TRAVEL DEMAND MODEL UPDATE FOR THE BASE YEAR 2021

PREPARED FOR FM METRO COG

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1. INTRODUCTION

The Fargo Moorhead MPO's (The F-M MPO) Travel Demand Model (TDM) is updated every five years to replicate new data and the advancements in state-of-the-art transportation modeling methods and techniques. The original timeline for the current model was set for 2020. However, due to COVID-19, travel patterns changed because of travel restrictions and work-from-home policies. Therefore, instead of 2020, the current model update reflects 2021 base year data. The four-step TDM includes trip generations, trip distributions, modal split, and trip assignment was used for developing the model. The model update process involves the calibration of model input parameters and validation of model output with ground truths. The calibration of the model is a cyclical process as shown in Figure 1.

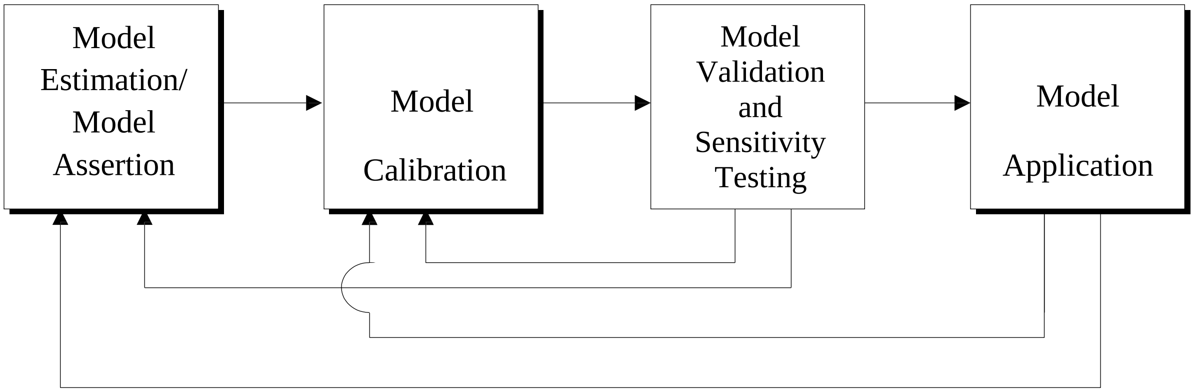

Figure 1 F-M TDM Calibration Flow Chart

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 2021 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 2021 TDM

For the 2021 base year model, several updates were made to reflect the availability of new and improved data, new and advanced methods in modeling software, and the modeling for long-haul freight movements as part of the model. New data that was used for the 2021 model update included: Origin Destination Data (obtained from Streetlight), the traffic analysis tool data, and incorporation node delays based on real data from Streetlight Data.

2.1.Origin Destination Data Obtained from Streetlight

Origin-destination (OD) data were obtained from a commercial vendor Streetlight. Streetlight uses data of millions of people country wide to develop mobility patterns of road users using their cellular data anonymously. They provide several analysis tools on their online interface to produce estimated data on AADT, VMT, turning movement counts, OD data, trip speed, demographic data, mode of travel, trip attributes (i.e., travel time, length), and proportion of purpose of trips (HBW, NHB, HBO) for any specified period ranging 15 minutes to yearly data. In the previous 2015 TDM OD data for a predefined attribute was obtained such as a fixed number of TAZs. However, Streetlight's online interface allowed us to change the size and number of TAZs for a better understanding of OD data. Due to privacy concerns, Streetlight analysis comes with some limitations such as the size of any TAZ cannot be small enough to reveal the identity and demographic information of the household. In such a case, a team from Streetlight reviewed the TAZ size and location to allow the users to run the analysis. Figure 2 shows the Streetlight analysis boundary to create TAZs of any size and shape for the analysis mentioned above.

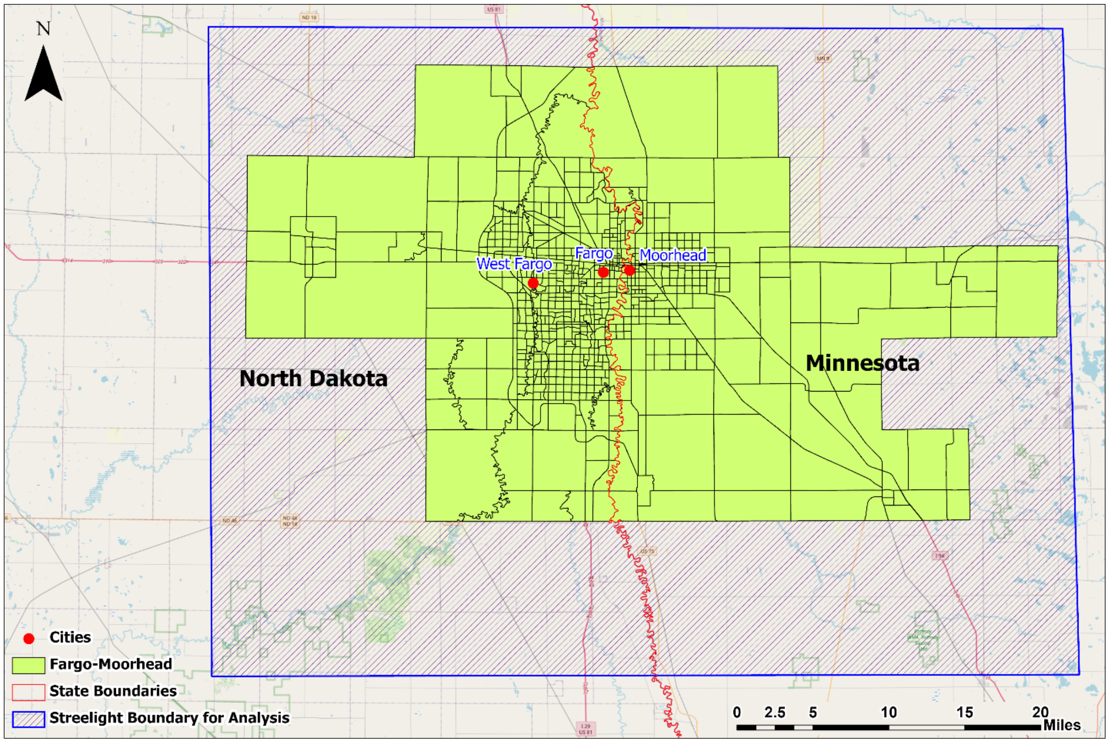

Figure 2 OD TAZs

Different datasets were estimated using Streetlight including the following: :

1. Three matrices each for weekdays, weekends, and all days were estimated showing OD trips separately for HBW, HBO, and NHB purposes.
2. Hourly OD trips were estimated for each trip's purposes including Home Based work (HBW), Home-based order (HBO), and Non-Home-Base (NHB) purposes, which were further divided into 15-minute time bins to identify the peak hour.
3. Daily trips were divided into four time periods to differentiate between peak hour trips and off-peak-hour trips. 7 AM to 9 AM was selected as AM peak hours, 3 PM to 6 PM was selected as PM peak hours, a time bin between 9 AM and 3 PM was selected as AM off-peak hours and the time between 6 PM and 7 AM is selected as PM off-peak hours.
4. Trips were estimated for the month of October 2021, this is because all the traffic data used for calibration of the TDM was also from October 2021.
5. The data was estimated separately for private vehicles and trucks. Further, long-distance OD trips were also estimated to reflect internal-external, external-internal, and external-external trips. These trips were processed separately for HBW, HBO, and NHB in the case of private vehicles, and in case of fright traffic, trips were analyzed as NHB trips.
6. Additional analyses were also carried out on Streetlight to estimate the node delays for different types of intersection controls i.e., signalized intersections and stop signs.

2.1.1. Internal-Internal OD Trip Summary

Table 1 shows the trip purposes by time of day for AM Peak, AM Off-Peak, PM Peak, and Night trips for the data collected from streetlight. For HBW trips AM Peak, PM Peak, AM off-Peak and Night had the proportions of 22.8%, 27.2%, 26%, and 24.1% respectively. Similarly, for HBO trips Night trips had the highest proportion of 36.4% trips, followed by the PM Peak (27.9%), AM Off-Peak(26.8%), and AM Peak (8.9%). This is expected and possibly because fewer non-work trips originate from homes during the morning peak period. The AM Off-Peak (9 AM to 3 PM) had the highest proportion of NHB trips (47%), followed by the PM Peak (25.4%), Night time (19%), and AM Peak (9%).

The % overall column reflects the percentage of trips that had at least one end in the Fargo Moorhead MPO area for the entire dataset. It can be seen that 26% of HBW, 39 % of HBO, and 35% of NHB, of total trips in the overall Internal-Internal trips in the F-M MPO area.

Table 1 Summary of Internal-Internal OD Data from Streetlight Analysis

Fargo - Moorhead MPO TAZ OD Trips

Purpose	7-9 AM	9 AM-3 PM	3-6 PM	Night	Total	% of Overall
HBW	39,728	45,341	47,523	42,004	174,596	26%
HBO	23,478	73,547	70,553	95,805	263,383	39%
NHB	21,423	59,355	108,886	44,351	234,015	35%
Total	84,629	178,243	226,962	182,160	671,994	100%

Proportions by Trip Purpose and Time of Day, F-M MPO TAZ Only

Purpose	7-9 AM	9 AM-3 PM	3-6 PM	Night	Total	% of Overall
HBW	22.80%	27.20%	26.00%	24.10%	100%	26%
HBO	8.90%	26.80%	27.90%	36.40%	100%	39%
NHB	9.00%	47.00%	25.40%	19.00%	100%	35%

NCHRP 718 Time-of-day Distributions by Purpose

Purpose	7-9 AM	9 AM-3 PM	3-6 PM	Night	Total
HBW	26.00%	21.10%	21.70%	31.20%	100%
HBO	7.30%	31.60%	24.90%	36.20%	100%
NHB	7.00%	45.70%	26.00%	21.90%	100%

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

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. Overall, IE/EI trips made up 8.1% of the total trips for the F-M MPO OD study area. For HBW trip purposes, the EI/IE trips are 13% of the total trips and ranged from 16.1% to 32.7% for the different periods. For HBO trips, the IE/EI made up 34% of total trips and ranged from 10.3% to 38.5% for the different periods. The NHB trips for IE/EI where 22.3% of the total F-M NHB trips and ranged from 9.6% to 43.9% for the different periods. Overall, most of the IE/EI trips were made between 9 AM to 3 PM.

Table 2 IE and EI Trips from OD Data for the F-M MPO Area

IE Trips Total

Purpose	7-9 AM	9 AM-3 PM	3-6 PM	Night	Total
HBW	3,567	2,275	3,688	4,626	14,155
HBO	3,532	8,859	8,668	13,168	34,226
NHB	5,010	22,946	12,179	12,105	52,240
Total	12,109	34,079	24,535	29,898	100,621

Percentage of IE Trips to Total Trips for F-M Area

Purpose	7-9 AM	9 AM-3 PM	3-6 PM	Night	Total
HBW	25.2%	16.1%	26.1%	32.7%	14.1%
HBO	10.3%	25.9%	25.3%	38.5%	34.0%
NHB	9.6%	43.9%	23.3%	23.2%	51.9%
Total	12.0%	33.9%	24.4%	29.7%	100%

2.1.3. External-External OD Data

External-External (EE) OD data shows the trips that pass through the F-M MPO area without stopping. Only external TAZs were selected for analysis in StreetLight. Similar to internal trips the analysis was carried out to estimate the EE OD trips for 4 time bins i.e., AM Peak, PM Peak, AM Off-Peak, and PM Off-Peak.

Table 3 shows the percentages of EE trips that pass through the F-M 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/IE trips. Overall, EE trips made up about 9% of total EE and EI/IE trips. This was a little lower than the typically used 10-12% through trip percentages.

The percentage of EE-only trips ranged from 15% for the PM Peak period to 39% for the late-morning to early-afternoon period. For HBW, the majority of trips occurred during the Night period (37%) with the least amount of trips occurring during the PM Peak period. For HBO trips, the pattern is similar to the HBW trips with 38% of trips occurring at night and 16% of trips occurring during the AM Peak period. For NHB trips, the late-morning to early-afternoon period had the highest percentage of trips (45%) followed by the AM Peak period (25%), Night periods (16%), and PM Peak (14%).

Table 3 EE Trips from OD Data

EE Trips Passing through F-M MPO					
Purpose	**7-9 AM**	**9 AM-3 PM**	**3-6 PM**	**Night**	**Total**
HBW	21	20	19	36	96
HBO	237	460	230	563	1,489
NHB	691	1,212	388	429	2,719
Total	948	1,692	637	1,027	4,304
Percentage of EE Trips Passing through F-M MPO					
Purpose	**7-9 AM**	**9 AM-3 PM**	**3-6 PM**	**Night**	**Total**
HBW	22%	21%	20%	37%	100%
HBO	16%	31%	15%	38%	100%
NHB	25%	45%	14%	16%	100%
Total	22%	39%	15%	24%	100%
Percentage of EE Trips to Total EE/EI Trips					
Purpose	**7-9AM**	**9AM-3PM**	**3-6PM**	**Night**	**Total**
HBW	2%	1%	2%	2%	2%
HBO	7%	9%	8%	9%	9%
NHB	14%	12%	9%	11%	12%
Total	10%	10%	8%	9%	9%

2.1.4. Use of StreetLight OD Data in the TDM

The OD data from StreetLight 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. The OD data from StreetLight was stratified into 24-hour periods, which helped to identify the peak hour and off-peak hour time periods for our model. 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 different trip types (II/IE/EI and EE trips). 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. Daily trips of each purpose (HBW, HBO, and NHB) for F-M MPO TDM are divided into four time periods i.e., AM peak hours, PM peak hours, AM off-peak hours, and PM off-peak hours.

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 origins and destination of each trip. For the F-M MPO TDM, the gravity model was used to distribute trips. 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”) as input. The K-factor is used to account for the effects of variables other than travel impedance in the model. The OD data from StreetLight were used to develop K-factor matrices imputed in the trip gravity model that were used for distributing trips for each period and purpose.

2.1.5. Shortcomings and Limitations of the OD Data from StreetLight

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

1. The results from StreetLight are sensitive to analysis settings. this includes the size and shape of TAZs too. Therefore, multiple OD estimation analyses were run the one giving the most rationale results was selected.
2. The results from StreetLight also include intrazonal trips, therefore, the output results were cleaned to exclude trips with origin and destination within the same zone. The visualization within the StreetLight module allows one to toggle between options of excluding or including trips when the origin TAZ number is equal to the destination TAZ number, however, the output in the excel format includes intrazonal trips.
3. The output from StreetLight is in the form of raw data which needs further processing to develop a K-factor matrix for its use in the trip distribution step.
4. All vehicles' ADT and trucks' ADT were not accurate for some links when compared with actual counts.

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 traverse 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 examines roadway elements under uniform traffic, roadway, and control conditions."

NCHRP 716 defined on the other hand "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 types of MPOs outside of North Dakota (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 4 summarizes the literature review used in different MPO planning models for capacity calculations.

Table 4 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 the 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 an 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 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 that 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 an 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 fewer 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	The model computes link capacities at run time. Capacities are initially based on functional class and number of lanes, adjusted

MPO (CAMPO)-MO, 2013	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 the Chattanooga model will be implemented using an equation that 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 the 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 Central 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 highway link: 1. Intersection and mid-link Hourly basis Time category Factored Future ramp metering improved the capacity growth by 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 the 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, which 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 3 shows the comparison of the base 2021 F-M 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 2021 F-M model. For ramps, the capacities for other MPO areas were typically lower in comparison to the 2021 F-M 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, the reason why their capacities were higher.

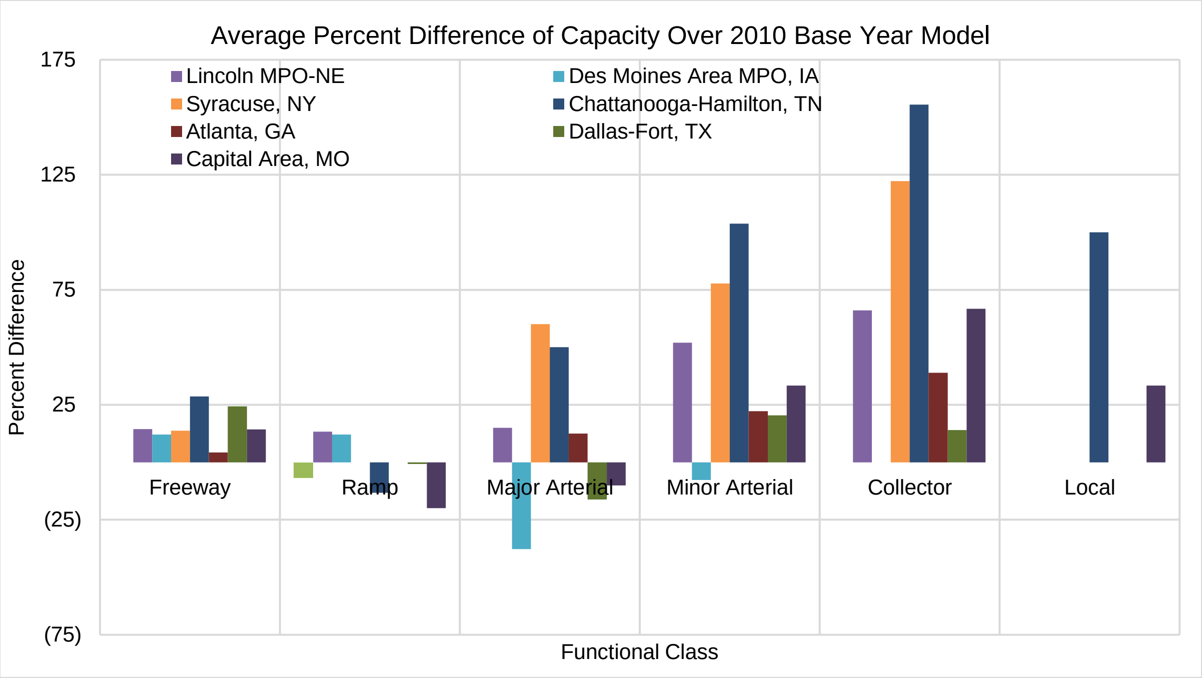

Figure 3 Capacity Comparisons to Fargo Moorhead MPO 2021 Base Year Model

For the 2021 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 2021 model were slightly different from the 2010 models and represent the state-of-the-art 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 2021 network, lane groups are defined by the Attribute Linkgrp1. Table 5 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 5. For example, if Linkgroup1 for a link was 20, it meant that the 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 5 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 a single exclusive right turn lane
N9	N through lanes, two exclusive right turn lanes, and a 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 lane group 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 parameters can potentially be used to estimate capacities. 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 the traffic stream

f_g = Adjustment factor for approach grade

f_p = Adjustment factor for the 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 the 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 shown next:

1. Base Saturation Flow Rate, S_O

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

2. Adjustment Factor for Lane Width, f_W

Using HPMS lane adjustment factors directly Table 9 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 = 2.0 passenger car equivalents

4. Adjustment for Grade, f_g

Due to a 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 a group

N_m = Number of parking maneuvers per hour (6 for two-way streets with parking on one side, 12 for two-way streets with parking on both sides or one-way streets with parking on 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 the non-availability of bus route data, f_{bb} is set to 1.0. Also, the 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}

An 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 the HPMS procedure due to the 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 the 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 follows 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, the follow-up time for each movement, and percent heavy vehicles as input parameters. Equation 6 is 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 6.

$t_{c,\,HV}$ = 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 6 and Table 7 show the default values that were used for calculating the potential capacities for stop-controlled intersections in the model.

Table 6 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 7 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,

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

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

Table 8 shows the different equations that are used to calculate the approach capacity for each lane group as described previously for stop-controlled intersections.

Table 8. 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	$C_A = N_T \times C_{p,SH(LT+T)} + N_{RT} + C_{p,RT}$
3	Shared RT + T lane; exclusive LT lane	$C_A = N_T \times C_{p,SH(RT+T)} + N_{LT} + C_{p,LT}$
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
$C_{p,SH}$ = The 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 detail 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 9 shows the adjustment factors for lane width. This value was set as zero since it was assuming the interstate where all 12 feet. However, if different widths exist, the values should be adjusted accordingly.

Table 9 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 10 shows the adjustment factors for right shoulder clearance. The model assumed a right shoulder clearance of greater than 6 ft. 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 10 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 11 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 11 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 12 details the adjustment factors used for adjusting freeway capacities based on the number of lanes.

Table 12 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

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

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

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 was 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 the maximum service flow rate;

C is the 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 the peak hour factor.

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

4. MODEL INPUT DATA

The main course of data that is used as input to the TDM are the road network, network-associated features such as nodes with information on traffic controls at intersections, and socioeconomic data. These 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 that represent the roadway, nodes that represent intersections, centroids that are the trip origin/destination points for transportation analysis zones (TAZ), and external centroids that 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 13 shows the percentage of centerline miles by functional class.

Table 13 Centerline Miles Distribution by Functional Classification

Functional Class	Centerline Miles	Percentage
Interstate	168.40738	14.68%
Major	80.123891	6.98%
Minors	224.599732	19.58%
Collectors	443.035333	38.62%
Locals	159.973842	13.95%
Ramps	49.120327	4.28%
Unpaved	21.851634	1.90%

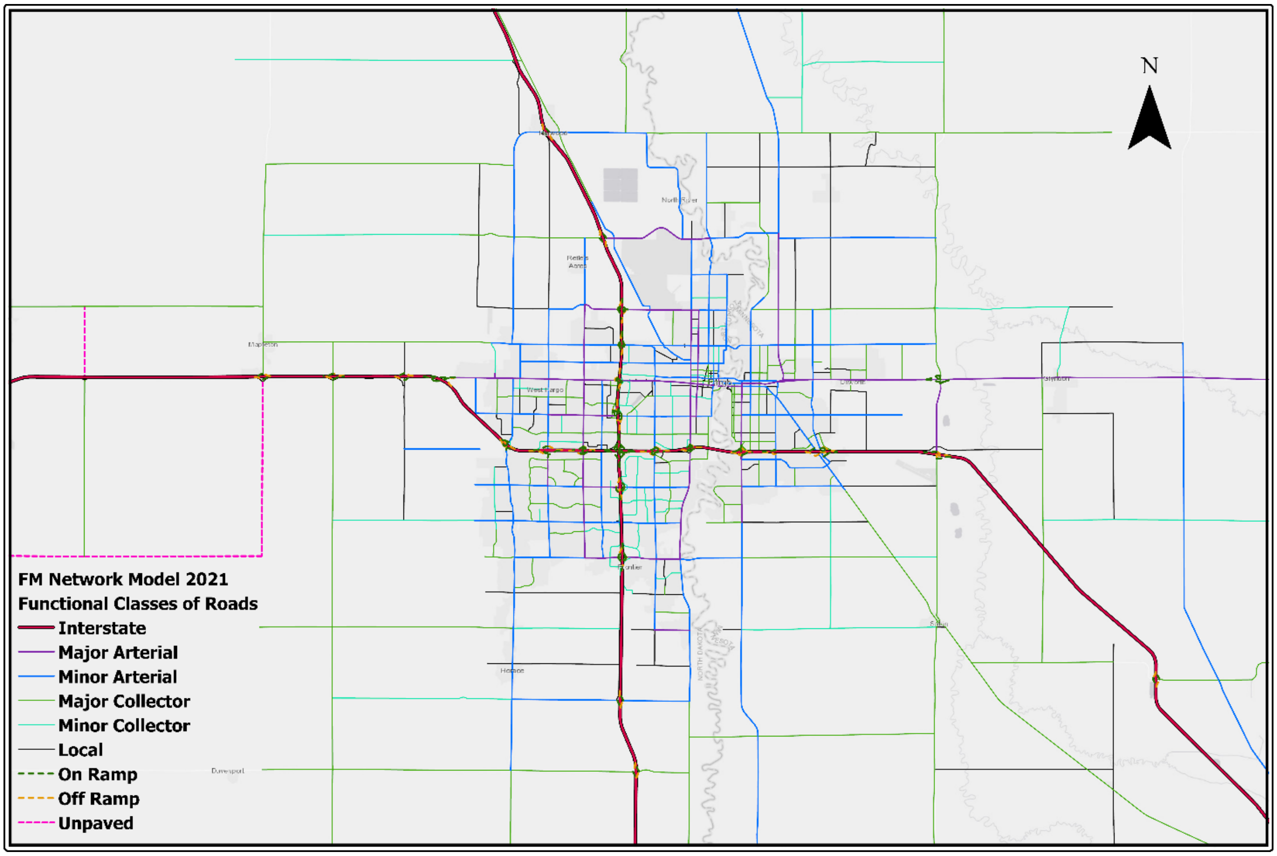

Figure 4 F-M 2021 Model Network

Figure 4 shows the modeled network distribution by functional class. Centroid connectors are not included in the network.

Intersection controls were added to the model to incorporate delays experienced by road users. 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 5.

The intersection control delays were identified through Streetlight using an analysis called “Segment Analysis”. Node delays to replicate the type of traffic control used were estimated separately for each road class. For example, Signal control delays on minor arterials, major arterials, minor collectors, major collectors, and local roads were estimated separately. The analysis was repeated for each of the types of signal control and roadway classes having different speeds. A total of 433 samples were used to identify delays. These delays were then incorporated into the network travel time calculation to improve the accuracy of the model.

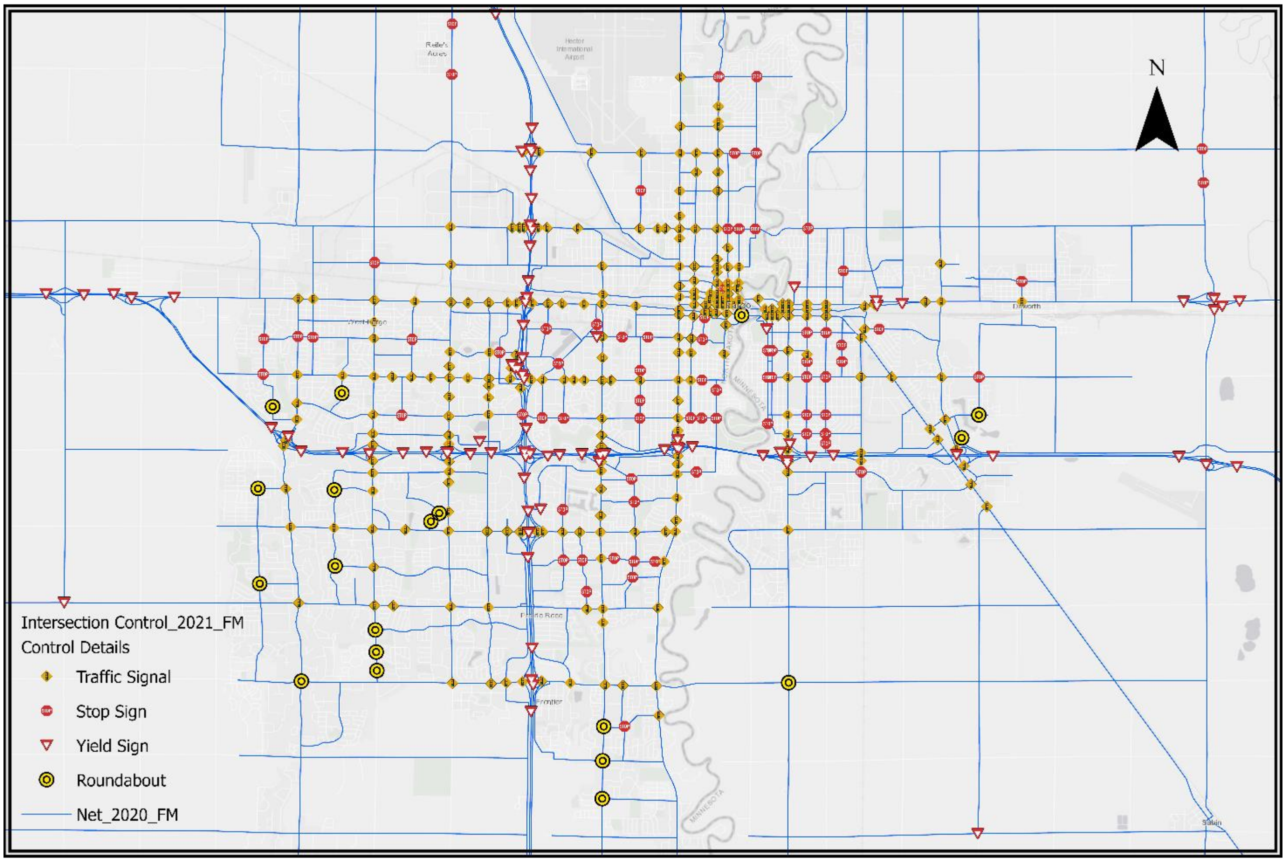

Figure 5 Intersection Data Used in Mode

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:

In 2015, there were a total 722 internal TAZs used for the 2015 model. In 2021, large-scale changes were made to 2015 TAZs (split or merged) based on input from both the MPO that also took into account the Diversion impacts. After modifications, the final number of internal TAZs used in the model is 809.

4.2.2. Socioeconomic Data TAZ Attributes

Data was provided by MPO to ATAC from the source “Data Axle”. The first goal was to identify the deficiencies and errors in the households and jobs data set and then the updated data set is assigned to traffic analysis zones (TAZ) developed for the travel demand model for the base year. Various other datasets required to complete the travel demand modeling were also provided such as TAZ (later modified by ATAC), traffic counts, etc.

4.2.3. Addition of Data Axle Data to TAZ Data

Data was provided in MS excel format along with the “Dictionary” for details of variables given in the excel sheets. There were two different files each for household data and job data. In each file, latitude and longitude coordinates were also provided. These coordinates were used to plot the data on a map. The spatial Join tool is used to assign the data to each TAZ in which the point was placed.

4.2.3.1. Household Data

The household data file was comprised of thirty different fields such as address details, city, county, state, zip code, population, etc. However, the attributes of interest available in the data were the number of members in the household, income details, and age details. One important attribute “age of household members” was missing for both Cass and Clay counties.

4.2.3.2. Jobs Data

Jobs data was provided for both counties (Cass in ND and Clay in MN) comprised in TAZs. In total, there were 85 fields in the data table file. NAICS codes were used to identify different types of jobs such as manufacturing, construction & and resources, retail, service, agriculture, wholesale trade, transportation utilities, and education.

4.2.4. Validating 2021 TAZ Jobs and Household Data

Validating the data is critically important because the accuracy of the final travel demand model results relies on the input data. Socioeconomic data was provided for Cass County (Fargo, South Fargo, and West Fargo city), which was assigned to new TAZs. Out of 809 TAZs, 558 TAZs are with in Cass County, and out of 44 census tracts, TAZs fully cover 40 census tracts and partially cover 3 census tracts (on the city boundary at northwest, southwest, and west side of Fargo; tract number 402,403 and 406).

The data for household was divided into 5 groups i.e., 1-person household, 2-person household, 3-person household, 4-person household, and households of 5 and more than 5. Four income levels were created to distribute data. Under $20,000 to $29,999, $30,000 to $49,999, $50,000 to $99,999, and $100,000 to $500,000 and above are the four income groups in which data is distributed. Cross-classification tables are also created for each category of the number of households group with the income level group. A sample is provided in Table 14:

Table 14: Sample of Household Data

TAZ_2021	1PPHHInc 1	1PPHHInc 2	1PPHHInc 3	1PPHHInc 4	…	5PPHHInc 3	5PPHHInc 4	Total # of Households
1	0	1	7	1	…	1	3	50
. .	. .	. .	. .	. .	… …	. .	. .	.
808	0	1	7	1	…	0	0	30
809	0	0	0	0	…	0	0	0

4.2.5. Household Data Validation

Most of the boundaries of TAZs are aligned with census tracts, therefore accuracy of data assigned to TAZs was checked by comparing the number of housing units and population with US census data. Though block level accuracy can provide a more accurate comparison, however, due to irregular boundaries and boundaries of census blocks shared by multiple TAZs, block level accuracy check was not adopted. There were 6 census tracts (3 in Cass County and 3 in Clay County) that were not fully bound by the TAZs' boundaries, therefore areas of those six census tracts were clipped so only population from census blocks that come within TAZs' boundaries be considered for analysis.

Data Axle shows that the total number of dwelling units (comprising single person to multiple families) is 106,927 contrasting which, there were 108,172 dwelling units in the data of census tracts. Out of these 108,172 dwelling units, 99,958 (92.41%) are occupied and 8,214 (7.59%) are vacant.

When Data Axle's number of dwelling units and the total number of dwelling units available from census data were compared, there were 1245 (1.15%) fewer dwelling units in the Data Axle source. The minimum difference (Data Axle minus Census data) is 614 for census tract number 30107 and the maximum difference (Data Axle minus Census data) of -1193 is observed in census tract 40700. 40700 tract is the area between 32 Ave. SW and I-94 are shown in Figure **6** and Figure **7** respectively.

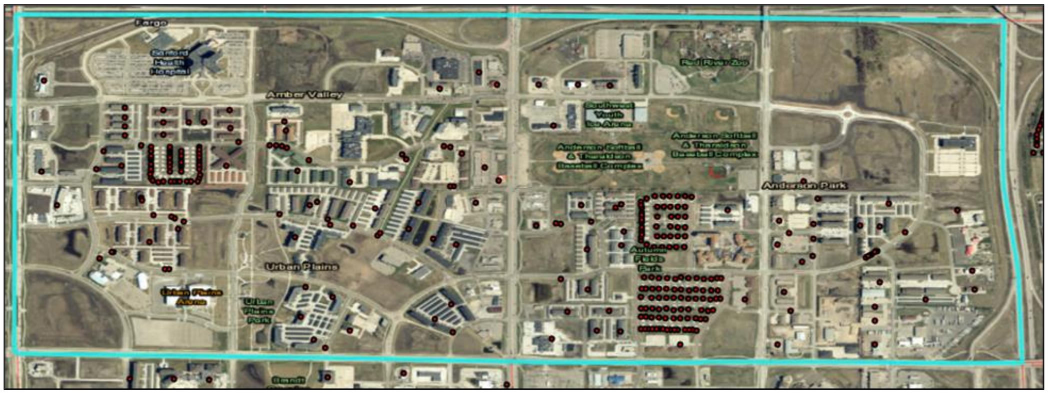

Figure 6: Satellite Image showing missing point data of residential buildings in census tract 40700

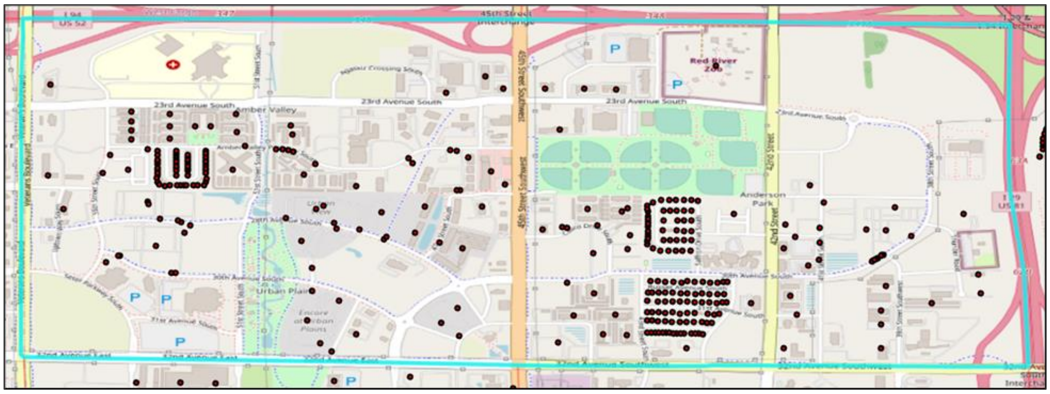

Figure 7: Map showing missing point data of residential buildings in census tract 40700

Results from both data sets show that tract 40502 has the highest number of houses (Census data: 3730, Data Axle: 3731). It was further found that there were significant data points having discrepancies in an exact location both in Cass and Clay County, and many of the data points in Data Axle were based on P.O. box addresses. Most of these P.O. box addresses were located in a single location and in some cases in commercial buildings. For example, a total of 36 P.O. box addresses along with demographic details of each household were provided in the data (Data Axle) at coordinate “46.648437, 97.018417”. When the coordinate was coded on a map, it was found that there is a USPS office at that location having an address “472 Elm St, Kindred, ND 58051”.

4.2.6. Geocoding of Data Axle Household Data

After random manual checks on Google, it was identified that many addresses were placed at the wrong locations (at a considerable distance from actual houses’ building location or in the middle of the streets), therefore, to improve accuracy Geocoding was carried out using ArcGIS Pro. After geocoding, a total of 103,913 household data points were placed on the map. The same census tract 40700 presented in Figure **7** is presented in Figure **8** again with Geocoded data.

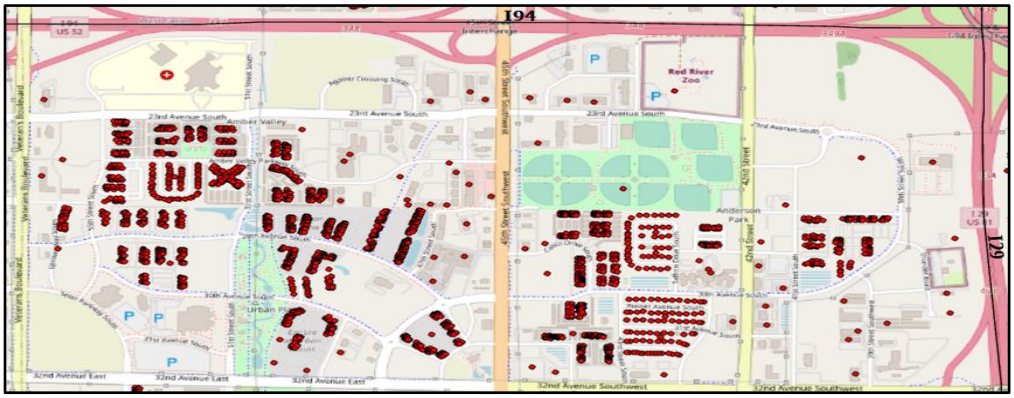

Figure 8: Map showing Geocoded data of residential buildings in census tract 40700

4.2.7. Adjustments of Geocoded Data Axle Household Data

Missing data points were mostly found in multifamily households. Keeping Census data as a reference, adjustment data points were generated for each census block where Data Axle households were less than census data in each census block. The demographic data of adjustment points were generated based on the average demographic data of the census block for which the new point was generated. Census blocks where the number of households was higher than the census data were manually checked. All such census blocks are present at locations which either situated on the peripheries of populated areas or where new home construction is being in progress such as the area near the west of “38th St S” opposite of Walmart in South Fargo. Similarly, many new houses were built in “Horace” in the vicinity of “Prairie Ave” after the 2020 census survey. Socio-demographic data for each adjustment data record was based on the average proportion of available households within each TAZ.

4.2.8. Final Adjusted Household Data

After adjustments of multistory residential buildings, 109,997 households were obtained which is 1.68% higher than the households recorded in census data. The heat density map showing the number of households in TAZs is presented in Figure **9**.

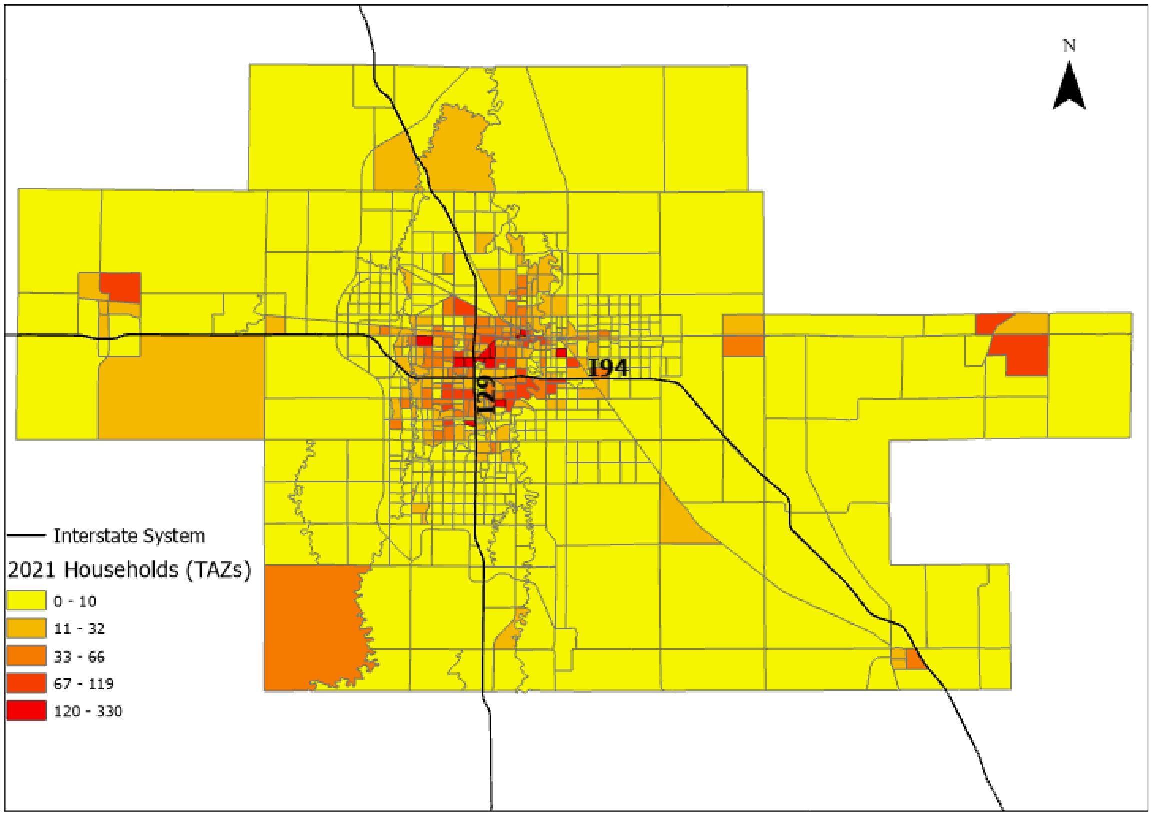

Figure 9: Final Households in FM TAZs in 2021

4.2.9. Jobs Data Validation

A separate data file in MS Excel format was provided by MPO from the source “Data Axle” having job data. All jobs are divided into 7 subcategories based on national North American Industry Classification System (NAICS) codes:

1. Manufacturing (NAICS: 31-33)
2. Construction and Resources (NAICS: 21, 23)
3. Retail (NAICS: 44-45)
4. Service (NAICS: 51,52,53,55,56,56,62,71,81,99)
5. Agriculture (NAICS: 11)
6. Wholesale Trade, Trans Utilities (NAICS:22,42,48-49)
7. Education (NAICS: 61)

The summary of categorized jobs data assigned to all TAZs is shown in Table **15**:

Table 15: Summary of Jobs in FM Metro COG Area Before Adjustments

Jobs Category	Manufacturing Jobs	Construction and Resources Jobs	Retail Jobs	Service Jobs	Agriculture Jobs	Wholesale Trade and Transportation Utilities Jobs	Education Jobs
Number of Jobs	10034	9206	21804	97892	572	13212	14599
Total Jobs	167504						

4.2.9.1. Comparison to 2015 Data

To make sure that there is no error in the data, Data Axle data was compared with the 2015 jobs data that was used in the 2015 travel demand model. The comparison was carried out in two levels i.e., at census tract level and TAZs level. Validation of Major Employers and Special Generators

Difference in total number of jobs for each census tract was identified for each subcategory (business or facility type) of jobs. Census tracts showing a significant increase or decrease in the number of jobs were investigated to check the accuracy and to develop a rationale for understanding. For example, during the COVID-19 period, many of the restaurants and hotels were either closed or reduced their employees. Similarly, those businesses that caused significant increases in the number of jobs were identified and most of such jobs fall into the service jobs category.

4.2.9.2. Final Adjusted Jobs Data

A detailed review of jobs data resulted in a reduction of 10663 jobs. This was mainly because of the duplication of employees listed in the data. For example, in the case of hospitals, the total number of employees was provided but then data of many doctors working in the same hospitals were repeated. Repeated data point errors were adjusted by manual deletion in ArcGIS to achieve high accuracy in the data. The final adjusted jobs data summary is provided in **Table 10**. A comparison of Jobs data for 2021 with jobs data for 2015 is provided in Table 16 and a heatmap showing total jobs in FM TAZs is shown in Figure 10:.

Table 16: Summary of Jobs in FM Metro COG Area After Adjustments

Jobs Category	Manufacturing Jobs	Construction and Resources Jobs	Retail Jobs	Service Jobs	Agriculture Jobs	Wholesale Trade and Transportation Utilities Jobs	Education Jobs
Number of Jobs	9965	9065	21651	88488	572	13166	13934
Total Jobs After Review Process and Adjustments	156841						

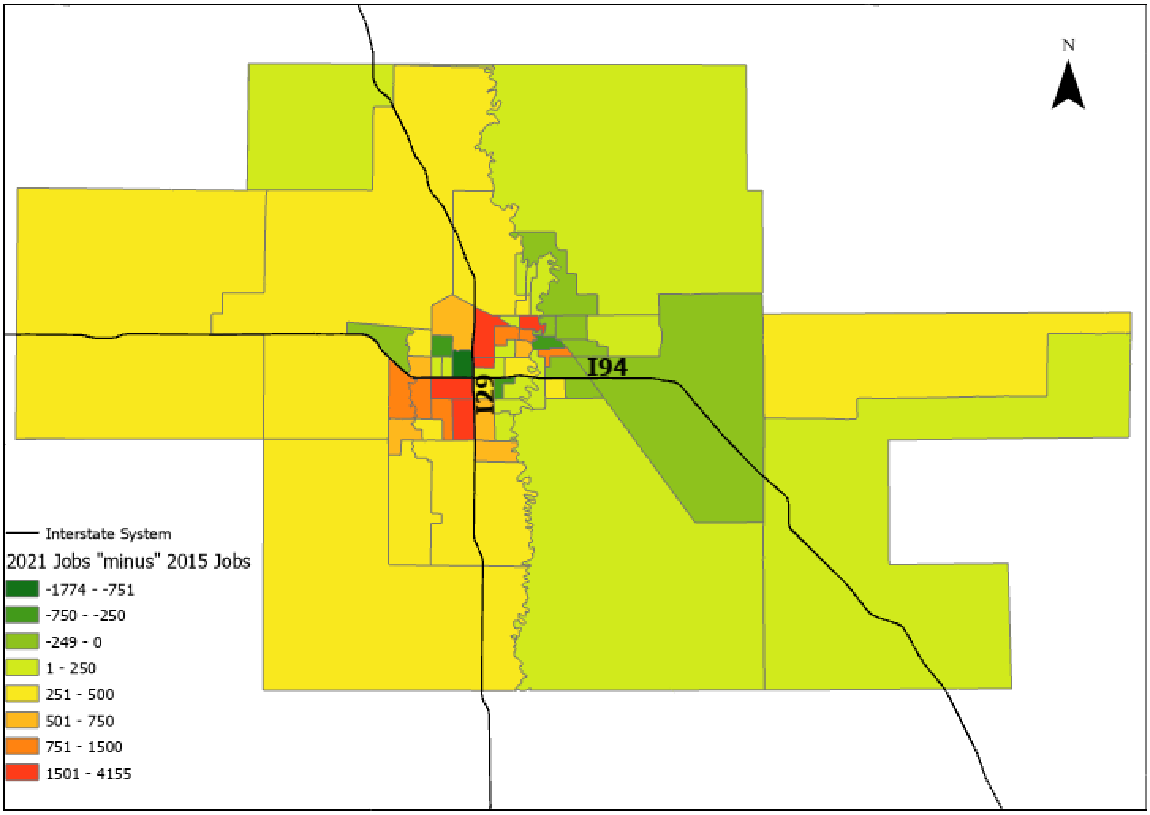

Figure 10: Comparison of 2021 Jobs with 2015 Jobs (2021 minus 2015 Jobs)

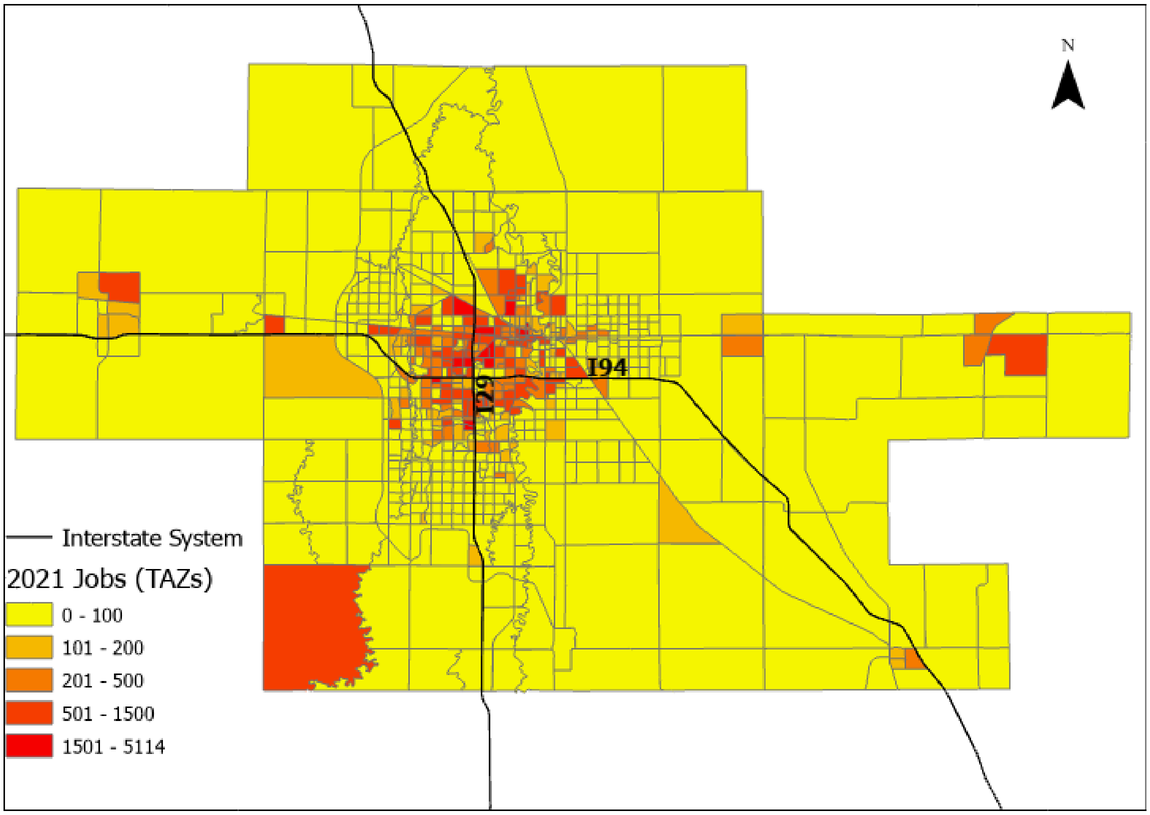

Figure 11: Final Jobs in FM TAZs in 2021

4.2.9.3. Additional Data for TDM

Another set of data obtained from official internet sources (i.e., North Dakota Department of Public Instruction, Minnesota IT Services) is schools' enrollments. School enrollments were stratified into the following categories:

1. Elementary School Enrollments
2. Middle School Enrollments
3. High School Enrollments
4. Private School Enrollments
5. Community College Enrollments

School Enrollments data was further curated based on district boundaries of elementary schools and middle/high schools. However, it was assumed that private schools do not follow any school district boundary.

5. TRIP GENERATION

Trip generation is the initial step of the TDM that estimates the number of trips produced and attracted to each TAZ. The socioeconomic data discussed in Chapter 4 was used together with regression parameters to estimate the trips produced and attracted to each TAZ. Trips Produced are typically a function of the household characteristics of each TAZ, while trips attracted are a function of the employment of each TAZ. As mentioned previously, an improvement of this model was the inclusion of long-haul freight movements. The next sections describe in detail, the different trip generation procedures that were used and their results.

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 17 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 17 Internal-Internal Passenger Trip Rates

Person per Household					
Purpose	**1**	**2**	**3**	**4+**	**Overall**
HBW	**1.003** *(14.90)*	**1.718** *(19.83)*	**2.559** *(13.61)*	**2.408** *(16.77)*	**1.745** (30.30)
HB-Shop	**0.21** *(5.03)*	**0.73** *(11.52)*	**0.75** *(5.70)*	**0.90** *(6.65)*	**0.60** *(14.23)*
HBSchool (K-12)	**0.00** *(0.88)*	**0.13** *(5.09)*	**1.27** *(8.38)*	**2.91** *(14.35)*	**0.77** *(13.23)*
HBO	**0.88** *(10.71)*	**1.67** *(16.89)*	**1.76** *(7.81)*	**3.17** *(12.32)*	**1.71** *(22.27)*
NHB	**1.57** *(11.44)*	**2.40** *(17.80)*	**2.89** *(7.39)*	**3.39** *(9.77)*	**2.39** *(22.44)*
IE	**0.05** *(2.25)*	**0.30** *(6.73)*	**0.18** *(2.80)*	**0.32** *(3.56)*	**0.21** *(7.74)*
Total	**3.73** *(27.94)*	**7.13** *(36.04)*	**9.52** *(18.53)*	**13.22** *(23.32)*	**7.53** *(39.05)*

Table 18: Internal-Internal Vehicle Trip Rates

Person per Household					
Purpose	**1**	**2**	**3**	**4+**	**Overall**
HBW	**0.914** *(13.32)*	**1.422** *(16.34)*	**2.327** *(12.37)*	**2.240** *(15.54)*	**1.547** *(26.97)*
HB-Shop	**0.19** *(4.85)*	**0.41** *(9.12)*	**0.71** *(5.70)*	**0.71** *(6.99)*	**0.44** *(13.30)*
HBSchool (K-12)	**0.00** *(0.80)*	**0.00** *(0.76)*	**0.47** *(4.49)*	**0.42** *(4.92)*	**0.15** *(6.85)*
HBO	**0.58** *(8.15)*	**1.06** *(14.25)*	**1.05** *(6.34)*	**2.01** *(11.56)*	**1.08** *(19.63)*
NHB	**1.43** *(11.06)*	**1.55** *(13.61)*	**2.03** *(6.07)*	**2.34** *(8.06)*	**1.73** *(19.21)*
IE	**0.05** *(2.25)*	**0.18** *(5.90)*	**0.16** *(2.55)*	**0.21** *(2.84)*	**0.14** *(6.74)*
Total	**3.18** *(21.51)*	**4.73** *(24.19)*	**6.74** *(14.12)*	**8.00** *(19.23)*	**5.16** *(34.98)*

5.1.2. Trip Attractions

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

Table 19 Trip Attraction Rates

Purpose	**Retail**	**Service**	**Basic**
HBW	1.4	1.4	1.4
HBO	8.4	1.2	0.7
NHB	4.7	0.9	0.5

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 and were calibrated to the local conditions.

Table 20 School Trip Attraction Rates

School	**Fargo/Moorhead Schools**	**West Fargo Schools**	**Dilworth/Barnesville/Hawley**	**Private Schools**
Elem	2.50	2.50	2.50	4.10
Junior/ Middle	2.35	2.35	2.35	2.48
High	1.94	1.94	1.94	2.17

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

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

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 was used for distributing IE/EI trips.
For the TDM, trips were distributed separately for the different periods.

K-factors were developed from the OD-analysis of StreetLight analysis. the output data set from StreetLight was post-processed using a code written in Python to identify the K-factors for each OD pair of TAZ. For EE trips, the OD data from StreetLight were used to develop K factors similar to those described for EI/IE trips. This was 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 Fargo Moorhead Public Schools. The K-factor matrix used ensured that no public school trips should be exchanged between school zones.

7. TRIP ASSIGNMENT

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

The user equilibrium traffic assignment method was used for assigning trips for the model. Additionally, In the user equilibrium method, road users of the system choose the route that would minimize their cost (or travel time) without consideration to the overall average travel time on the system. In system equilibrium, system users would behave cooperatively in choosing their own route to ensure the most efficient use of the system, thus optimizing the overall average cost of travel on the system.

The formulation used to calculate the travel cost for the equilibrium assignment method is shown in **Error! Reference source not found.** 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.

8. VALIDATION AND CALIBRATION

Model calibration refers to the adjustment of model input parameters to replicate observed real-world data for a base year. 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 in the model's replication of real-world data was achieved.

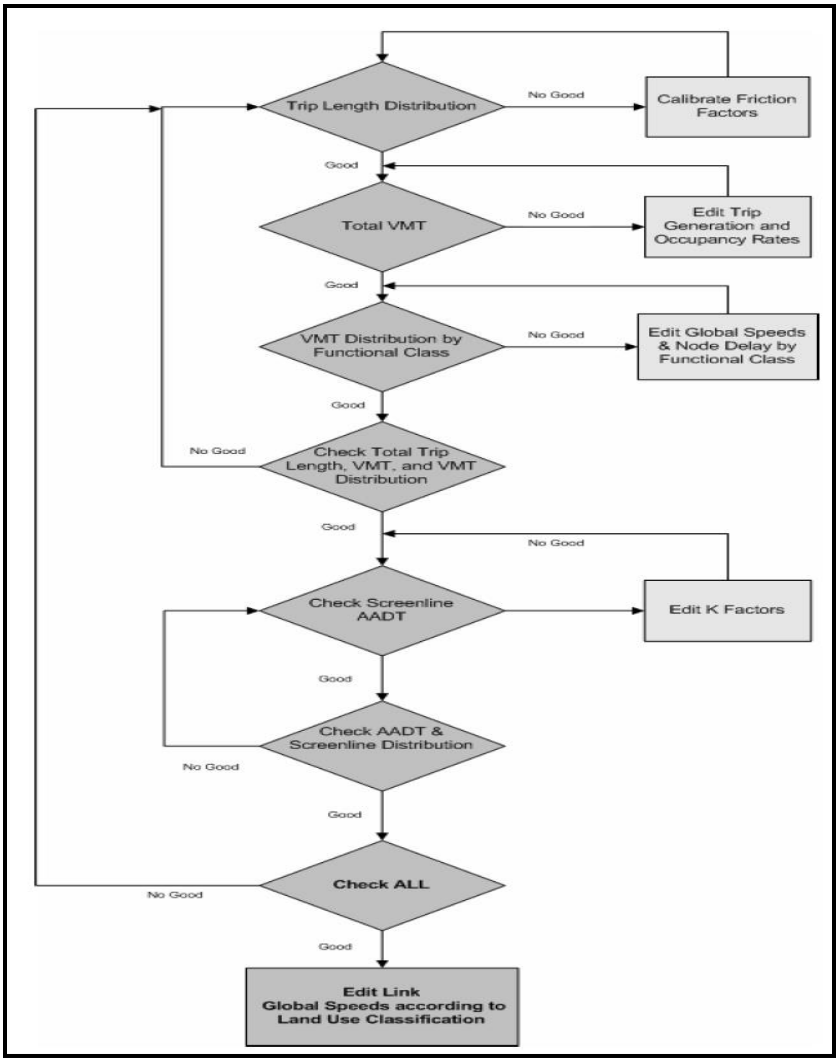

Figure 12 Calibration Flow Chart

Model validation compares base year calibrated models output to observed data. Ideally, model estimation and calibration data should not be used for validation but this is not always feasible. The two processes, calibration and validation typically go hand in hand in an iterative process. The next sections describe the different model parameters that were used for model calibration and validation.

8.1.Trip Length Frequency Calibration and Validation

Trip length frequency distributions describe the traveler’s 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 is shown in Figure 13.

Equation 14 Friction Factor Equation

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

Where,

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

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

a, b, and c are gamma function scaling factors.

The friction factors were calibrated by adjusting the b and c parameters until the desirable trip length frequency distribution for Home Based Work Travel times was 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 60 minutes were considered with the assumption that 60 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 13.78 minutes compared to the average trip length of 15.22 minutes produced by the model for HBW trips. The desired average trip lengths for HBO and NHB trips were 72% and 66% of the average trip length for HBW trips. The average trip length for the models HBO and NHB trips were 14.04 and 16.98 minutes respectively.

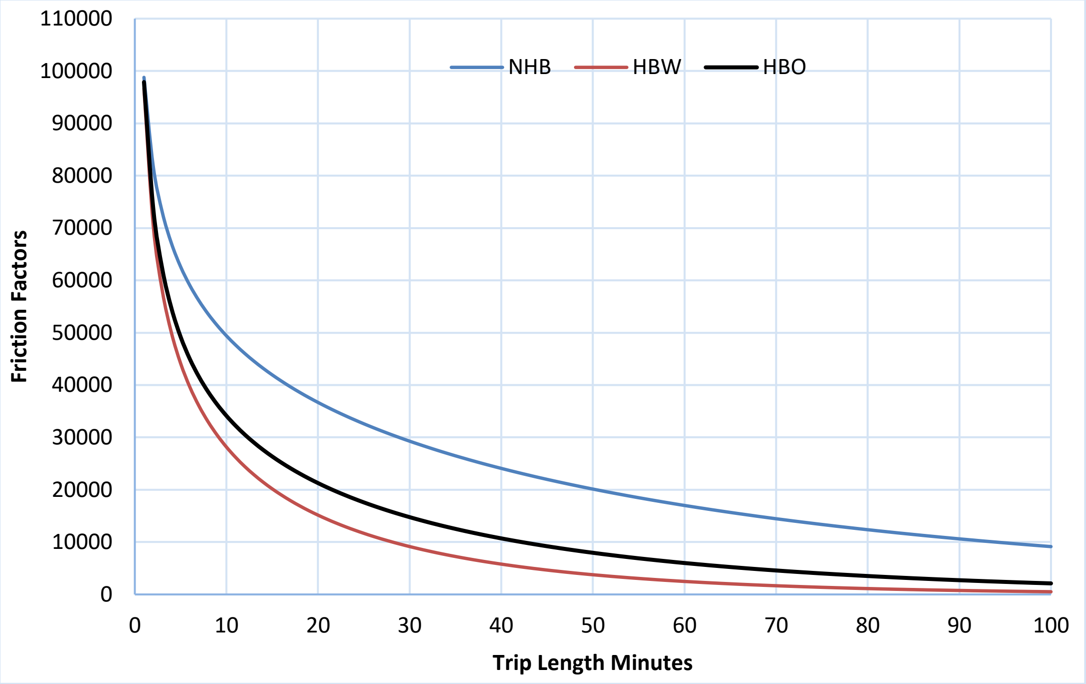

Figure 13 Friction Factors

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.

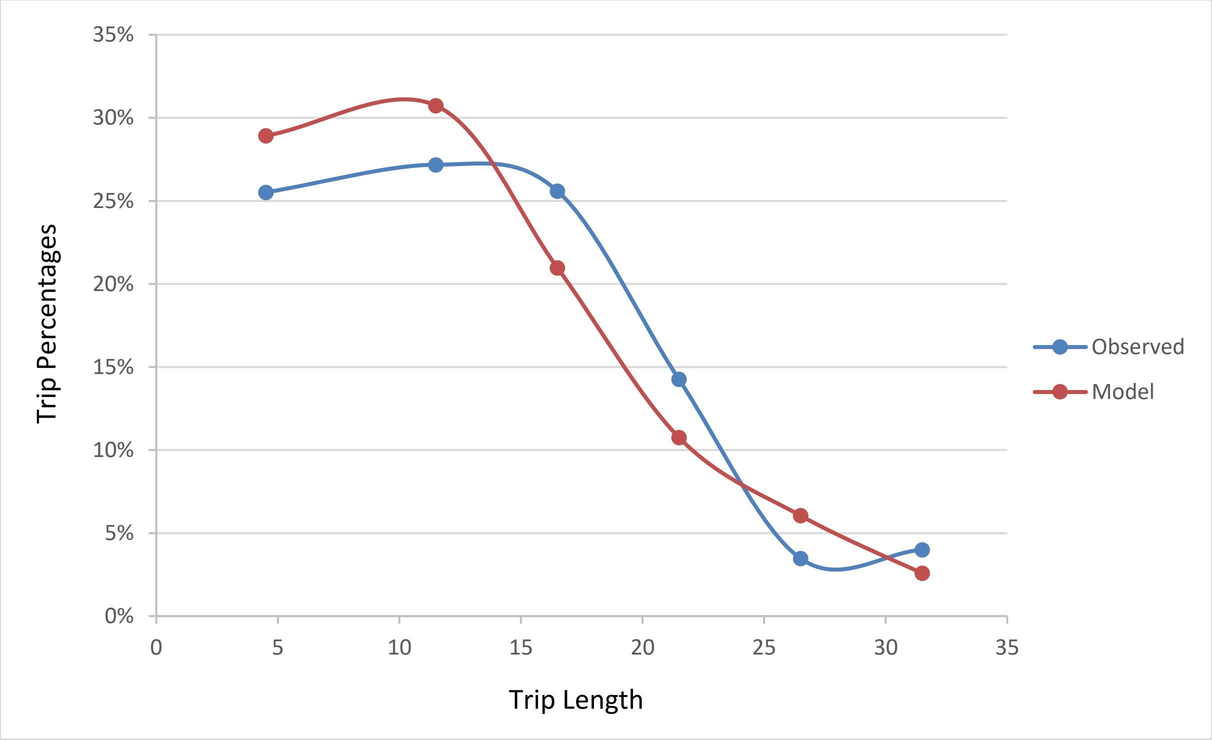

Figure 14 Comparison of Observed to Model Trip Length Frequency

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 certain functional class VMT distribution was off target, global speeds by that facility type were adjusted.

Table 21 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 Minor arterials with VMT differences of less than 5% and had similar distributions to the observed VMTs. Overall, the model performs within reasonable deviations in replicating VMTS by functional class with overall 2.8% deviation.

Table 21 Modeled VMTs compared to Observed VMTs

Functional Class	Observed VMT	Modeled VMT	% Diff
Interstate	1,100,860.63	1,208,053.00	8.9%
Major	590,228.71	989,396.00	40.3%
Minors	1,035,961.38	1,187,775.00	12.8%
Collectors	223,764.84	350,824.00	36.2%
Locals	953,162.52	61,792.00	-1442.5%*
Total	3,903,978.08	3,797,840.00	-2.8%

** It should be noted that in TDM not all locals roads are included*

8.3.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 MPO provided traffic counts for several links that were compared to the Model ADTs. Two comparisons are made, one for the different functional classifications and one by volume ranges.

Table 23 shows the comparison of the modeled and observed ADTs by functional classification. Overall, the model performs reasonably well replicating over 75% of observed counts. Major arterials have the lowest replication of observed counts at 68%.

Table 22 Comparison of Modeled and Observed ADTS by Functional Classification

Functional Classification	Below Criteria	Within Criteria	Above Criteria	Total	%age Within
Interstates	0	60	5	65	92.31%
Major Arterials	17	108	33	158	68.35%
Minor Arterial	73	346	57	476	72.69%
Collectors	49	279	47	375	74.40%
Locals	7	68	5	80	85.00%
Total	146	861	147	1,154	74.61%
Percent	12.65%	74.61%	12.74%		

Table 23 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 criteria for all the volume ranges and replicates 75% of the observed traffic.

Table 23 Comparison of Modeled and Observed ADT by Volume Range

ADT Range	#Above	#Within	#Below	%Within	RMSE
ADT >25,000	4	37	1	88%	0.1208
25,000 TO 10,000	27	143	35	70%	0.2377
10,000 TO 5,000	40	143	66	57%	0.3831
5,000 TO 2,500	29	155	44	68%	0.4727
2,500 TO 1,000	24	217	0	90%	0.7278
ADT<1000	23	166	0	88%	1.8848
Total	147	861	146	75%	

8.4.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 include ing link *i, (number of links with counts)*

Table 24 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 volumes. This is an indication that the model is performing reasonably in replicating observed traffic. The overall % RMSE for the model is 33.97.

Table 24 RMSE Comparison by Volume Range

Volume Range	RMSE (%)	Typical Limits (%)
AADT>25,000	12%	15-20 %
25,000 to 10,000	24%	25-30 %
10,000 to 5,000	38%	35-45 %
5,000 to 2,500	47%	45-100 %
2,500 to 1,000	73%	45-100 %
AADT<1000	188%	>100 %

8.5.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 15 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. They typically measure 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 0.914 shows a strong linear relationship between modeled and observed traffic counts.

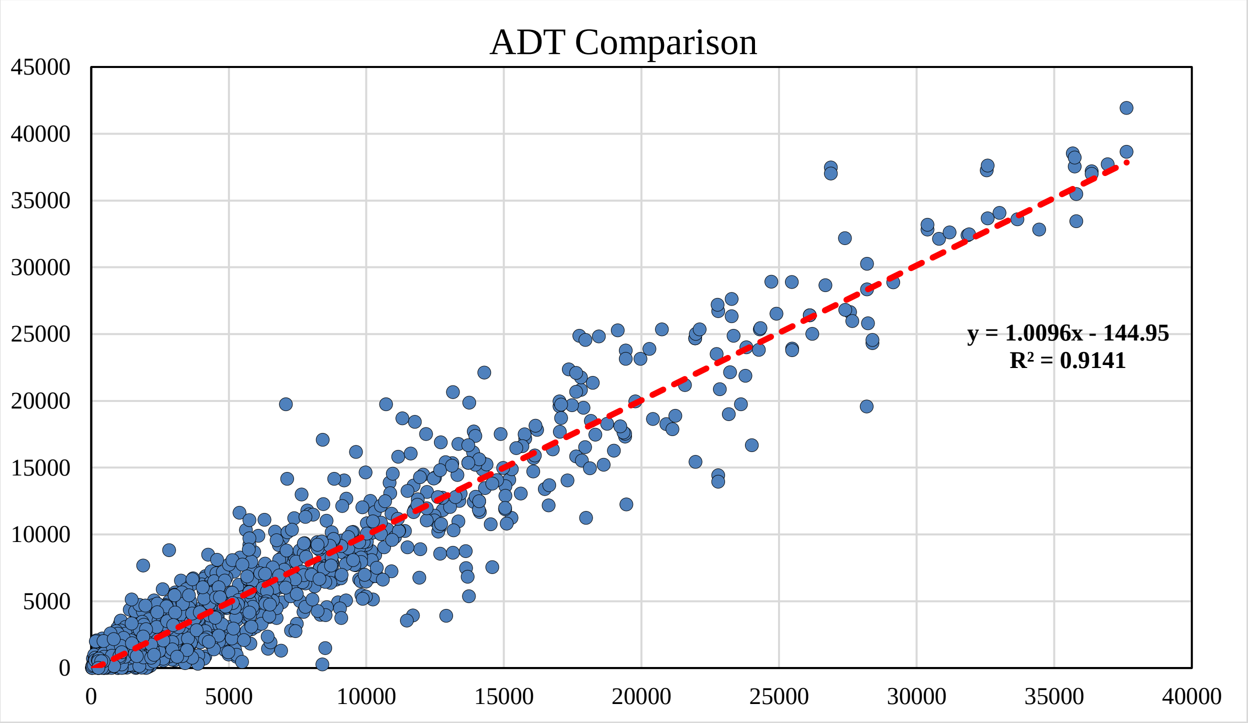

Figure 15 Scatter Plot of Modeled and Observed ADTs

8.6.Screenline Comparisons

Table 25 shows the Screenline comparisons for three major Screenlines: I-94, I-29, and the Red River. The difference between modeled and observed volumes for all screenlines is below 3% which is within reasonable deviations.

Table 25 Screenline Comparisons

Screenline	Modeled	ADT	% Difference
I-29	263,575	271,237	-2.9%
I-94	278,746	273,029	2.1%
Red River	116,701	114,212	2.2%

9. CONCLUSIONS

This document describes the development, calibration, and validation of the F-M MPO base 2021 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 traffic within typically accepted deviation limits.

10.APPENDIX

Table 26 Calculated Capacities for Signalized Intersections for Different Functional Classifications

Lane Group	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 Group	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 Group	**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 Group	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 Group	**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**

Lane Group	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	2			**Rural**	**1**	**1900**	0.99	3178	3496	**0.4**	1398	**13,984**
	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**

Lane Group	**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	0.55	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**
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**

Lane Group	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	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**
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**

Lane Group	**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	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**
	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 27 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