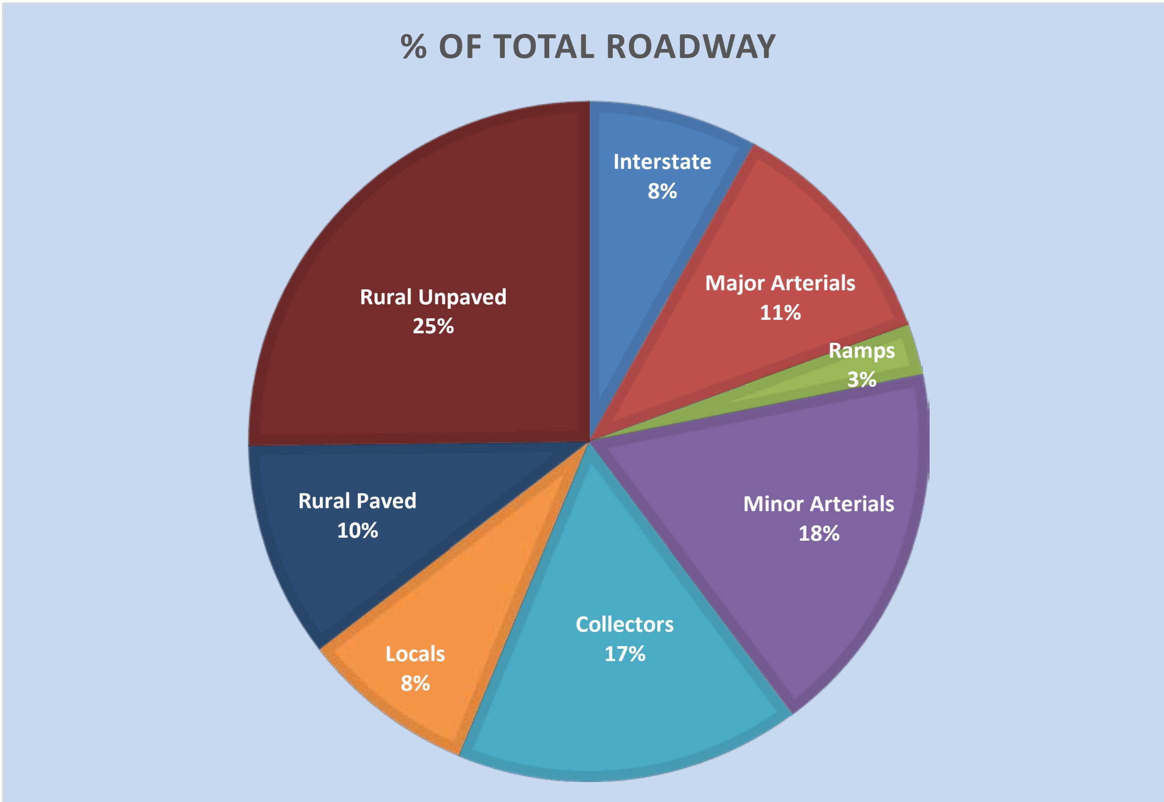


Figure 8 Centermile Distribution of Links in Network by Functional Class

Table 15 shows the percentage of lanemiles by functional class.

Table 15 LaneMiles Distribution by Functional Classification

Roadway Type	Interstate	Major Arterials	Ramps	Minor Arterials	Collectors	Locals	Rural Paved	Rural Unpaved
% Distribution	7%	19%	1%	17%	15%	8%	9%	23%
Lane Miles	46	118	7	107	94	47	58	143

Figure 9 show the lanemiles distribution by functional class. Lanemiles take into account the total number of through lanes and do not account for the turn lanes. Major arterials make up 19% of lanemiles in contrast to the 11% proportion for centermiles. The proportional distributions for the rest of the functional classes for lanemiles are within 2% points when compared to the centerline miles.

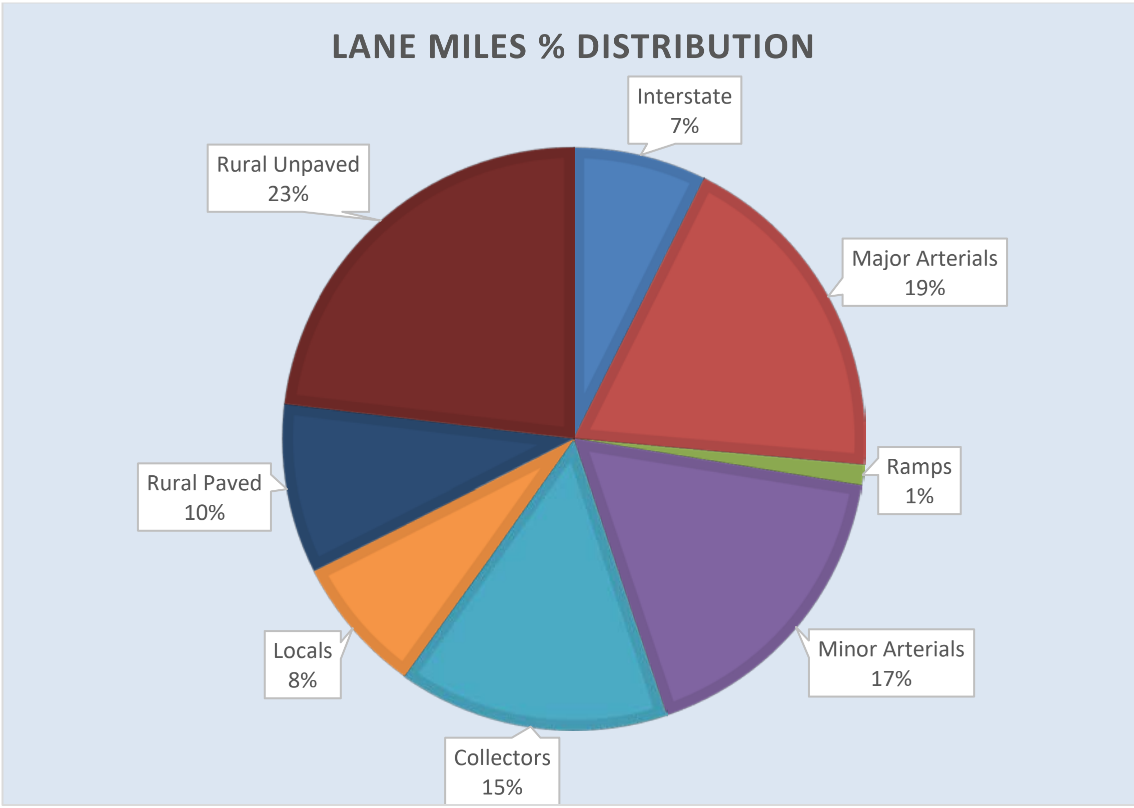


Figure 9 Lanemile Distribution of Links in Network by Functional Class

Figure 10 shows the modeled network distribution by functional class. The network does not show the centroid connectors.

Intersection controls were added to the model to incorporate delay experienced by road users. CUBE software uses a built in algorithm to calculate the delays that each intersection type contributes to the model. Two way stop controls; four way stop controls; Signals; Roundabouts and Yield controls were added as inputs to the model and are shown in Figure 11.

The intersection control signal timing data was provided by the GF-EGF MPO and represented actual signal timing data for signals for three time periods: AM Peak, PM Peak and Off peak periods. Using intersection data significantly enhanced the models replication of actual travel times. Without the intersection data, the model could only reasonable replicate 60% of ADT. Additionally, intersection delays would have to be added to the network travel times to represent delays, which may not be represent real world conditions.

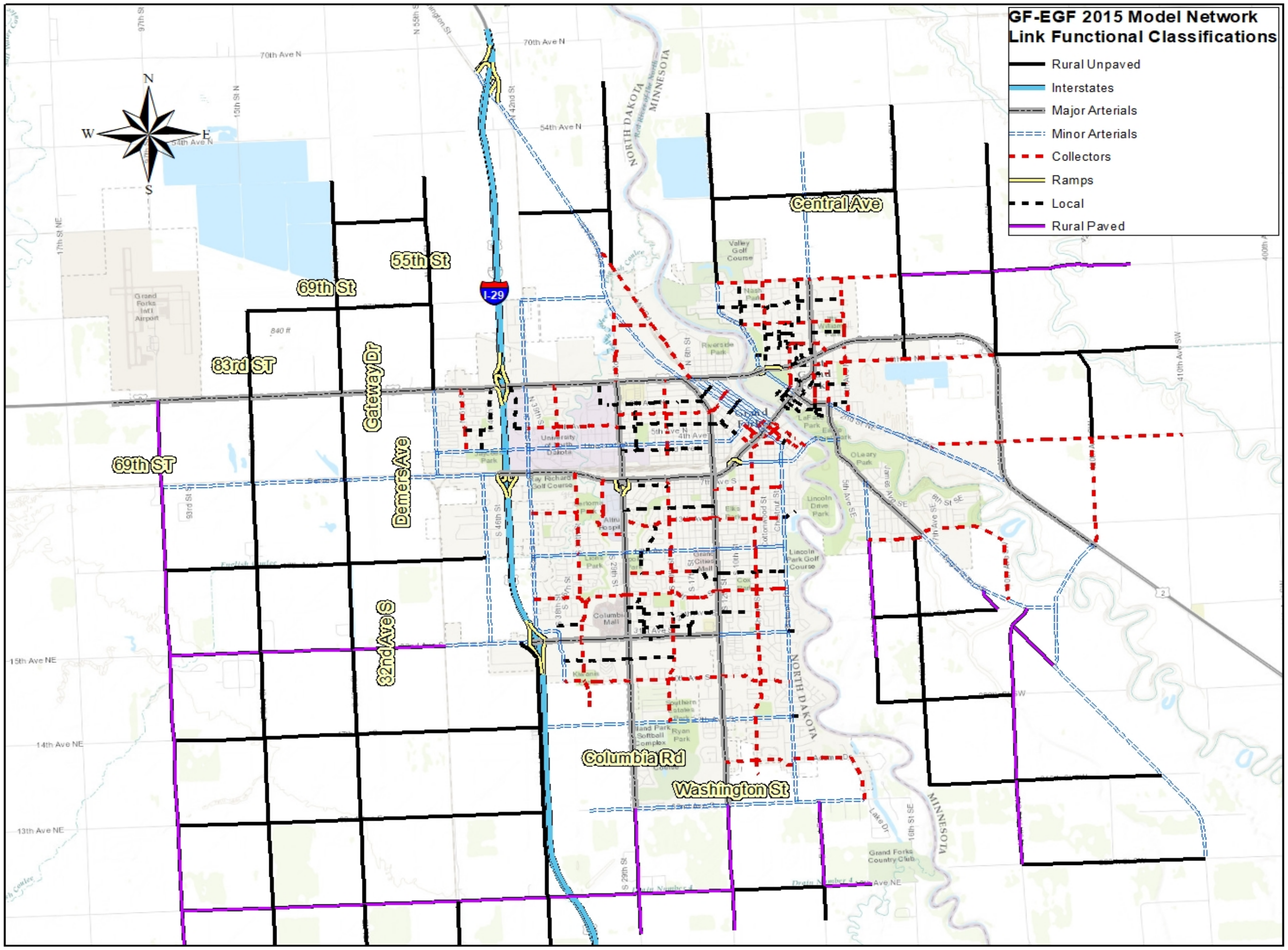


Figure 10 GF-EGF 2015 Model Network

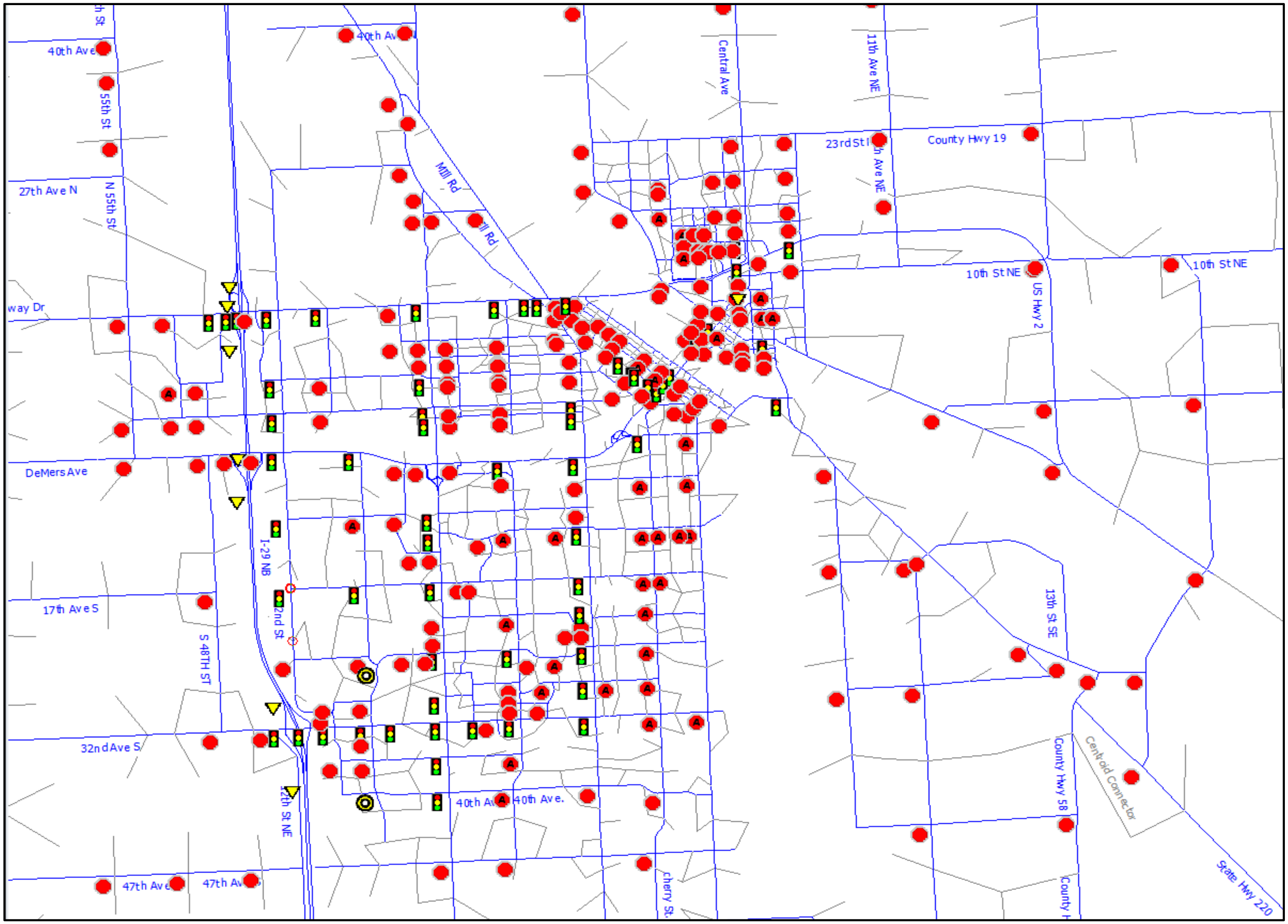


Figure 11 Intersection Data for Core Urban Area

4.2. Socioeconomic Data

Socioeconomic data are used to generate the total number of trips produced and attracted by each TAZ in the TDM. The TAZ geographies and the socioeconomic data included within each TAZ were developed by a collaborative effort between MPO staff and the ATAC. The socioeconomic data that was used in the model is described next.

4.2.1. TAZ Geography files:

584 internal total TAZs were used for the 2015 model. Several TAZs were modified (split or merged) based on input from both the MPO and ATAC.

4.2.2. Socioeconomic Data TAZ Attributes

The socioeconomic data within the TAZ contained the following fields

4.2.2.1. Number of Persons per household in each TAZ according to the following categories (attributes)

1. # of one person households
2. # of two person households
3. # of three person households
4. # of four person households
5. # of five person households
6. > # five person households
7. Total number of households

4.2.2.2. Vehicles per household in each TAZ[1]

1. # of zero vehicle households
2. # of one vehicle households
3. # of two vehicle households
4. # of three vehicle households
5. # of four vehicle households
6. > 4 vehicle households

4.2.2.3. School age children per household in each TAZ in four categories[2]

1. # of Grade school age children
2. # of Middle age school children
3. # of High school age children
4. # of College age (18-24)

[1] Data was not in the 2010 model
[2] Data was not in the 2010 model

4.2.2.4. Employment data (# for each TAZ)[3]

1. Manufacturing (NAICS 31-33)
2. Construction and resources (NAICS 21, 23)
3. Retail (NAICS 44-45)
4. Service (NAICS 52,53,55,56,56,51,62,71,81,99)
5. Agriculture (NAICS 11)
6. Wholesale Trade, Trans Utilities (NAICS:22,48-49,42)
7. Education (NAICS 61) with the following additional fields
    a. Elementary school enrollment for each TAZ
    b. Middle school enrollment for each TAZ
    c. High school enrollment for each TAZ
    d. College enrollment data
    e. Number of on campus students for each college
    f. Number of off campus students for each college
    g. Number of parking spots reserved for college students
    h. Number of parking spots reserved for staff

4.2.2.5. Enplanements

8. Yearly enplanements for the Grand Forks Airport for 2015 (145,272)

4.2.2.6. Special generators

9. Special generator TAZS (wholesale distributors (Walmart and Super Target, large retail stores, and the Columbia Mall).

4.2.2.7. ADT at external locations

Used as estimates of trips that have at least one trip end outside of the MPO area.

[3] Data has been disaggregated (Previously, it included retail, other and service jobs)

5. TRIP GENERATION

Trip generation is the first modeling step of TDM. The number of trips produced and attracted to each TAZ are developed in this step. Regression models were applied to the socioeconomic data to generate the number of trips produced and attracted to each TAZ. Trips Produced are typically a function of the household characteristics for each TAZ and represent the origins of trips. Trips attracted are a function of the employment magnitude and type for each TAZ and represent where trips generated are being attracted to. The inclusion of long-haul freight movements was an addition to the current model in contrast to previous version of the GF-EGF TDM. The next subsections describe in detail, the different trip generation methods that were used and the output from the trip generation step.

5.1. Internal-Internal Passenger Vehicle Trip Productions and Attractions

The Internal-Internal Passenger Vehicle Trip Generations (II Trips) represent the passenger vehicle trips that originate and terminate within the MPO area. These trips are classified into five main trip purposes including (Home Based Work) HBW, Home-Based Shop (HB-Shop), Home Based Other (HBO), Home Based School K-12 (HBSchool K-12), Home Based University (HBU) and Non Home Based (NHB) trips.

5.1.1. Trip Productions

Table 16 shows the trip generation equations that were used to develop the II trip production tables. The numbers in bold show the actual regression parameters used while the number underneath each one shows the p-value for each of the regression equations. The model parameters were developed from a household travel survey that was done in the Fargo-Moorhead area. These parameters are the starting equations that were used, the final equations were adjusted during the calibration process to reflect different area types and to match the observed traffic counts in the trip assignment step.

Table 16 Internal-Internal Passenger Trip Generation Equations

	Persons per Household				
Purpose	**1**	**2**	**3**	**4+**	**Overall**
HBW	**1**	**1.72**	**2.56**	**2.42**	**1.75**
	14.9	*19.82*	*13.61*	*17.15*	*30.45*
HBO	**1.09**	**2.4**	**2.51**	**4.8**	**2.46**
	11.9	*21.04*	*9.64*	*9.74*	*20.81*
NHB	**1.57**	**2.4**	**2.89**	**3.57**	**2.43**
	11.44	*17.78*	*7.39*	*10.1*	*22.49*
HB-HiSch	**0**	**0**	**0.47**	**0.46**	**0.16**
	.	.	*4.65*	*4.66*	*6.64*
HB-GrSch	**0**	**0.13**	**0.8**	**2.4**	**0.62**
	0.88	*5.09*	*6*	*12.52*	*11.94*
HB-Sch	**0**	**0.13**	**1.27**	**2.86**	**0.77**
	0.88	*5.09*	*8.38*	*14.21*	*13.29*
IE	**0.05**	**0.3**	**0.18**	**0.31**	**0.21**
	2.25	*6.71*	*2.8*	*3.52*	*7.71*
Total	**3.72**	**7**	**9.52**	**14.04**	**7.66**
	27.77	*35.97*	*18.52*	*19.59*	*35.69*

Table 17 shows the total number of households for each household type (PHH1 = 1 person Households) that were used for the 2015 GF-EGF TDM. A total of 27,326 households were modeled for the 2015 base year TDM. One person households represented 34% of total households while only 2% of the households had 6 or more persons.

Table 17 Total Households per Household Type for the 2015 GF-EGF TDM

Household Category	PHH1	PHH2	PHH3	PHH4	PHH5	PHH6	Total
Total # of Households	9,357	8,956	4,332	2,939	1,133	609	27,326
Percent of total	34%	33%	16%	11%	4%	2%	100%

Applying the equations from Table 16 to the household data from each TAZ, the trip productions estimated in 2015 TDM are shown in Table 18. HB-Shopping and HBO were added together and are shown in the HBO column. NHB trips represented the highest number of trips followed by HBO and HBW trips. The Elementary school's trips were more than twice the Middle school trips.

Table 18 Total Trips Produced by Purpose for the 2010 TDM

Purpose	HBW	NHB	HBO	Elem	Mid	High
Total	41,573	117,472	47,010	8,630	3,793	5,308

5.1.2. Trip Attractions

Trip attractions represent the number of trips attracted to each zone based on employment or the size of the school for school trips. Table 19 shows the trip attraction rates (from NCHRP 718) that applied to the socioeconomic data to develop trip attraction tables. Although the socioeconomic data showed several different job types, these were aggregated to represent the categories shown in Table 19. The trip attractions by purpose were balanced and are identical to the trip productions shown in Table 18.

Table 19 Trip Attraction Rates

Purpose	Retail	Service	Other
HBW	1.2	1.2	1.2
HBO	8.1	1.5	.2
NHB	4.7	1.4	.5

Table 20 shows the school trip attraction rates that were used for the model. These trip rates were obtained from the ITE Trip Generation Manual. School trip attractions were balanced to the productions and were identical to the trip productions shown in Table 18.

Table 20 School Trip Attraction Rates

School	Rate
Elementary	1.88
Middle	1.88
High	1.88

5.1.3. UND Trip Generations

Since Universities do not fall under normal trip patterns used by the model, a special trip generation trip model was developed for UND students. Trip productions and attractions for UND students were divided into two main components, trip productions for students who live on campus and trip productions for students who live off campus.

For on campus trip generation, trip production rates were obtained from a study that was conducted at the University of Lincoln Nebraska (5). A trip rate of 0.22 was applied to the number of on campus students residing in each UND TAZ (dorms, student apartments, fraternities). The number of on campus students residing in each UND TAZ was obtained from several different sources including data from the GF-EGF MPO, and UND demographic data. UND campuses occupied nine of the 584 TAZs.

TAZs that are within two blocks of campus will be assumed to be 100% walk, shuttle or bike i.e. non-vehicle trips, between 2 and four blocks, 80%, etc. It was assumed that there were eight blocks per mile.

Several TAZs that were within the non-vehicle trip distances (< 12 blocks from UND campus), however had physical barriers to these modes. For these TAZs, all trips were considered to be 100% vehicle trips. These TAZs that were within non-vehicle trip mode choices include all TAZs West of I-29, TAZS South of Demers, TAZs North of 10th Ave N and TAZs East of 20th St N.

For students residing off campus, a trip generation rate of 3.8 was applied to the percentage of 18-24 year olds for each TAZ who were assumed to be UND students. The number of UND students for each TAZ was calculated as a proportion of the total UND off campus students to the total of 18-24 year olds for each TAZ. UND student trip production rates were added to HBO for on campus students and HBO for off campus trips.

5.2. Freight Trip Productions and Attractions

The decisions that involve the movement of freight differ from those involving passenger trips. For this reason a separate freight trip model was developed. A commodity-based model will using the Commodity Flow Survey Data from the U.S. Census Bureau was used . This data is publicly available for the 2015 base year and forecasts are also available for the next 30 years. Commodity Flow Survey Data exists only for the largest metropolitan areas and for the rest of the states. The implication is that for the GF-EGF MPO, the commodity flow survey data had to be disaggregated from statewide totals to local data. Data on the employment for the two states-ND and MN was used to disaggregate freight data to each MPO and for the rest of the state.

Ordinary Least Square Models were used to develop model parameters that were applied to the number of jobs for each freight generation industry for productions and attractions. The model used data for the metropolitan areas that had disaggregate commodity flow survey data to develop the parameter estimates. This parameter estimates were then applied to the commodity flow survey data for both North Dakota and Minnesota to obtain the total tonnage of freight produced and attracted to the MPO. The total tonnage was assigned to the TAZ level based on the number of jobs for each commodity group in the TAZ. Table 21 shows the results of the freight model by industry type.

Table 21 Freight Trip Productions and Attractions

Productions			
NAICS Category	**Grand Forks**	**East Grand Forks**	**Total**
Manufacturing and Agriculture	108	122	229
Manufacturing	459	530	990
Industrial	1,084	138	1,222
Total	**1,651**	**790**	**2,441**
Attractions			
NAICS Category	Grand Forks	East Grand Forks	Total
Wholesale	2,367	753	3,121
Industrial	1,902	200	2,103
Manufacturing,	102	66	168
Retail	520	46	566
Retail, Wholesale	590	52	642
Total	**5,482**	**1,118**	**6,600**

6. TRIP DISTRIBUTION

The trip distribution step takes the trip productions and attractions developed in the trip generation step and assigns them between Origin-Destination pairs. The gravity model assigns trips based on the number of productions, attractions, a friction factor (F), and a scaling factor (K). The friction factor is a value that is inversely proportional to distance, time, or cost which is a measure of the travel impedance between any two zonal pairs. The k factor is a scaling factor that is used during calibration and it limits or increases the volume of traffic that crosses sections of the network. Equation 12 shows the gravity model formulation that was used.

Equation 12 Gravity Model Used for Trip Distribution

$$T_{ij} = P_i \frac{K_{ij} A_j F_{ij}}{\sum K_j A_j F_j}$$

Where,

T_{ij}= Number of trips assigned between Zones i and j; P_i = Number of Productions in Zone i;

A_j= Number of Attractions in Zone j;

F_{ij}= Friction Factor; and

K_{ij}= Scaling factor used in calibration to influence specific ij pairs

The typical output of the trip distribution step in TDMs is a matrix showing the origins and destination of each trip. The gravity model uses the trip generation outputs (production and attractions by trip purpose for each zone), a measure of travel impedance between each zonal pair (travel time), and socioeconomic/area characteristic variables ("K-factor") variables as input. The K-factor is used to account for the effects of variables other than travel impedance in the model. The OD data were used to develop K-factor matrices imputed in the trip gravity model that were used for distributing IE/EI trips.

For the TDM, trips were distributed separately for the different periods.To develop K-factors, it was necessary to aggregate the external portions of these trips into four main external super zones. For example, all the trips that originated from zones to the North of the MPO area were aggregated to one "super TAZ". The proportions of trips from every internal GF/EGF OD TAZ to the "super TAZ" was calculated and used as the K-Factor for the trip distribution of trips. The K-factors used in this way enabled the model to distribute trips more efficiently.

For EE trips, the OD data were used to develop K factors in a similar manner to those described for EI/IE trips. This were then used in the EE trip distribution step for the TDM.

For K-12 school trip distribution, school zones were used to assign trips for Grand Forks Public Schools. For East Grand Forks Schools and for Private schools, the gravity model was used to distribute K-12 school trips. The K-factor matrix used ensured that no Public school trips between the cities

7. TRIP ASSIGNMENT

Trip assignment is computationally the last step in travel demand modeling. The trip assignment step develops routes and paths that each trip will be choosing on the network when going from its origin to its destination. Trip assignments were carried out for three origin destination matrixes; AM peak, PM peak and off peak periods.

A hybrid model that combined the user equilibrium traffic assignment method to estimate the link travel cost and the intersection control data for intersection delays was used to estimate the travel cost between any two points on the network. A volume delay function was used to calculate the overall cost of travel for each link. The volume delay function uses the BPR formulation that adds cost to a link as additional trips get assigned to that link. It is meant to mimic the fact that as more and more vehicles use a particular link, congestion will occur and will slow down traffic.

The formulation used to calculate the travel cost for the equilibrium assignment method is shown in equation Equation 13. It takes into account the link travel time, the value of travel time and the link distance.

Equation 13 Trip Assignment Cost Equation

$$TC = (VTT * L_t) + 0.76 * L_d$$

Where:

TC = Link Travel Cost

VTT= Value of Travel Time ($12.85 for the metro area)

L_t = Link Travel Time, and

L_d = Link Length.

Junction-based assignment uses an intersection constrained assignment method and uses the intersection controls to assign node delays to the network. Junction-based modeling attempts to simulate congestion on a roadway network by modeling what happens at the intersections using the intersection control data like signal timing data.

8. CALIBRATION AND VALIDATION

Model calibration refers to the adjustment of model input parameters in order to replicate observed real world data for a base year to otherwise produce reasonable results. It involves adjusting model input parameters such as trip generation rates, node delays, free flow speeds, K factors and friction factors. Figure 12 shows the calibration and validation flow chart that was used for the model. It was an iterative process that involved adjusting the model parameters until a certain level of confidence of the model's replication of real world data was achieved.

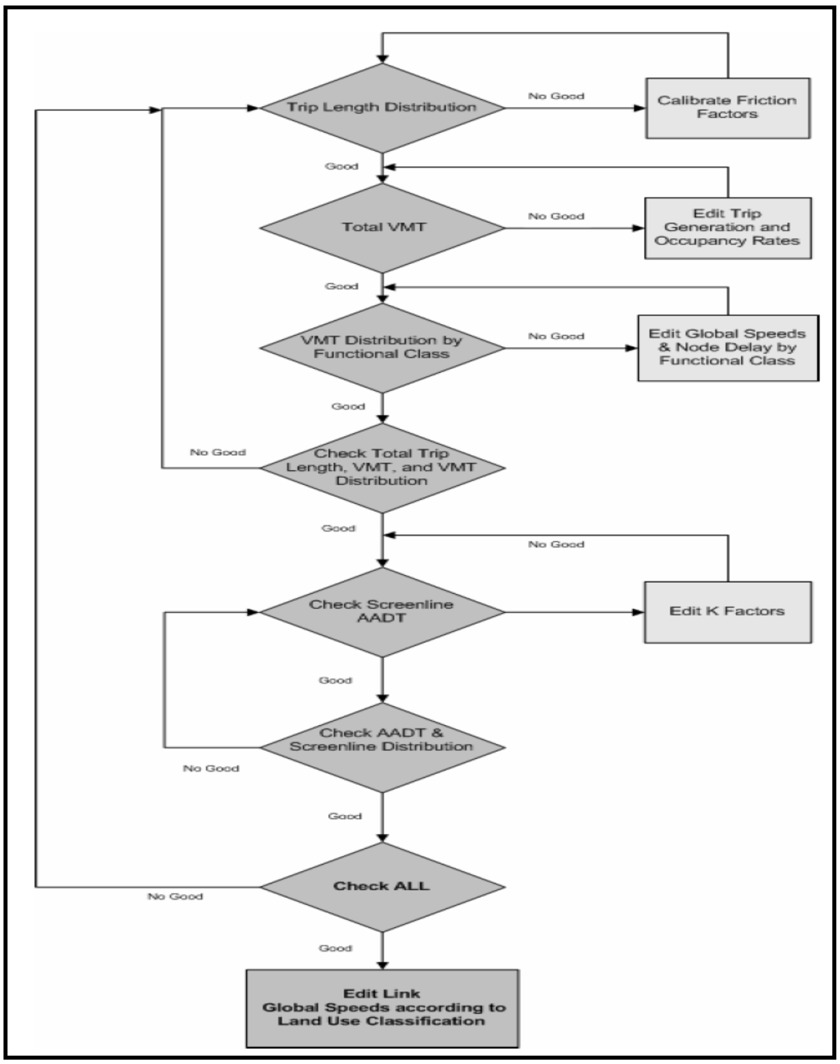


Figure 12 Calibration Flow Chart

Model validation compares base year calibrated models output to observed data. Ideally, model calibration data should not be used for validation purposes but this is not always feasible. Model validation is the ultimate step of the travel demand models and gives and indication of how well the model performs in replicating real world data.

The two processes, calibration and validation typically go hand in hand in an iterative process as was done for this model update. The next subsections describe the different methods, models and parameters that were used for model calibration and validation.

8.1. Trip Length Frequency Calibration and Validation

Trip length frequency distributions describe the travelers sensitivity to travel time by trip purpose. Steeper curves mean more sensitive travel times. Friction factors are calibrated until a desired trip length frequency is validated against observed data. The friction factors are the main dependent variable in the gravity model. The gamma function was used to develop the friction factor for this model and are shown in Figure 13.

Equation 14 Friction Factor Equation

$$\boldsymbol{F_{ij}^{p} = a * t_{ij}^{b} * exp(c * t_{ij}^{b})}$$

Where,

F_{ij}^{p} = Friction factor for purpose p (HBW,HBO, NHB)

t_{ij}^{b} = travel impedance between zone i and j,

a, b and c are gamma function scaling factors.

The friction factors were calibrated by adjusting the a, b and c parameters until the desirable trip length frequency distribution for Home Based Work Travel times were reached. Observed trip length frequency data for the home-based work trips were obtained from the census journey to work database for the metropolitan area. Only trips lower than 35 minutes were considered with the assumption that 35 minutes was the highest possible travel time between any two points within the metro area.

The average trip length for the observed data was calculated as 11.85 compared to the average trip length of 11.76 produced by the model for HBW trips. The desired average trip lengths for HBO and NHB trips were 88% and 82% of the average trip length for HBO and NHB trips. The average trip length for the models HBO and NHB trips were 10.4 and 9.77 minutes respectively.

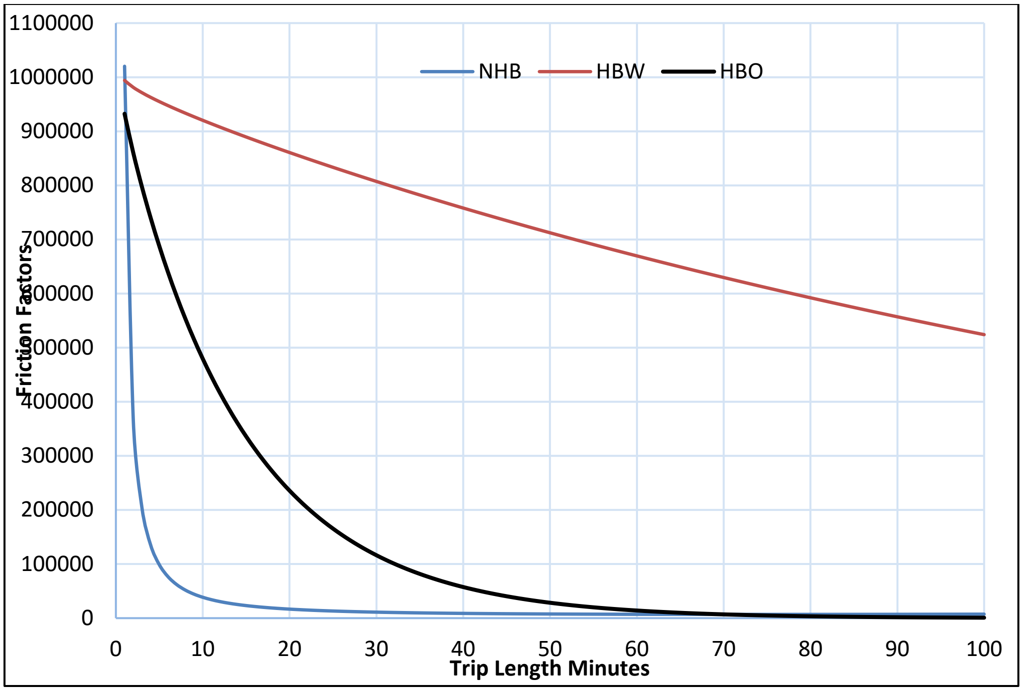


Figure 13 Friction Factors

Figure 14 shows the comparison between observed trip length frequencies and the modeled trip length frequencies for HBW trips. The comparison was done for only HBW trips since that's the only observed data available. The two graphs are very similar to each other.

Coincidence ratios were also calculated to verify the fit between the observed and modeled trip lengths. The coincidence ratio is the area under both curves divided by the area under at least one of the curves when both curves are plotted together. It measures how the percent of area between that coincides between two curves. Mathematically, the sum of the lower value of the two distributions for each time increment is divided by the sum of the higher value of the two distributions at each increment. Coincidence ratios lie between 0 and 1.0 with a ratio of 1.0 indicating identical distributions. The coincidence ratio calculated between the modeled and observed data was 0.89 showing a strong coincidence between modeled and observed trip lengths.

Given Figure 14 and the coincidence ratio calculations, the trip length frequency and average trip lengths were reasonably calibrated and validated. , it is reasonable to assume that trip length frequencies had been reasonably validated with observed data. Figure 15 shows the modeled trip length frequencies for all purposes.

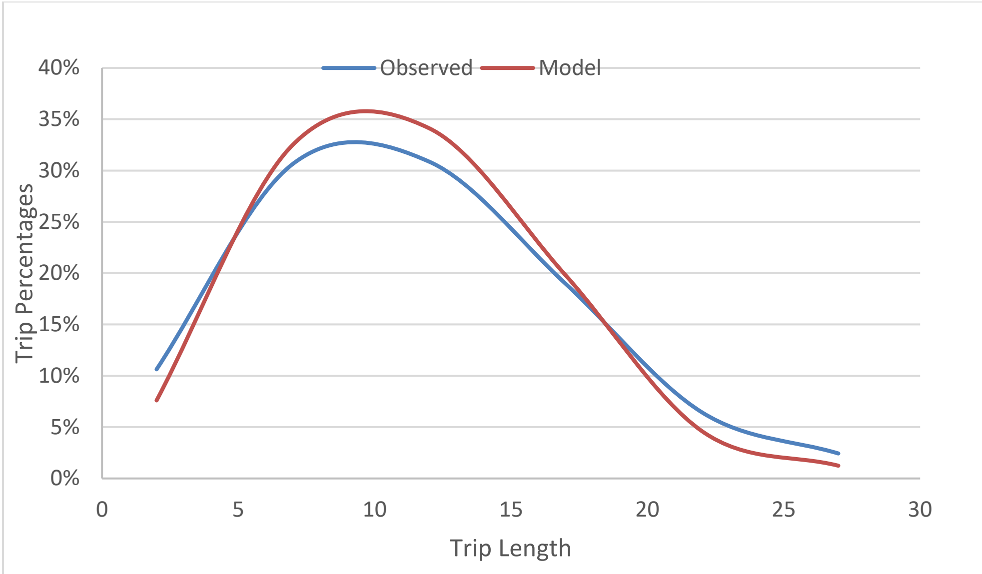


Figure 14 Comparison of Observed to Model Trip Length Frequency

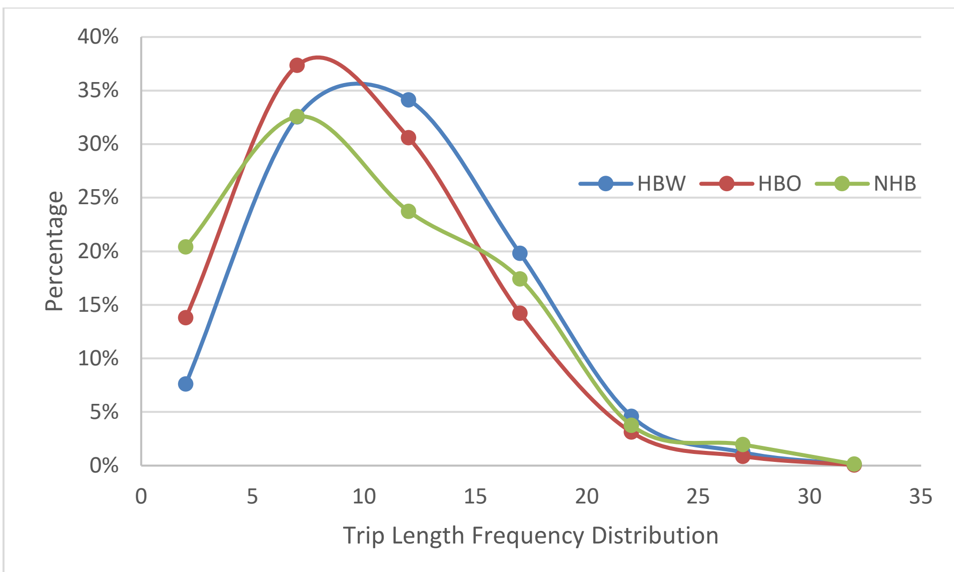


Figure 15 Modeled Trip Length Frequencies for All Trip Purposes

8.2. Vehicle Miles Traveled (VMT) Calibration and Validation

The modeled vehicle miles traveled are a function of trips generated by the model and the length of those trips in miles. VMTs summaries provide an indication of the overall reasonableness of the travel demand in the study area. To calibrate the VMT values, ATAC first calibrated the total VMT for the entire model area. If the modeled VMT values were different from the values calculated by multiplying the counted ADTs by length (observed VMTs), ATAC adjusted the trip generation and vehicle occupancy rates until the model and reported VMT values were similar. Adjusting the trip generation and occupancy rates changes the total number of trips that are generated within the transportation model. This in turn increases or decreases the total number of vehicle miles traveled.

Once the total VMT was reasonable, ATAC checked the VMT distribution according to the functional class. VMT summaries by functional classification provide an indication of how well the models assignment procedures perform. They will indicate if the model handles free flow speeds, capacities or whether the trip assignment function has any issues. To calibrate the VMT by facility type, if functional class VMT distribution was off target, global speeds by facility type were adjusted.

Table 22 shows the VMT comparison between modeled and observed VMTs and their various distributions as a percentage of total VMT. The model performs very well in replicating the VMTs for Interstates and Major arterials with VMT differences of less than 2% and had similar distributions to the observed VMTs. The VMTs for Local and rural roads of 5% and -6% respectively which is an acceptable deviation. Collectors had a -12% VMT difference. Collectors had the most discrepancy between the modeled and observed VMTs. Overall, the model performs within reasonable and acceptable deviations in replicating VMTS by functional class.

Table 22 Modeled VMTs compared to Observed VMTs

	Observed VMT	Modeled VMT	Difference	% Difference	Observed Distribution	Modeled Distribution
Interstate	101,054	103,024	1,970	2%	21%	21%
Major Arterial	207,238	212,044	4,806	2%	43%	44%
Minor Arterial	95,705	95,741	36	0%	20%	20%
Collectors	61,287	54,706	(6,581)	-12%	13%	11%
Local	5,079	5,320	241	5%	1%	1%
Rural	11,340	10,726	(614)	-6%	2%	2%
Total	481,703	481,561	(142)	0%	100%	100%

8.3. Screenline Comparisons

Screenlines are barriers to travel between two areas in a travel demand model including natural barriers such as rivers, mountains, etc. and man-made barriers such are interstates and major arterials, railroads etc. Five screenlines were used for the model: BNSF Mainline railroad, the Red River, 32nd Ave S., Columbia Rd and I-29. Table 23 lists the Screenlines that were used in the GF EGF model.

The 32nd avenue south Screenline had the highest Screenline difference (-6.16%) between observed and Modeled screenlines. However, it still falls within a reasonable difference between modeled and observed volumes of ±10%. Based on Travel Model Validation and Reasonableness Checking Manual the values fall within stated reasonable deviation limits.

Table 23 Observed Screenlines Compared to Modeled Screenlines

	Observed	Modeled	Difference	% Difference
Red River	41,100	41,708	608	1.48%
BNSF Mainline Rail Road	79,195	80,172	977	1.23%
I-29	52,585	51,307	-1,278	-2.43%
32nd Ave S	63,423	59,513	-3,910	-6.16%

8.4. Modeled ADT Comparison to Observed ADT

Comparing the modeled ADTs to the Observed ADTs is the ultimate test of how well the model can replicate ground truths. The MP provided traffic counts for several links that were compared to the Model ADTs. Two comparisons are made, one for the different functionally classifications and one by volume ranges. Table 24 shows the comparison of the modeled and observed ADTs by functional classification. Overall, the model performs reasonably replicating over 87 of observed counts. Collector roads have the lowest replication of observed counts at 85%.

Table 24 Comparison of Modeled and Observed ADTS by Functional Classification

Functional Class	Above Criteria	Meets Criteria	Below Criteria	Within Criteria
Freeway	0	10	0	100%
Major Arterials	9	85	5	86%
Minor Arterials	5	126	14	87%
Rural Paved	0	20	0	100%
Collector	5	118	16	85%
Local Roads	2	23	1	88%
Total	21	382	36	87%

Table 25 shows the comparison of modeled and Observed ADTs by volume range. The FHWA criterion sets limits to the deviations between observed and modeled ADTs. Overall the model meets all deviation criterion for all the volume ranges.

Table 25 Comparison of Modeled and Observed ADT by Volume Range

Volume Range	Above Criteria	Meets Criteria	Below Criteria	Within Criteria	Criteria Deviation
AADT>25,000	0	9	0	100%	±15%
25,000 to 10,000	4	58	6	85%	±20%
10,000 to 5,000	6	62	22	69%	±25%
5,000 to 2,500	3	101	8	90%	±50%
2,500 to 1,000	3	93	0	97%	±100%
AADT<1000	5	59	0	92%	±100%
Total	**21**	**382**	**36**	87%	

8.5. Root Mean Square Error and Percent Root Mean Squared Error

The comparison between the modeled and observed ADTS give a good indication of a how well the model replicates real life. However, they do not provide statistical measures of goodness of fit test for the models replication of ground truths. Root Mean Squared Error (RMSE) and Percent Root Mean Squared Errors %RMSE were used to calculate the accuracy of the model. RMSE compares the error between the modeled and observed traffic volumes for the entire network, giving a statistical measure of the accuracy of the model. RMSE and % RMSE were found by squaring the error (difference between modeled and counted ADTs) for each link and then taking the square root of the averages as shown in Equation 15.

Equation 15 RMSE and % RMSE Calculations

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}[(Count_i - Model_i)^2]}{N}}$$,and

$$\%RMSE = \left[\frac{RMSE}{\sum_{i=1}^{N} Count_i / N}\right] * 100$$

Where:

$Count_i$ = Observed traffic count on link *i;*

Modeli = Modeled traffic volume for link *I;* and

N = The number of links in the group of links including link *i, (number of links with counts)*

Table 26 shows the %RMSE by volume range. The %RMSE is below the typical deviation limits for all the volume ranges shown indicating a good fit between the modeled and observed traffic volumess model is performing reasonably in replicating observed traffic.

Table 26 RMSE Comparison by Volume Range

Volume Range	RMSE (%)	Typical Limits (%)
AADT>25,000	6.72%	15-20 %
25,000 to 10,000	13.68%	25-30 %
10,000 to 5,000	24.71%	35-45 %
5,000 to 2,500	32.27%	45-100 %
2,500 to 1,000	51.42%	45-100 %

AADT<1000	98.71%	>100 %

8.6. Scatter Plots, R Squares of Model and Observed Traffic

Scatter plots of the modeled traffic volumes against the observed traffic volumes are a good indicator of the model's fit. Figure 16 shows the scatter plot of modeled traffic volumes versus observed counts. The scatter plot suggests that the amount of error in the modeled volumes is proportional to the observed traffic count which is an indication of a good fit between the model and the observed traffic counts.

The R-square (coefficient of determination) is the proportion of the variance in a dependent variable that is attributable to the variance of the independent variable. It measures the strength of the relationships between the assigned volumes and the traffic counts. It measures the amount of variation in traffic counts explained by the model. The modeled R-square of 0.93 shows a strong linear relationship between modeled and observed traffic counts.

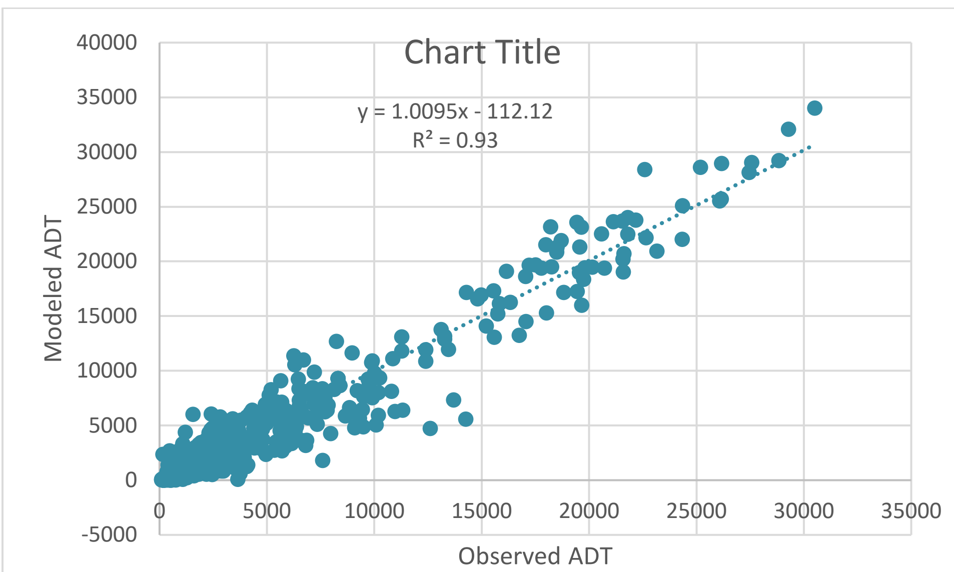


Figure 16 Scatter Plot of Modeled and Observed ADTS

8.7. Link Travel Time Validation

To evaluate how well the assignment algorithms and the intersection control data performed in the model assignment, sample travel times from the model were compared to average travel times that were obtained using online mapping tools. An online API was developed to collect the data for AM, PM and Off-peak travel times for the average weekdays. Table 27 shows the comparison of the modeled travel times and the average travel times collected. The modeled travel times are within plus or minus one minute for the different peak periods for the group of selected roadways. This is an indication that the model's assignment algorithms are performing very well in terms of replicating real time travel time data.

Table 27 Travel Time Validation

Link Type/Location	Distance (Miles)	Observed Travel Time (Min)			Modeled Travel Time (Min)		
Principal Arterials		AM	PM	OFF	AM	PM	OFF
Gateway Drive - 16th St to N 55th St	2.8	3	3	3	3.52	3.69	3.39
Gateway Drive - N Columbia Rd to 5th Ave NE	2.9	6	7.5	6	6.53	7.37	5.48
Demers Ave - I-29 to Washington St	2.3	6	7	6	5.79	6.84	4.77
Washington St - Gateway Drive to 24th Ave S	2.6	9	10	8	8.11	9.35	6.43
32nd Ave S - I-29 Ramp W to Washington St	2.1	7	7.5	7	6.78	7.99	6.16
Minor Arterials							
32nd Ave S - Washington St to Belmont RD	0.7	3	3	3	1.89	2.22	1.85
N 42nd St - 27th Ave N to University Ave	1.7	5	5	5	3.76	3.92	3.57
17th Ave S - Columbia RD to Belmont Rd	1.7	6	7	6	5.29	5.97	4.65
Belmond Rd - 13th Ave S to 62nd Ave S	3.3	7	8	7	7.09	8.07	6.5
Collectors							
40th Ave S - to Washington St	1.3	4	4	4	3.77	3.86	3.71
40th Ave S - Washington to Belmont Rd	0.8	3	3	3	1.99	2.28	1.96
13th Ave S - S Columbia to Washington	1	4	5	4	2.98	3.65	2.61
20th St S - 20th Ave S to 36th Ave S	1	4	4	4	4.25	4.67	3.44

9. CONCLUSIONS

This document describes the development, calibration and validation of the GF-EGF MPO base 2015 TDM. Several improvements were made to previous modeling efforts including the addition of Freight movements and better representation of capacities. Overall the model replicates observed travel demand within typically accepted deviation limits.

10. APPENDIX

Table 28 Calculated Capacities for Signalized Intersections for Different Functional Classifications

Lane Grp	Number of Through Lanes (N)	Number of Left Turn Lanes	Number of Right Turn Lanes	Total Number of Through Lanes	Type of Arterial	Area Type	Area Type Adjustment Factor (f_a)	Base Saturation Flow Rate (S_o)	Heavy Vehicle Adjustment Factor (f_{HV})	Saturation Flow Rate for Through Lanes (S)	Total Saturation Flow Rate	Effective Green Ratio (g_i/C)	Intersection Approach Hourly Capacity (C_A)	Intersection Daily Approach Capacity
N0	1	0	0	1	**Principal**	**Urban**	**0.9**	**1900**	**0.90**	**1416**	**1416**	**0.55**	**779**	**7,787**
	1	0	0			**Rural**	**1**	**1900**	**0.90**	**1505**	**1505**	**0.55**	**828**	**8,276**
	1	0	0		Minor	Urban	0.9	1900	0.90	1416	1416	0.45	637	**6,371**
	1	0	0			Rural	1	1900	0.90	1505	1505	0.45	677	**6,772**
	1	0	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	1308	1308	**0.4**	523	**5,233**
	1	0	0			**Rural**	**1**	**1900**	0.99	1390	1390	**0.4**	556	**5,562**
	2	0	0	2	Principal	Urban	0.9	1900	0.90	2832	2832	0.55	1557	**15,575**
	2	0	0			Rural	1	1900	0.90	3010	3010	0.55	1655	**16,553**
	2	0	0		Minor	Urban	0.9	1900	0.90	2832	2832	0.45	1274	**12,743**
	2	0	0			Rural	1	1900	0.90	3010	3010	0.45	1354	**13,543**
	2	0	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	2866	2866	**0.4**	1146	**11,463**
	2	0	0			**Rural**	**1**	**1900**	0.99	3046	3046	**0.4**	1218	**12,183**
	3	0	0	3	Principal	Urban	0.9	1900	0.90	4248	4248	0.55	2336	**23,362**
	3	0	0			Rural	1	1900	0.90	4514	4514	0.55	2483	**24,829**
	3	0	0		Minor	Urban	0.9	1900	0.90	4248	4248	0.45	1911	**19,114**
	3	0	0			Rural	1	1900	0.90	4514	4514	0.45	2031	**20,315**
	3	0	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	4439	4439	**0.4**	1776	**17,755**
	3	0	0			**Rural**	**1**	**1900**	0.99	4718	4718	**0.4**	1887	**18,870**

Lane Grp	Number of Through Lanes (N)	Number of Left Turn Lanes	Number of Right Turn Lanes	Total Number of Through Lanes	Type of Arterial	Area Type	Area Type Adjustment Factor (f_a)	Base Saturation Flow Rate (S_o)	Heavy Vehicle Adjustment Factor (f_{HV})	Saturation Flow Rate for Through Lanes (S)	Total Saturation Flow Rate	Effective Green Ratio (g_i/C)	Intersection Approach Hourly Capacity (C_A)	Intersection Daily Approach Capacity
N1	1	1	0	2	Principal	Urban	0.9	1900	0.90	1416	1841	0.55	1012	**10,124**
	1	1	0			Rural	1	1900	0.90	1505	1956	0.55	1076	**10,759**
	1	1	0		Minor	Urban	0.9	1900	0.90	1416	1841	0.45	828	**8,283**
	1	1	0			Rural	1	1900	0.90	1505	1956	0.45	880	**8,803**
	1	1	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	1433	1863	**0.4**	745	**7,451**
	1	1	0			**Rural**	**1**	**1900**	0.99	1523	1980	**0.4**	792	**7,919**
	2	1	0	3	Principal	Urban	0.9	1900	0.90	2832	3257	0.55	1791	**17,911**
	2	1	0			Rural	1	1900	0.90	3010	3461	0.55	1904	**19,036**
	2	1	0		Minor	Urban	0.9	1900	0.90	2832	3257	0.45	1465	**14,654**
	2	1	0			Rural	1	1900	0.90	3010	3461	0.45	1557	**15,575**
	2	1	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	2959	3403	**0.4**	1361	**13,612**
	2	1	0			**Rural**	**1**	**1900**	0.99	3145	3617	**0.4**	1447	**14,467**
	3	1	0	4	Principal	Urban	0.9	1900	0.90	4248	4672	0.55	2570	**25,698**
	3	1	0			Rural	1	1900	0.90	4514	4966	0.55	2731	**27,312**
	3	1	0		Minor	Urban	0.9	1900	0.90	4248	4672	0.45	2103	**21,026**
	3	1	0			Rural	1	1900	0.90	4514	4966	0.45	2235	**22,346**
	3	1	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	4486	4934	**0.4**	1974	**19,736**
	3	1	0			**Rural**	**1**	**1900**	0.99	4767	5244	**0.4**	2098	**20,976**
N2	1	2	0	3	Principal	Urban	0.9	1900	0.90	1416	2265	0.55	1246	**12,460**
	1	2	0			Rural	1	1900	0.90	1505	2408	0.55	1324	**13,242**
	1	2	0		Minor	Urban	0.9	1900	0.90	1416	2265	0.45	1019	**10,194**

Lane Grp	Number of Through Lanes (N)	Number of Left Turn Lanes	Number of Right Turn Lanes	Total Number of Through Lanes	Type of Arterial	Area Type	Area Type Adjustment Factor (f_a)	Base Saturation Flow Rate (S_o)	Heavy Vehicle Adjustment Factor (f_{HV})	Saturation Flow Rate for Through Lanes (S)	Total Saturation Flow Rate	Effective Green Ratio (g_i/C)	Intersection Approach Hourly Capacity (C_A)	Intersection Daily Approach Capacity
	1	2	0			Rural	1	1900	0.90	1505	2408	0.45	1083	**10,835**
	1	2	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	1480	2367	**0.4**	947	**9,469**
	1	2	0			**Rural**	**1**	**1900**	0.99	1573	2516	**0.4**	1006	**10,064**
	2	2	0	4	Principal	Urban	0.9	1900	0.90	2832	3681	0.55	2025	**20,247**
	2	2	0			Rural	1	1900	0.90	3010	3912	0.55	2152	**21,519**
	2	2	0		Minor	Urban	0.9	1900	0.90	2832	3681	0.45	1657	**16,566**
	2	2	0			Rural	1	1900	0.90	3010	3912	0.45	1761	**17,606**
	2	2	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	2990	3887	**0.4**	1555	**15,550**
	2	2	0			**Rural**	**1**	**1900**	0.99	3178	4132	**0.4**	1653	**16,526**
	3	2	0	5	Principal	Urban	0.9	1900	0.90	4248	5097	0.55	2803	**28,034**
	3	2	0			Rural	1	1900	0.90	4514	5417	0.55	2980	**29,795**
	3	2	0		Minor	Urban	0.9	1900	0.90	4248	5097	0.45	2294	**22,937**
	3	2	0			Rural	1	1900	0.90	4514	5417	0.45	2438	**24,378**
	3	2	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	4532	5439	**0.4**	2175	**21,755**
	3	2	0			**Rural**	**1**	**1900**	0.99	4817	5780	**0.4**	2312	**23,121**
N3	1	1	0	2	Principal	Urban	0.9	1900	0.90	1416	1841	0.55	1012	**10,124**
	1	1	0			Rural	1	1900	0.90	1505	1956	0.55	1076	**10,759**
	1	1	0		Minor	Urban	0.9	1900	0.90	1416	1841	0.45	828	**8,283**
	1	1	0			Rural	1	1900	0.90	1505	1956	0.45	880	**8,803**
	1	1	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	1433	1863	**0.4**	745	**7,451**
	1	1	0			**Rural**	**1**	**1900**	0.99	1523	1980	**0.4**	792	**7,919**

Lane Grp	**Number of Through Lanes (N)**	**Number of Left Turn Lanes**	**Number of Right Turn Lanes**	**Total Number of Through Lanes**	**Type of Arterial**	**Area Type**	**Area Type Adjustment Factor (f_a)**	**Base Saturation Flow Rate (S_o)**	**Heavy Vehicle Adjustment Factor (f_{HV})**	**Saturation Flow Rate for Through Lanes (S)**	**Total Saturation Flow Rate**	**Effective Green Ratio (g_i/C)**	**Intersection Approach Hourly Capacity (C_A)**	**Intersection Daily Approach Capacity**
	2	1	0	3	Principal	Urban	0.9	1900	0.90	2832	3257	0.55	1791	**17,911**
	2	1	0			Rural	1	1900	0.90	3010	3461	0.55	1904	**19,036**
	2	1	0		Minor	Urban	0.9	1900	0.90	2832	3257	0.45	1465	**14,654**
	2	1	0			Rural	1	1900	0.90	3010	3461	0.45	1557	**15,575**
	2	1	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	2959	3403	**0.4**	1361	**13,612**
	2	1	0			**Rural**	**1**	**1900**	0.99	3145	3617	**0.4**	1447	**14,467**
	3	1	0	4	Principal	Urban	0.9	1900	0.90	4248	4672	0.55	2570	**25,698**
	3	1	0			Rural	1	1900	0.90	4514	4966	0.55	2731	**27,312**
	3	1	0		Minor	Urban	0.9	1900	0.90	4248	4672	0.45	2103	**21,026**
	3	1	0			Rural	1	1900	0.90	4514	4966	0.45	2235	**22,346**
	3	1	0		**Collector**	**Urban**	**0.9**	**1900**	0.99	4486	4934	**0.4**	1974	**19,736**
	3	1	0			**Rural**	**1**	**1900**	0.99	4767	5244	**0.4**	2098	**20,976**
N4	1	0	1	2	Principal	Urban	0.9	1900	0.90	1416	1557	0.55	857	**8,566**
	1	0	1			Rural	1	1900	0.90	1505	1655	0.55	910	**9,104**
	1	0	1		Minor	Urban	0.9	1900	0.90	1416	1557	0.45	701	**7,009**
	1	0	1			Rural	1	1900	0.90	1505	1655	0.45	745	**7,449**
	1	0	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	1433	1576	**0.4**	630	**6,305**
	1	0	1			**Rural**	**1**	**1900**	0.99	1523	1675	**0.4**	670	**6,701**
	2	0	1	3	Principal	Urban	0.9	1900	0.90	2832	2973	0.55	1635	**16,353**
	2	0	1			Rural	1	1900	0.90	3010	3160	0.55	1738	**17,380**
	2	0	1		Minor	Urban	0.9	1900	0.90	2832	2973	0.45	1338	**13,380**

Lane Grp	Number of Through Lanes (N)	Number of Left Turn Lanes	Number of Right Turn Lanes	Total Number of Through Lanes	Type of Arterial	Area Type	Area Type Adjustment Factor (f_a)	Base Saturation Flow Rate (S_o)	Heavy Vehicle Adjustment Factor (f_{HV})	Saturation Flow Rate for Through Lanes (S)	Total Saturation Flow Rate	Effective Green Ratio (g_i/C)	Intersection Approach Hourly Capacity (C_A)	Intersection Daily Approach Capacity
	2	0	1			Rural	1	1900	0.90	3010	3160	0.45	1422	**14,220**
	2	0	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	2959	3107	**0.4**	1243	**12,429**
	2	0	1			**Rural**	**1**	**1900**	0.99	3145	3302	**0.4**	1321	**13,209**
	3	0	1	4	Principal	Urban	0.9	1900	0.90	4248	4389	0.55	2414	**24,141**
	3	0	1			Rural	1	1900	0.90	4514	4665	0.55	2566	**25,657**
	3	0	1		Minor	Urban	0.9	1900	0.90	4248	4389	0.45	1975	**19,752**
	3	0	1			Rural	1	1900	0.90	4514	4665	0.45	2099	**20,992**
	3	0	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	4486	4635	**0.4**	1854	**18,540**
	3	0	1			**Rural**	**1**	**1900**	0.99	4767	4926	**0.4**	1970	**19,704**
N5	1	0	2	3	Principal	Urban	0.9	1900	0.90	1416	1699	0.55	934	**9,345**
	1	0	2			Rural	1	1900	0.90	1505	1806	0.55	993	**9,932**
	1	0	2		Minor	Urban	0.9	1900	0.90	1416	1699	0.45	765	**7,646**
	1	0	2			Rural	1	1900	0.90	1505	1806	0.45	813	**8,126**
	1	0	2		**Collector**	**Urban**	**0.9**	**1900**	0.99	1480	1776	**0.4**	710	**7,102**
	1	0	2			**Rural**	**1**	**1900**	0.99	1573	1887	**0.4**	755	**7,548**
	2	0	2	4	Principal	Urban	0.9	1900	0.90	2832	3115	0.55	1713	**17,132**
	2	0	2			Rural	1	1900	0.90	3010	3311	0.55	1821	**18,208**
	2	0	2		Minor	Urban	0.9	1900	0.90	2832	3115	0.45	1402	**14,017**
	2	0	2			Rural	1	1900	0.90	3010	3311	0.45	1490	**14,898**
	2	0	2		**Collector**	**Urban**	**0.9**	**1900**	0.99	2990	3289	**0.4**	1316	**13,157**
	2	0	2			**Rural**	**1**	**1900**	0.99	3178	3496	**0.4**	1398	**13,984**

Lane Grp	Number of Through Lanes (N)	Number of Left Turn Lanes	Number of Right Turn Lanes	Total Number of Through Lanes	Type of Arterial	Area Type	Area Type Adjustment Factor (f_a)	Base Saturation Flow Rate (S_o)	Heavy Vehicle Adjustment Factor (f_{HV})	Saturation Flow Rate for Through Lanes (S)	Total Saturation Flow Rate	Effective Green Ratio (g_i/C)	Intersection Approach Hourly Capacity (C_A)	Intersection Daily Approach Capacity
	3	0	2	5	Principal	Urban	0.9	1900	0.90	4248	4531	0.55	2492	**24,919**
	3	0	2			Rural	1	1900	0.90	4514	4815	0.55	2648	**26,484**
	3	0	2		Minor	Urban	0.9	1900	0.90	4248	4531	0.45	2039	**20,389**
	3	0	2			Rural	1	1900	0.90	4514	4815	0.45	2167	**21,669**
	3	0	2		**Collector**	**Urban**	**0.9**	**1900**	0.99	4532	4834	**0.4**	1934	**19,338**
	3	0	2			**Rural**	**1**	**1900**	0.99	4817	5138	**0.4**	2055	**20,552**
N6	1	0	1	2	Principal	Urban	0.9	1900	0.90	1416	1557	0.55	857	**8,566**
	1	0	1			Rural	1	1900	0.90	1505	1655	0.55	910	**9,104**
	1	0	1		Minor	Urban	0.9	1900	0.90	1416	1557	0.45	701	**7,009**
	1	0	1			Rural	1	1900	0.90	1505	1655	0.45	745	**7,449**
	1	0	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	1433	1576	**0.4**	630	**6,305**
	1	0	1			**Rural**	**1**	**1900**	0.99	1523	1675	**0.4**	670	**6,701**
	2	0	1	3	Principal	Urban	0.9	1900	0.90	2832	2973	0.55	1635	**16,353**
	2	0	1			Rural	1	1900	0.90	3010	3160	0.55	1738	**17,380**
	2	0	1		Minor	Urban	0.9	1900	0.90	2832	2973	0.45	1338	**13,380**
	2	0	1			Rural	1	1900	0.90	3010	3160	0.45	1422	**14,220**
	2	0	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	2959	3107	**0.4**	1243	**12,429**
	2	0	1			**Rural**	**1**	**1900**	0.99	3145	3302	**0.4**	1321	**13,209**
	3	0	1	4	Principal	Urban	0.9	1900	0.90	4248	4389	0.55	2414	**24,141**
	3	0	1			Rural	1	1900	0.90	4514	4665	0.55	2566	**25,657**
	3	0	1		Minor	Urban	0.9	1900	0.90	4248	4389	0.45	1975	**19,752**

Lane Grp	Number of Through Lanes (N)	Number of Left Turn Lanes	Number of Right Turn Lanes	Total Number of Through Lanes	Type of Arterial	Area Type	Area Type Adjustment Factor (f_a)	Base Saturation Flow Rate (S_o)	Heavy Vehicle Adjustment Factor (f_{HV})	Saturation Flow Rate for Through Lanes (S)	Total Saturation Flow Rate	Effective Green Ratio (g_i/C)	Intersection Approach Hourly Capacity (C_A)	Intersection Daily Approach Capacity
	3	0	1			Rural	1	1900	0.90	4514	4665	0.45	2099	**20,992**
	3	0	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	4486	4635	**0.4**	1854	**18,540**
	3	0	1			**Rural**	**1**	**1900**	0.99	4767	4926	**0.4**	1970	**19,704**
N7	1	1	1	3	Principal	Urban	0.9	1900	0.90	1416	1982	0.55	1090	**10,902**
	1	1	1			Rural	1	1900	0.90	1505	2107	0.55	1159	**11,587**
	1	1	1		Minor	Urban	0.9	1900	0.90	1416	1982	0.45	892	**8,920**
	1	1	1			Rural	1	1900	0.90	1505	2107	0.45	948	**9,480**
	1	1	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	1480	2071	**0.4**	829	**8,286**
	1	1	1			**Rural**	**1**	**1900**	0.99	1573	2202	**0.4**	881	**8,806**
	2	1	1	4	Principal	Urban	0.9	1900	0.90	2832	3398	0.55	1869	**18,690**
	2	1	1			Rural	1	1900	0.90	3010	3612	0.55	1986	**19,863**
	2	1	1		Minor	Urban	0.9	1900	0.90	2832	3398	0.45	1529	**15,292**
	2	1	1			Rural	1	1900	0.90	3010	3612	0.45	1625	**16,252**
	2	1	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	2990	3588	**0.4**	1435	**14,354**
	2	1	1			**Rural**	**1**	**1900**	0.99	3178	3814	**0.4**	1526	**15,255**
	3	1	1	5	Principal	Urban	0.9	1900	0.90	4248	4814	0.55	2648	**26,477**
	3	1	1			Rural	1	1900	0.90	4514	5116	0.55	2814	**28,140**
	3	1	1		Minor	Urban	0.9	1900	0.90	4248	4814	0.45	2166	**21,663**
	3	1	1			Rural	1	1900	0.90	4514	5116	0.45	2302	**23,023**
	3	1	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	4532	5137	**0.4**	2055	**20,546**
	3	1	1			**Rural**	**1**	**1900**	0.99	4817	5459	**0.4**	2184	**21,836**

Lane Grp	Number of Through Lanes (N)	Number of Left Turn Lanes	Number of Right Turn Lanes	Total Number of Through Lanes	Type of Arterial	Area Type	Area Type Adjustment Factor (f_a)	Base Saturation Flow Rate (S_o)	Heavy Vehicle Adjustment Factor (f_{HV})	Saturation Flow Rate for Through Lanes (S)	Total Saturation Flow Rate	Effective Green Ratio (g_i/C)	Intersection Approach Hourly Capacity (C_A)	Intersection Daily Approach Capacity
N8	1	2	1	4	Principal	Urban	0.9	1900	0.90	1416	2407	0.55	1324	**13,238**
	1	2	1			Rural	1	1900	0.90	1505	2558	0.55	1407	**14,070**
	1	2	1		Minor	Urban	0.9	1900	0.90	1416	2407	0.45	1083	**10,831**
	1	2	1			Rural	1	1900	0.90	1505	2558	0.45	1151	**11,512**
	1	2	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	1495	2542	**0.4**	1017	**10,167**
	1	2	1			**Rural**	**1**	**1900**	0.99	1589	2701	**0.4**	1081	**10,806**
	2	2	1	5	Principal	Urban	0.9	1900	0.90	2832	3823	0.55	2103	**21,026**
	2	2	1			Rural	1	1900	0.90	3010	4063	0.55	2235	**22,346**
	2	2	1		Minor	Urban	0.9	1900	0.90	2832	3823	0.45	1720	**17,203**
	2	2	1			Rural	1	1900	0.90	3010	4063	0.45	1828	**18,283**
	2	2	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	3021	4079	**0.4**	1632	**16,316**
	2	2	1			**Rural**	**1**	**1900**	0.99	3211	4335	**0.4**	1734	**17,341**
	3	2	1	6	Principal	Urban	0.9	1900	0.90	4248	5239	0.55	2881	**28,813**
	3	2	1			Rural	1	1900	0.90	4514	5568	0.55	3062	**30,623**
	3	2	1		Minor	Urban	0.9	1900	0.90	4248	5239	0.45	2357	**23,574**
	3	2	1			Rural	1	1900	0.90	4514	5568	0.45	2505	**25,055**
	3	2	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	4532	5590	**0.4**	2236	**22,359**
	3	2	1			**Rural**	**1**	**1900**	0.99	4817	5941	**0.4**	2376	**23,763**
N9	1	1	2	4	Principal	Urban	0.9	1900	0.90	1416	2124	0.55	1168	**11,681**
	1	1	2			Rural	1	1900	0.90	1505	2257	0.55	1241	**12,415**
	1	1	2		Minor	Urban	0.9	1900	0.90	1416	2124	0.45	956	**9,557**

Lane Grp	**Number of Through Lanes (N)**	**Number of Left Turn Lanes**	**Number of Right Turn Lanes**	**Total Number of Through Lanes**	**Type of Arterial**	**Area Type**	**Area Type Adjustment Factor (f_a)**	**Base Saturation Flow Rate (S_o)**	**Heavy Vehicle Adjustment Factor (f_{HV})**	**Saturation Flow Rate for Through Lanes (S)**	**Total Saturation Flow Rate**	**Effective Green Ratio (g_i/C)**	**Intersection Approach Hourly Capacity (C_A)**	**Intersection Daily Approach Capacity**
	1	1	2			Rural	1	1900	0.90	1505	2257	0.45	1016	**10,157**
	1	1	2		**Collector**	**Urban**	**0.9**	**1900**	0.99	1495	2243	**0.4**	897	**8,971**
	1	1	2			**Rural**	**1**	**1900**	0.99	1589	2384	**0.4**	953	**9,534**
	2	1	2	5	Principal	Urban	0.9	1900	0.90	2832	3540	0.55	1947	**19,468**
	2	1	2			Rural	1	1900	0.90	3010	3762	0.55	2069	**20,691**
	2	1	2		Minor	Urban	0.9	1900	0.90	2832	3540	0.45	1593	**15,929**
	2	1	2			Rural	1	1900	0.90	3010	3762	0.45	1693	**16,929**
	2	1	2		**Collector**	**Urban**	**0.9**	**1900**	0.99	3021	3777	**0.4**	1511	**15,107**
	2	1	2			**Rural**	**1**	**1900**	0.99	3211	4014	**0.4**	1606	**16,056**
	3	1	2	6	Principal	Urban	0.9	1900	0.90	4248	4956	0.55	2726	**27,256**
	3	1	2			Rural	1	1900	0.90	4514	5267	0.55	2897	**28,967**
	3	1	2		Minor	Urban	0.9	1900	0.90	4248	4956	0.45	2230	**22,300**
	3	1	2			Rural	1	1900	0.90	4514	5267	0.45	2370	**23,701**
	3	1	2		**Collector**	**Urban**	**0.9**	**1900**	0.99	4532	5288	**0.4**	2115	**21,150**
	3	1	2			**Rural**	**1**	**1900**	0.99	4817	5620	**0.4**	2248	**22,479**

Table 29 Calculated Capacities for Ramps

	Speed	Ideal Capacity (Ex 13-10)	Speed Adjustment	V/C	PHF	Capacity	Daily Capacity
Urban	>50	2,100	1.00	0.9	0.800	1,512	15,120
	>40-50	2,100	0.95	0.9	0.800	1,443	14,433
	>30-40	2,100	0.91	0.9	0.800	1,375	13,745
	>=20-30	2,100	0.86	0.9	0.800	1,306	13,058
	<20	2,100	0.82	0.9	0.800	1,237	12,371
Rural	>50	2,200	1.00	0.9	0.868	1,719	17,186
	>40-50	2,200	0.95	0.9	0.868	1,641	16,405
	>30-40	2,200	0.91	0.9	0.868	1,562	15,622
	>=20-30	2,200	0.86	0.9	0.868	1,484	14,843
	<20	2,200	0.82	0.9	0.868	1,406	14,062