Socio-Economic Data

Travel Model Review

Best Practices

BISMARCK MANDAN METROPOLITAN PLANNING ORGANIZATION

Travel Model Review and Socio-Economic Update Study
Final Report

December 2018

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Contents

Glossary

Average Daily Traffic (ADT): A traffic volume that represents an average, 24-hour period.

AirSage: A data company that estimates travel patterns based on anonymous tracking of mobile devices.

Bismarck-Mandan: Used to describe the entire MPO area, including Bismarck, Mandan, Lincoln and the metropolitan portions of Burleigh and Morton County.

Centroid: A point that represents the center of an area. In travel modeling, the centroid represents where all traffic generated by a transportation analysis zone (TAZ) is loaded onto the travel model's network via centroid connectors or pseudo links.

Centroid Connectors: An abstract link that connects the centroid to the TDM roadway network. Typically, centroid connectors are intended to represent one or more local street or driveways where development-generated traffic connects to the functionally-classified street network. Also known as Pseudo Links.

Feedback Loop: A process where the output from a step in a model sequence is used as a revised input for a prior step, and the model sequence is executed again. In the Bismarck-Mandan TDM, the congested travel time results of the traffic assignment step are "fedback" as inputs for the trip distribution step.

Freight Analysis Framework (FAF): FAF is typically produced every 5 years by the Bureau of Transportation Statistics (BTS) and Federal Highway Administration (FHWA). It is a data source that provides current year and forecasted future year freight movement among states and major metropolitan areas.

Friction Factors: Parameters used in the Gravity Model to represent the relative impact various travel costs have on trip length choice.

Functional Classification: A system used to classify streets and roadways according to the function they provide. Example classifications for the Bismarck-Mandan area include Interstate, arterial, collector, and local streets. All collectors, arterials, and Interstates in the Bismarck-Mandan region are included in the TDM.

Geographical Information System (GIS): A software package that integrates spatial mapping and databases, providing spatial analysis and mapping capabilities.

Gravity Model: A trip distribution approach that estimates trip levels exchanged between two zones based on the pair's trip productions, trip attractions, and cost of traveling between the zones.

Goodness of Fit: A statistical measure that describes how well a set of model-estimated data fit with observed (or real) data.

Gross Metropolitan Product (GMP): The measure of the market value of all final goods and services produced in a metropolitan area.

Infogroup: A company that provides a range of data products. The Infogroup data referred to in this report are estimates of existing employment levels by location and industry used by the MPO for model data development.

K-Factors*:* A parameter used in the Gravity Model to adjust trip distribution levels between zones. K-Factors are asserted values, sometimes referred to as a "socioeconomic" adjustments, that are inserted to account for trip-making factors not otherwise explained by zonal productions, attractions, or travel costs.

Pseudo Links: An abstract link that connects the centroid to the TDM roadway network. Typically, centroid connectors are intended to represent one or more local street or driveways where development-generated traffic connects to the functionally-classified street network. Also known as Centroid Connectors.

Mode Choice: In a traditional four-step model, mode choice is the third step following the trip distribution and prior to traffic assignment. Mode choice evaluates reasonable travel modes between TAZs, and assigns a mode of travel to each trip. Mode choice is not currently included in the Bismarck-Mandan TDM.

Sensitivity Test: A model run that evaluates model response to controlled changes to a model input variable.

Socio-Economic Data: Characteristics of a community's population such as household status, vehicles available, employment type, and educational status. Socio-economic data is the independent variable which the Bismarck-Mandan TDM uses to generate trips.

Time-of-Day Factors: Parameters that convert the daily trip tables by trip purpose to peak period trip tables according to the estimated percentage of daily traffic that occurs during peak periods.

Traffic Assignment: The final step in the Bismarck-Mandan model, traffic assignment is the module that assigns or routes each trip to network links between its origin and destination.

Transportation Analysis Zone (TAZ): Also called traffic analysis zones, the TAZ is the basic unit of geography for the travel model. The MPO defines the TAZ boundaries for the model.

Travel Demand Model (TDM): A computerized application that combines an area's transportation system data, land use data, and tailored region-specific travel parameters to forecast regional or statewide travel. A TDM can evaluate how land development and the transportation system interact, and how transportation investments and land use development decisions can impact travelers and system performance.

Trip Attraction: Trips generated have both a production and an attraction. The number of trip attractions in a zone is defined by the amount of trip-attracting socio-economic data in that zone. Employment, measured in jobs, is the primary unit for trip attractions in the Bismarck-Mandan model.

Trip Distribution: The process of matching generated productions and attractions, thereby estimating the number of trips exchanged between all TAZs. The Bismarck-Mandan TDM uses the gravity model for trip distribution

Trip Generation: The first step in the model process that that estimates the number of trips occurring for all TAZs, based on the input socio-economic data. Trips generated have both a production and an attraction.

Trip Production: Trips generated have both a production and an attraction. The number of trip productions in a zone is defined by the amount of trip-producing socio-economic data in that zone. Households are the primary unit for trip productions in the Bismarck-Mandan model.

Overview

Travel Demand Model (TDM) Background

Over the past several decades, the MPO and its member organizations continually invested in the region's travel demand model (TDM). The TDM is a computerized application that forecasts travel across the transportation system by combining data on the Bismarck-Mandan area's transportation system, its land use and development patterns, and the travel characteristics of area residents. The TDM is used by the MPO and its partners to evaluate how land development and the transportation system interact, and how transportation investments and land use development decisions can impact travelers and the performance of the transportation system. The MPO and its partners recognize the utility and importance of the TDM, as it provides technically-sound and reasonable results at a level of detail required for the analyses of these local scenarios.

The Bismarck-Mandan TDM is developed and maintained by the Advanced Traffic Analysis Center (ATAC) at North Dakota State University. ATAC provided the model files and validation statistics for this study.

Study Purpose

There were two primary purposes of the Model Review and Socio-Economic Update Study. The first was to **update the future socio-economic scenario** to the year 2045, to be consistent with the planning horizon with the ongoing Metropolitan Transportation Plan update. The second was to provide an independent **technical review of the TDM**.

This study came at a critical juncture for the Bismarck-Mandan area, as the past several years saw intense growth in development and traffic. The oil boom in Western North Dakota led to a significant increase in the Bismarck-Mandan region's rate of growth, and this study provides an opportunity to evaluate what this recent "boom" looked like, and what future growth trajectories the region might experience as a result. The remainder of this document summarizes these two elements of the study.

Socio-Economic Update

The primary purpose of the socio-economic data update was to provide updated land use growth information to support the MPO's future transportation planning efforts. MPO staff used several sources of data such as Infogroup employment data, the 2010 Census, local jurisdiction building permits, and aerial photography to create a 2015 base year socio-economic dataset. These socio-economic data were updated to the year 2045, to be consistent with the planning horizon with the ongoing Metropolitan Transportation Plan update. For the purposes of use by the TDM, socio-economic data were developed in the following categories:

- **Households**: Households were cross-classified, so the number of people and the number of vehicles available were estimated for each household.
- **Jobs**: Jobs were classified by employment type based on their industry. These six employment types were used:
    - Retail (retail trade, accommodation and food services)
    - Service (Information, finance and insurance, real estate, professional services, healthcare, arts, entertainment, and recreation)
    - Industrial (Mining, construction, wholesale trade, transportation and warehousing)
    - Manufacturing (Manufacturing employment)
    - Education (Educational services)
    - Other (administrative, management, government, utilities, forestry)

Several steps went into the update of the socio-economic data:

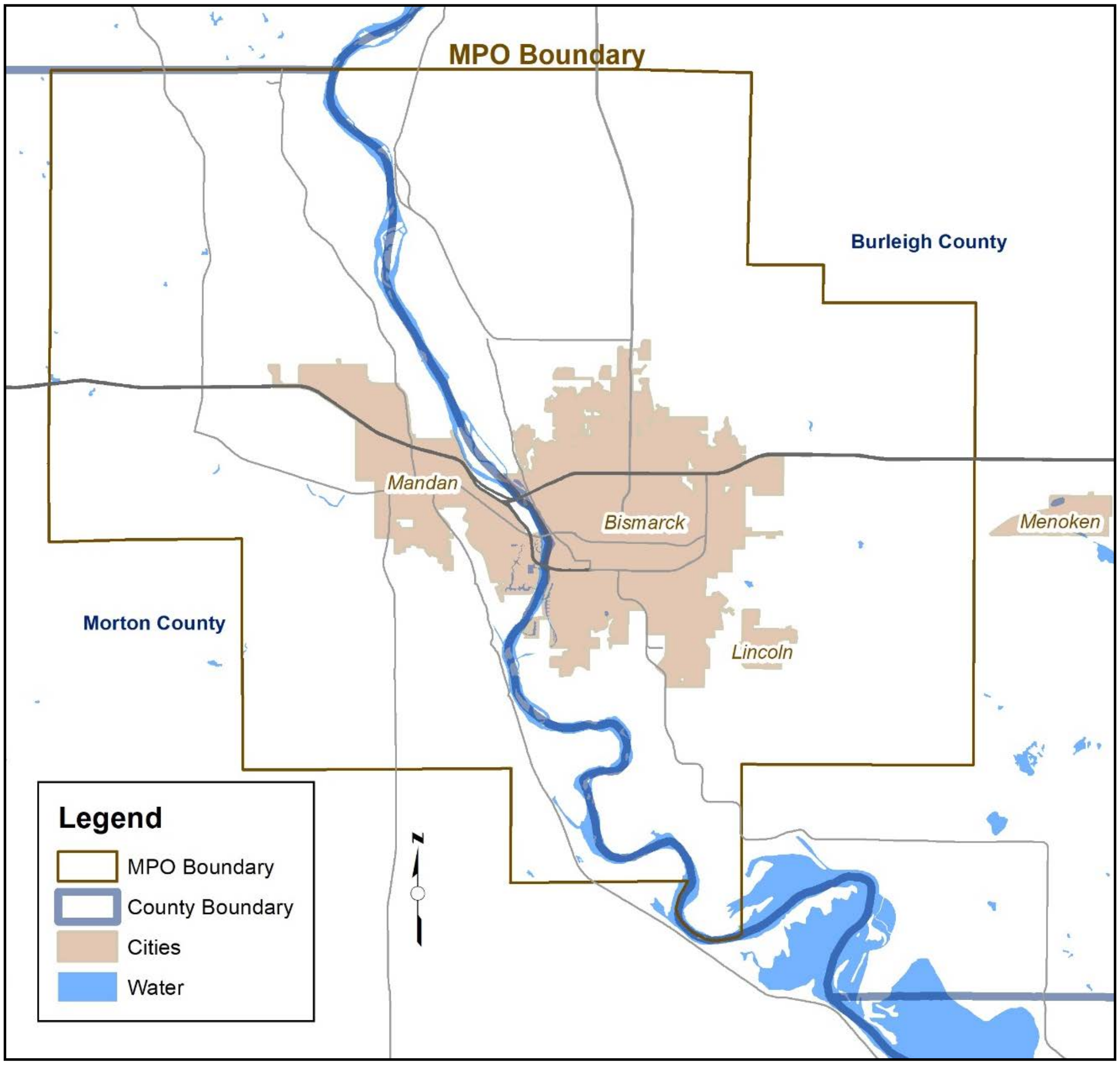
- Review of long-term and recent regional growth trends
- Review of other economic data for growth projections
- Identifying three potential development scenarios
- Selecting a preferred future development scenario
- Allocating future regional growth to traffic analysis zones

Regional Development Scenarios

The general process followed for the development of regional development scenarios was:

- The current growth context for Bismarck-Mandan was reviewed, including an assessment of recent population boom, and incorporated research on peer regions and looked at their historical and recent growth trends.
- HDR presented the research to the Steering Committee, MPO Technical Advisory Committee (TAC), and MPO Policy Board to get direction on potential development scenarios.
- HDR evaluated, and developed two-county regional control totals projections of future population, household, and employment through 2045.
- Estimating the MPO Study Area's portion the two-county population, households, and jobs. As shown in **Figure 1**, the MPO Study area is located in portions of northeast Morton County and southwest Burleigh County.

Figure 1. MPO Study Area Map



Growth Context

Several elements were considered when evaluating current trends and potential growth trajectories through 2045 for the Bismarck-Mandan metropolitan area. These perspectives included reviewing:

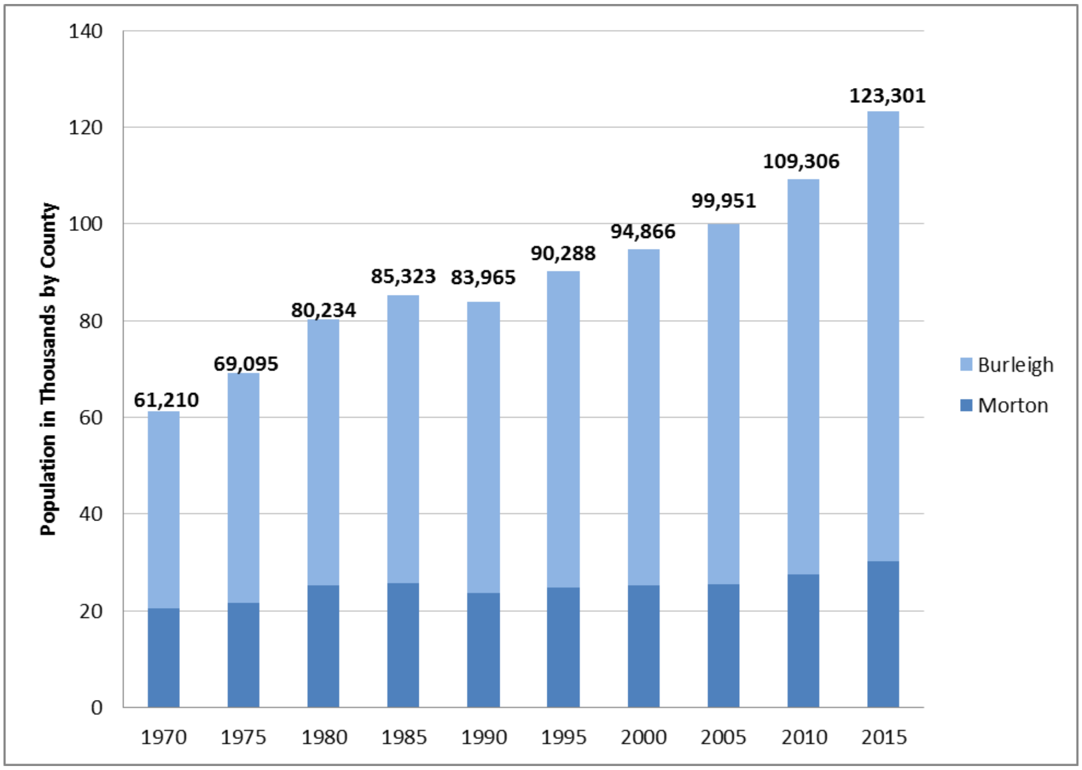
- Regional Historical Growth Trends
- National Historical Growth Trends
- Woods and Poole Data
- Peer Metropolitan Areas Growth Trends

The reason for these reviews was to identify likely trends for Bismarck-Mandan growth moving forward.

Regional Growth Trends

The Bismarck-Mandan area grew steadily over the past several decades, with some periods of rapid growth. In the period 1985-2015, the region has grown approximately 1.2% per year. **Figure 2** shows the population growth in Burleigh and Morton counties since 1970.

Figure 2. Historical Regional Population Growth by County



Source: US Census Bureau

The recent oil boom in Western North Dakota impacted the Bismarck-Mandan region between 2010 and 2016. During that time:

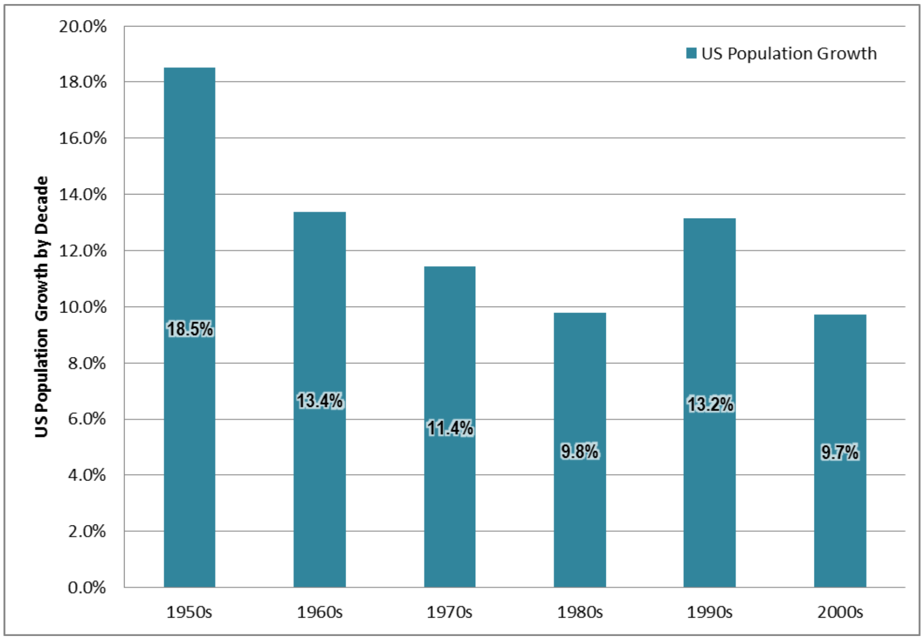
- Gross Metropolitan Product (GMP), the measure of the market value of all final goods and services produced in the metro area, grew an average of 8% annually, from $5.5 billion in 2010 to $8.1 billion in 2015. This was double the historical GMP growth rate for Bismarck-Mandan.[1]
- Population growth between 2010 and 2016 was 2.3% annually, nearly twice the historical rate of 1.2% annually.
- Employment growth between 2010 and 2016 was 2.9% annually, higher than the historic rate of 2.4% annually.

National Demographic and Growth Trends

When reviewing historical population trends in Bismarck-Mandan, it is important to consider them within the context of national demographic trends. As shown in **Figure 3**, overall US population growth rates have trended down since the 1950s, due in large part to declining birth rates.

[1] Source: US Bureau of Economic Analysis

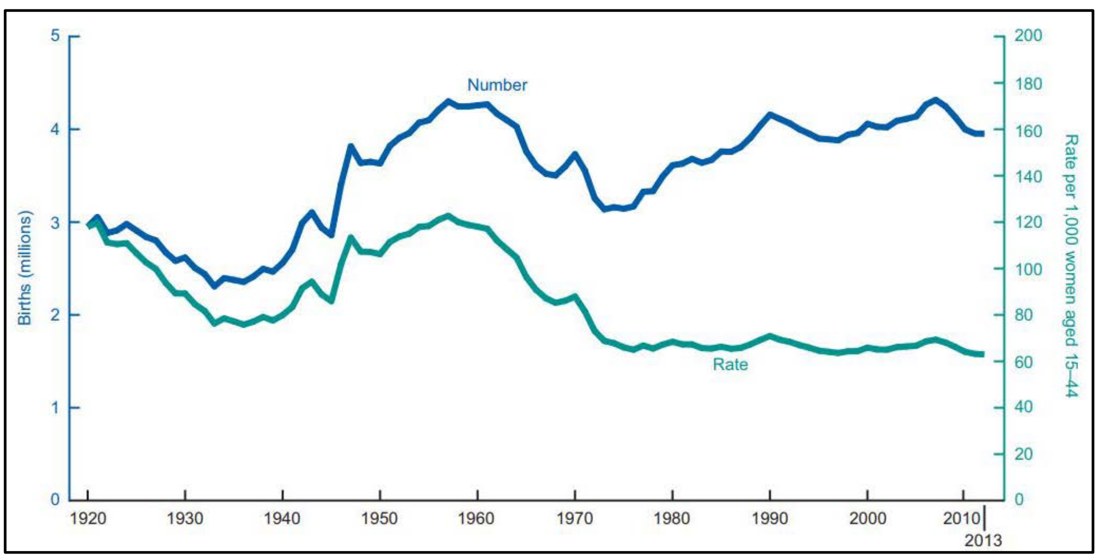
Figure 3. US Population Growth by Decade



Source: US Census Bureau

Figure 4 shows that while the number of US live births is at levels consistent with the 1950s, the birth rate has declined significantly over the past several decades.

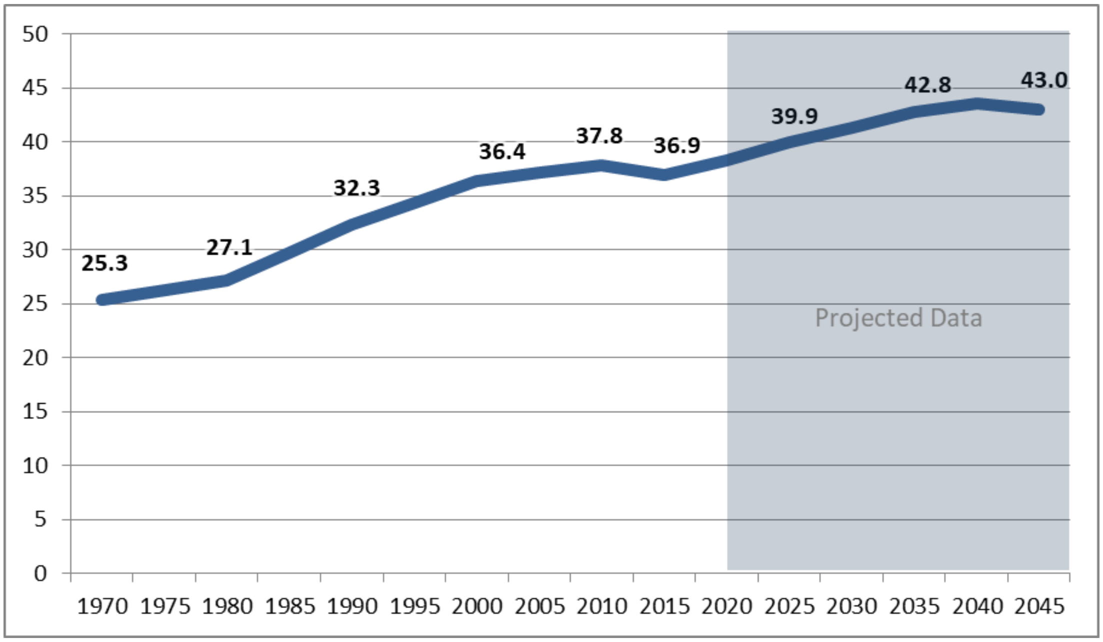
Figure 4. Historical US Live Births and Birth Rate



Source: National Vital Statistics Reports, Vol. 64, No. 1, January 15, 2015

Due in part to a nationally-declining a birth rate, the average age in the Morton and Burleigh county area increased from 25.3 years in 1970 to 36.9 (estimated) in 2015. Projections from Woods and Poole, shown in **Figure 5**, estimate average age in the 2-county area will increase to 43.0 years of age by 2045.

Figure 5. Average Historical and Projected Average Age, Burleigh and Morton Counties



Source: US Census, Woods and Poole

The key takeaway from **Figures 3, 4, and 5** is that trends indicate that declining birth rates and an aging population will have some downward impact on future growth rates for the nation and Bismarck-Mandan.

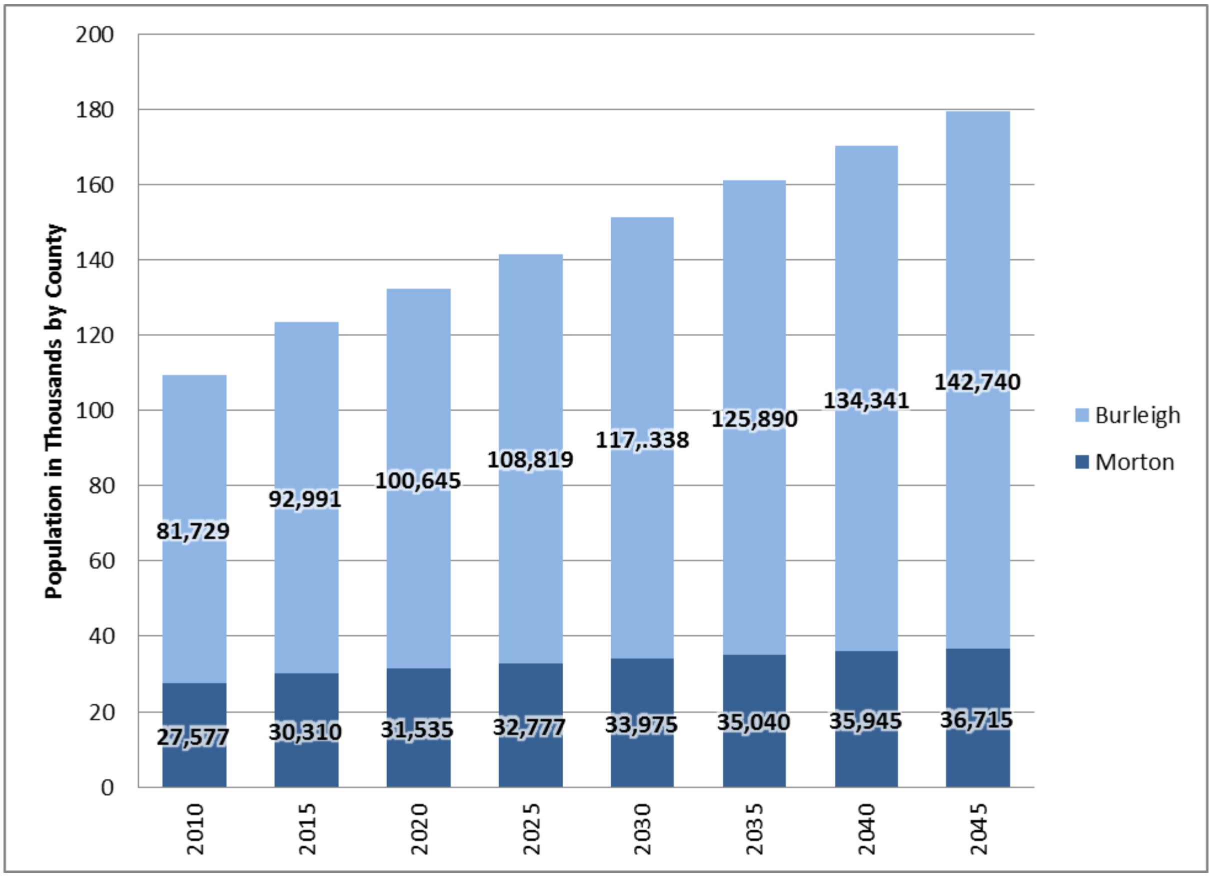
Woods and Poole Demographic Projections

Woods and Poole is an economics firm specializing in national and regional models for long-term county economic and demographic data projections. These data provide insights into employment trends within industry sectors and population changes within age cohorts. The Woods and Poole projections for Burleigh and Morton County indicate:

- Population is projected to grow at a rate of 1.26% per year for the two-county area between 2015 and 2045. The breakdown in population projections by county is shown in **Figure 6**[2].

[2] As indicated in Figure 1, the MPO study area encompasses only a portion of Burleigh and Morton Counties. Based on 2010 Census block-level population data, the MPO area represents approximately 96% of Burleigh County population and 80% of Morton County population, for a total of approximately 92% of the combined two-county population.

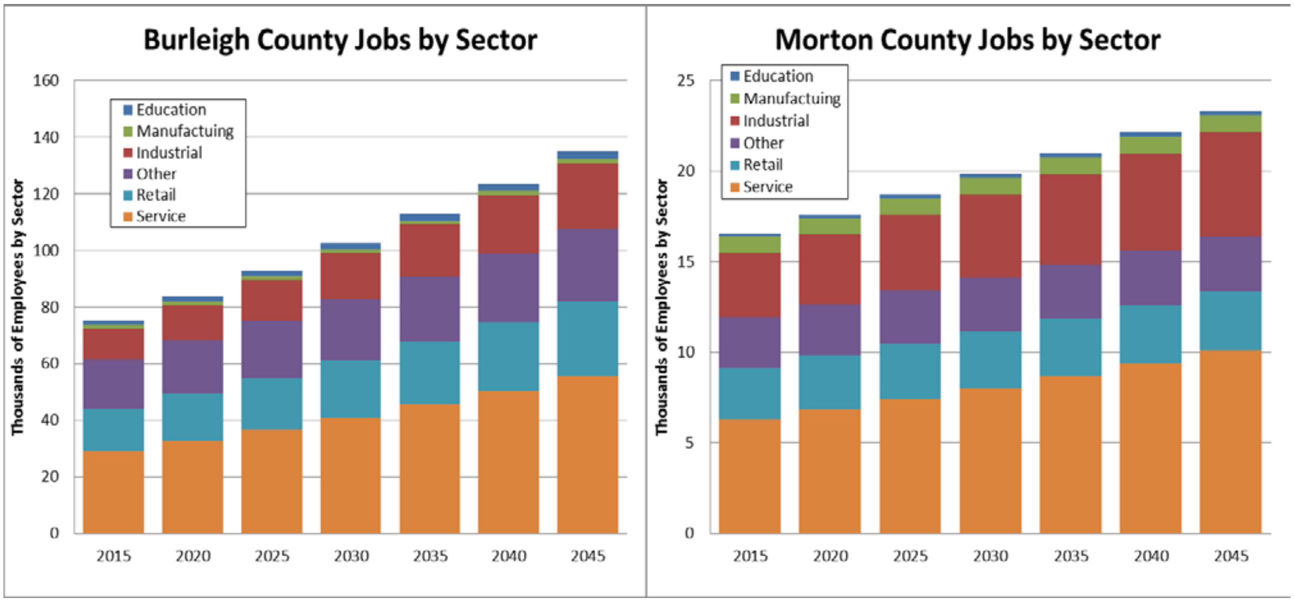
Figure 6. Woods and Poole Population Projections by County



Source: Woods and Poole Economics

- Employment growth projected for 1.83% per year for the two-county area between 2015 and 2045. Employment by industry sector for both counties is shown in **Figure 7**. The three fastest growing sectors are projected to be:
  - Industrial (+2.4% / year)
  - Service (+2.1% / year)
  - Retail (+1.8% / year)

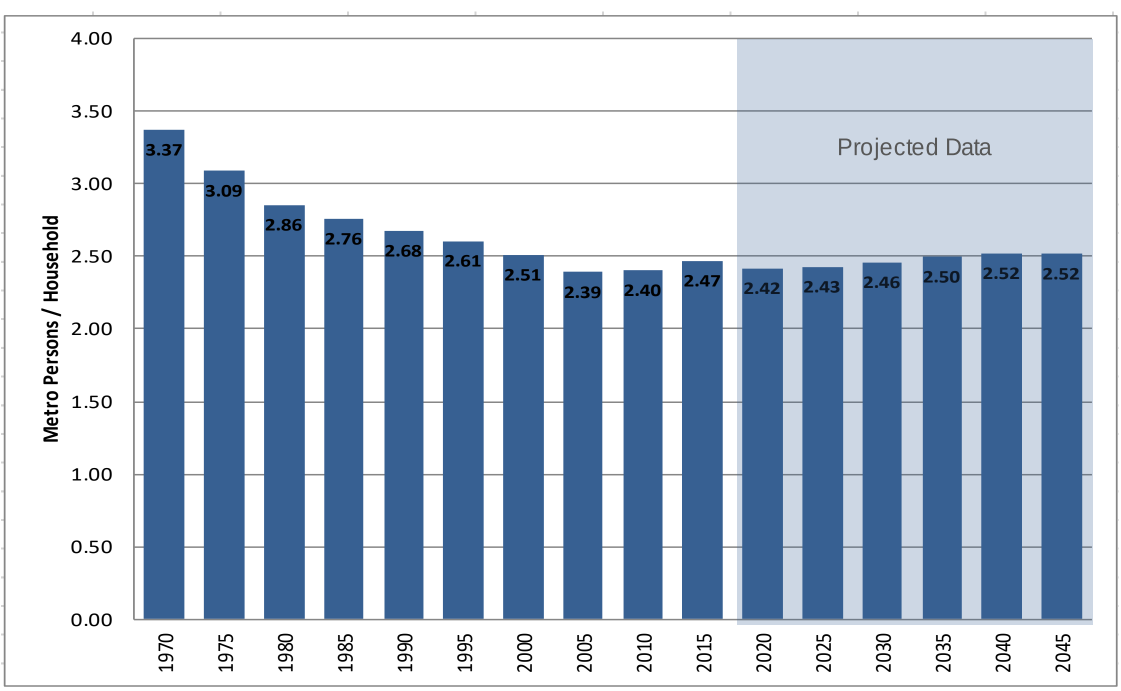
Figure 7. Employment Projections by Sector[3]



Source: Woods and Poole

- Household sizes are projected to stabilize in the future, after declining over the last several decades. As shown in **Figure 8**, those trends recently stabilized, and Woods and Poole project minor increases in household size between 2015 and 2045.

Figure 8. Historical and Projected Household Size for Burleigh and Morton Counties



Source: Woods and Poole

[3] Note that the Woods and Poole data were used as a basis for forecasting relative growth rates by job sector, not for developing an absolute number of forecasted jobs.

- The ratio of regional employment to population is projected to increase in the future. This ratio increased rapidly over the last several decades, but the rate of increase is projected to decline in the future. By year, the employment-to-population ratios are:
  - 1970 – 43 jobs / 100 people
  - 1990 – 60 jobs / 100 people
  - 2015 – 75 jobs / 100 people (estimated)
  - 2045 – 88 jobs / 100 people (projected)

One item to note when considering employment trends shown in the bullet points above is that Woods and Poole tends to include secondary jobs other data sources do not. These include part time, private household employees, miscellaneous workers, and proprietors. Thus, absolute levels of base year employment were taken from the Infogroup data used by the Bismarck-Mandan MPO to estimate current year employment levels in the TDM. The critical insights offered by the Woods and Poole data are the growth trends by industry sector that can be applied to the current year data.

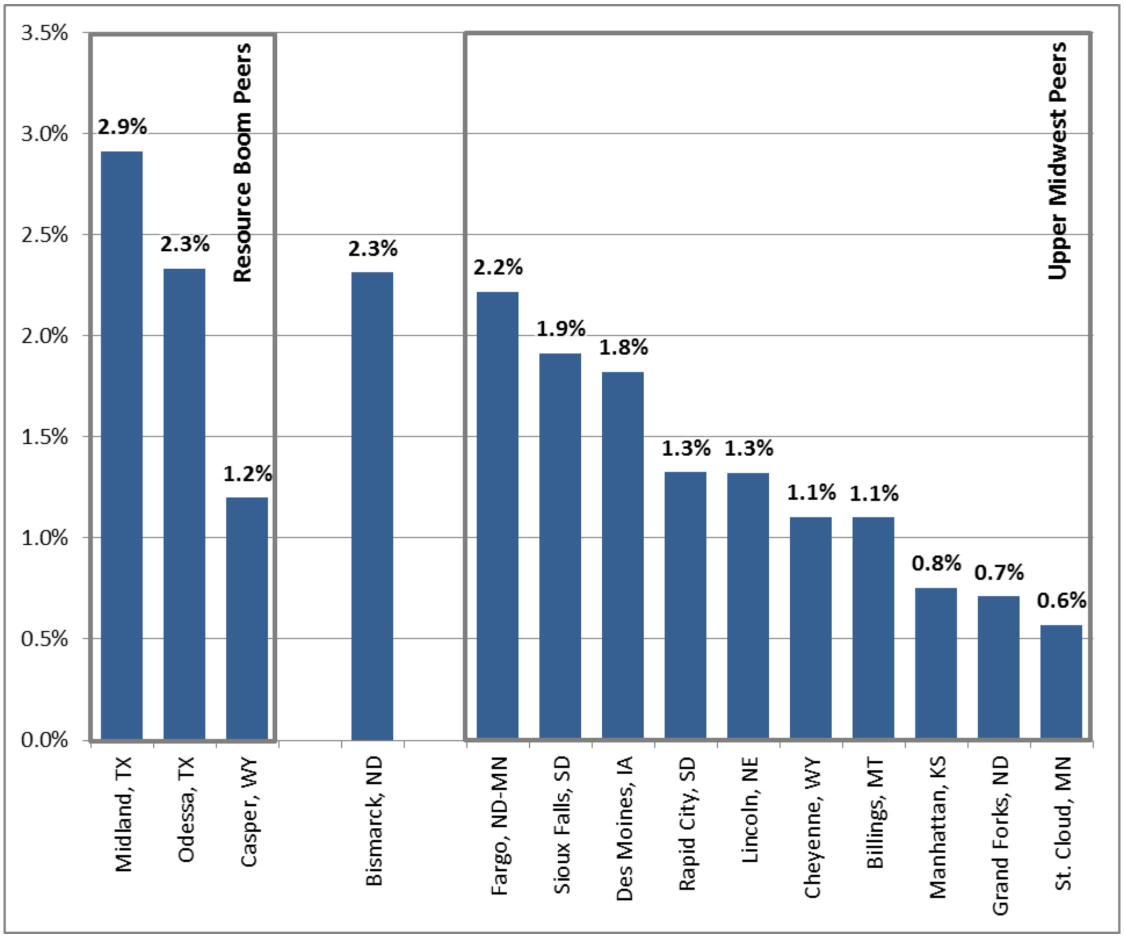
Peer Metropolitan Regions Growth Trends

Another growth evaluation perspective was an assessment of recent growth trends of peer metropolitan regions to Bismarck-Mandan. Peers were selected for two reasons:

- Other medium-sized upper Midwest metropolitan areas.
- Other metropolitan areas that have undergone resource-based “booms” since 2010.

Figure 9 shows Bismarck-Mandan’s metro growth rate for the period 2010-2016 compared to several upper Midwest peers, and three resource-based “boom” peers.

Figure 9. Annual Metropolitan Population Growth, Bismarck-Mandan and Peers, 2010-2016



Source: US Census Bureau

As shown in **Figure 9**, Bismarck-Mandan had the highest rate of growth (at 2.3% per year) of the upper Midwest peers. Only Midland and Odessa, TX, who both had similar oil extract booms during the period, had higher growth rates. During that same 2010-2016 period, Bismarck-Mandan was the 11th fastest growing metropolitan area in the US, behind:

- The Villages, FL Metro Area
- Austin-Round Rock, TX Metro Area
- Myrtle Beach-Conway-North Myrtle Beach, SC-NC Metro Area
- Midland, TX Metro Area
- Cape Coral-Fort Myers, FL Metro Area
- Greeley, CO Metro Area
- St. George, UT Metro Area
- Raleigh, NC Metro Area
- Bend-Redmond, OR Metro Area
- Odessa, TX Metro Area

Bismarck-Mandan was the fastest-growing metropolitan area outside of the high-growth southern, west coast, and mountain states. This demonstrates that the last six years were a remarkable period of growth for Bismarck-Mandan, and are unlikely to continue at this pace long-term.

Potential Development Scenarios Considered

Based on the data and trends reviewed, the study steering committee convened and identified four preliminary scenarios for further consideration. These four different scenarios were developed from a population growth perspective only, with an understanding that employment and household details would be developed based on the selected population scenario. These four potential scenarios were:

High Growth Scenario: "Another Oil Boom"

- This scenario assumes a short boom period (+2.6% annually for 5 years) occurs during the 30-year horizon, then remainder of the period is a return to 1.2% historic rate.
- Total scenario 2045 MPO-Area Population of 176,500.

Reduced High Growth: "Moderate Boom"

- This scenario assumes a short boom period (+1.8% annually for 5 years) occurs during the 30-year horizon, then remainder of period is a return to 1.2% historic rate.
- The "Boom" is smoothed across overall horizon for 1.3% annual population growth overall between 2015 and 2045.
- Total scenario 2045 MPO-Area Population of 169,800.

Moderate Scenario: "Continue Past Trends"

- This scenario assumes population growth consistent with historical (1985-2015) rates.
- This scenario yields a 1.2% annual growth.
- This scenario is consistent with Woods and Poole population projections.
- Total scenario 2045 MPO-Area Population of 164,500.

Reduced Growth Scenario: "Typical U.S. Urban Area"

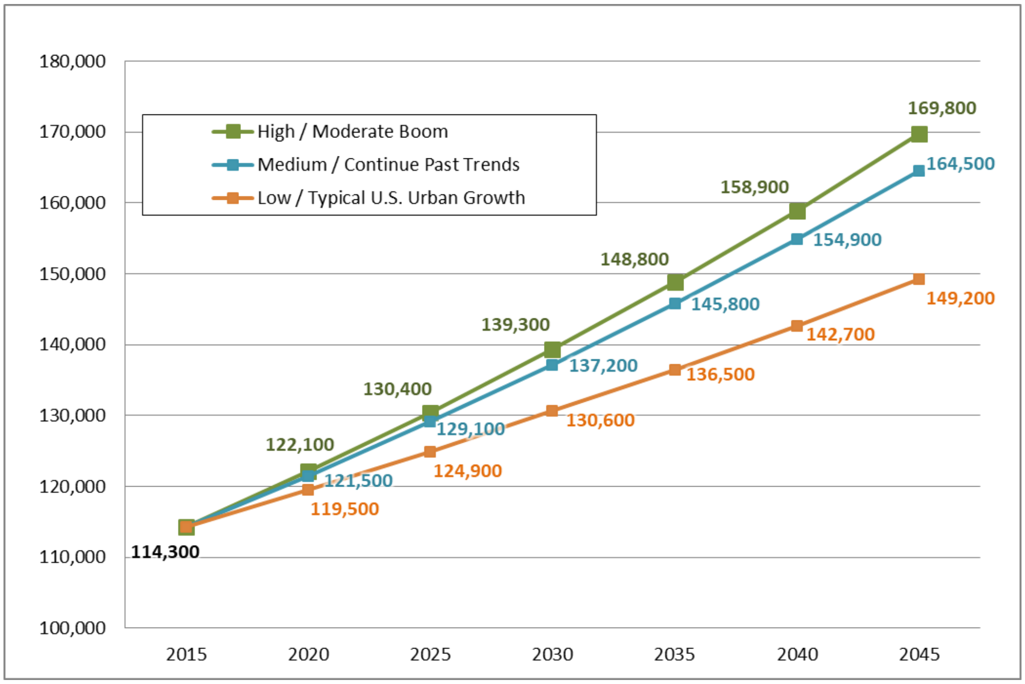
- This scenario assumes population growth at average U.S. Metro Area annual rate of 0.9% (below 1985-2015 trend).
- This scenario assumes growth that is somewhat lower than local historical rates.
- Total scenario 2045 MPO-Area Population of 149,200.

These four scenarios were presented to the MPO's TAC and Policy Board in December 2017. Based on the recommendation of the Steering Committee, the TAC and Policy Board decided to advance these three development scenarios for further consideration, and inclusion of all three in the scenario planning efforts of the Metropolitan Transportation Plan (MTP) update:

- High: "Moderate Boom" (previously "Reduced High Growth")
- Medium: "Continue Past Trends"
- Low: "Typical U.S. Urban Area"

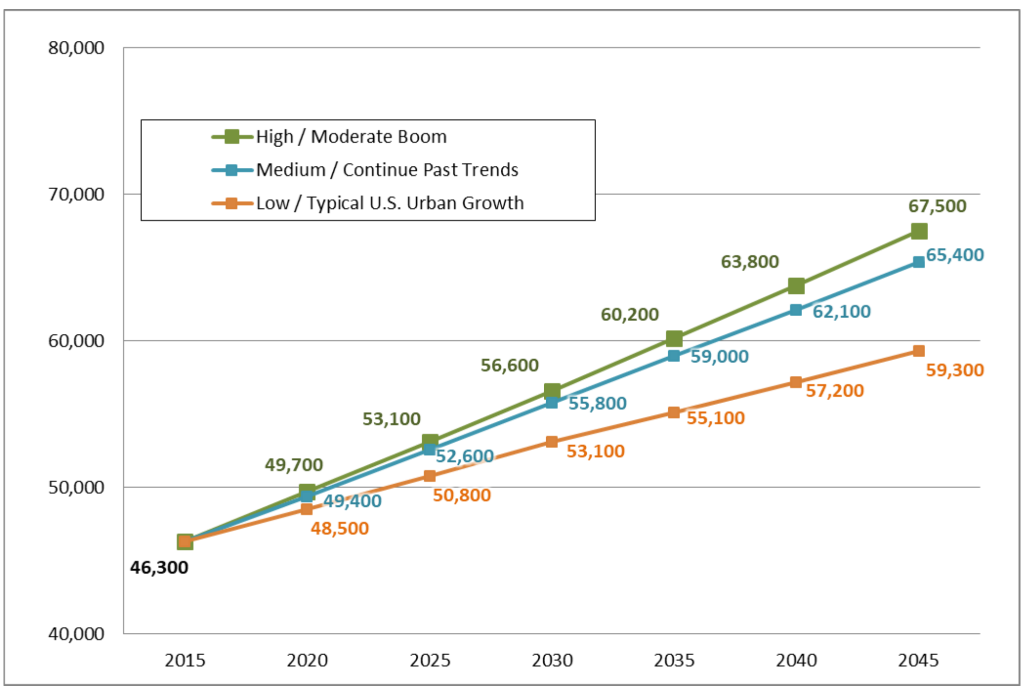
The MPO-area population growth associated with these three scenarios is illustrated in **Figure 10**.

Figure 10. Population Development Scenarios Considered for Bismarck-Mandan MPO



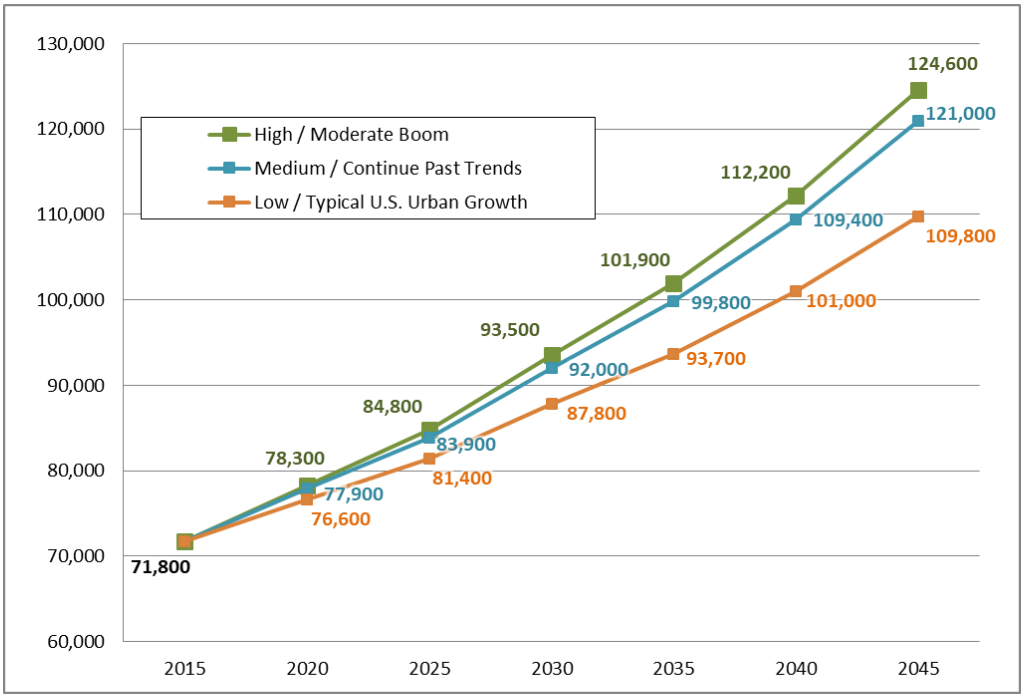
Future levels of households and employment totals were projected based on the trends from Woods and Poole for the three development scenarios established by the TAC and Policy Board. Household growth forecasts were derived by applying the household size factors identified in **Figure 8**. The resulting MPO study area household totals by scenario are illustrated in **Figure 11**.

Figure 11. Final MPO Study Area Household Development Scenarios for Bismarck-Mandan



Employment growth forecasts were developed by industry sector, based on projected trends from Woods and Poole. The resulting MPO study area employment totals by scenario are illustrated in **Figure 12**.

Figure 12. Final MPO Study Area Employment Development Scenarios for Bismarck-Mandan



Officially Adopted Development Scenario

For the MPO's planning purposes, it was necessary to select an official future development scenario. This official development scenario would be the baseline planning scenario for 2030 and 2045 planning purposes, including the basis for developing the "fiscally-constrained" elements of the MPO's MTP.

The process for adopting the official development scenario included discussions and decisions from three different groups.

Study steering committee

A presentation and discussion of the three final development scenarios was held with the steering committee on June 14, 2018. The purpose of this meeting was the selection of a recommended official MPO development scenario. The steering committee discussed the past and future economic and demographic trends, both within the metropolitan area and the wider state and nation, and decided that the Medium / "Continue Past Trends" scenario was the most reasonable scenario to use. The reasons communicated by steering committee members for this recommendation were:

- The medium or "Continue Past Trends" scenario reflects 30 years of booms and busts in Bismarck-Mandan, including the late 1980s (bust) and early 2010s (boom). Thus, the same highs and lows the region might experience in the future are reflected by this development scenario.

- Outside economic modeling from Woods and Poole provided very similar growth projections for Burleigh and Morton Counties.
- Recent research indicates the oil extraction industry and technology has matured, and even if a significant prolonged increase in oil prices occurs during the planning horizon it would likely require less of a worker influx than the recent oil boom.

Technical Advisory Committee

The MPO's TAC met on June 18, 2018, with an action item to provide a recommendation for selecting a development scenario. After a brief presentation and some discussion, the TAC forwarded the recommendation for approval of the Medium / "Continue Past Trends" scenario as the official MPO development scenario.

Policy Board

The MPO's Policy Board met on June 19, 2018, with an action item to approve a final MPO development scenario. After a brief presentation and some discussion, the Policy Board voted to adopt the Medium / "Continue Past Trends" scenario as the official MPO development scenario.

Development Allocation

The purpose of development allocation was to identify the location and timing of the new jobs and housing associated with the three future development scenarios. For the purposes of use in the TDM, this growth needed to be allocated to the transportation analysis zone (TAZ) structure of the model for the 2030 interim horizon or the 2045 planning horizon.

The allocation of future land development was rooted in:

- An understanding of current development densities (jobs per acre, housing units per acre).
- Local planning and development expertise on the land development market.
- Geographic Information System (GIS) mapping of recent building permits, future land use plans, and land suitability elements such as flood zones, elevations, and wetlands.

The development allocation was structured in sequential development tiers. The development tiers were a combination of year (either 2030 or 2045) and development scenario (low, medium, or high). Thus, six tiers were identified so that each growth area was assigned to a tier according to its assumed sequence of timing:

- Tier 1: Low / Typical US Growth Scenario for 2030
- Tier 2: Medium / Continue Past Trends Scenario for 2030
- Tier 3: High / Moderate Boom Scenario for 2030
- Tier 4: Low / Typical US Growth Scenario for 2045
- Tier 5: Medium / Continue Past Trends Scenario for 2045
- Tier 6: High / Moderate Boom Scenario for 2045

The tiers were structured to be additive, so the Medium / Continue Past Trends level of job and housing growth for 2030 included all of the development associated with Tiers 1 and Tier 2.

Current Development Densities

Typical development densities were identified through a review of current development patterns based on a combination of geographic information system (GIS) aerial photos, parcel data, and Infogroup employment data from the MPO. This review indicated the following typical development densities:

- **Multi-Family Residential**: 16 units / acre
- **Urban Single-Family Residential**: 2.6 units / acre
- **Rural Single-Family Residential**: 0.6 units / acre
- **Commercial**: 18 jobs / acre
- **Industrial**: 6 jobs / acre

Commercial developments looked at office developments and shopping developments separately, looking at the breakdown of service industry, retail industry, and "other" industry jobs for each. It was noted that more recent suburban commercial developments in the Bismarck-Mandan area had seen higher job densities. For instance, the area northeast of State Street and Century Avenue in Bismarck, which is a mix of retail, service, and office uses, has over 23 jobs per acre. In discussions with city planning staff, it was decided that future commercial developments would trend slightly towards being denser, so future commercial densities were assumed to be approximately 20 jobs per acre.

Similar to commercial, industrial developments looked at the breakdown of industrial industry, manufacturing industry, and "other" industry jobs for each. Many industrial developments in the region are relatively low-density and a relatively inefficient use of land. The city staff on the steering committee suggested more typical developments would trend towards a density of 6 jobs per acre for future developments.

Development Allocation Workshop and Revisions

Once the expected future development densities were established, the allocation effort transitioned into working with the steering committee, particularly members involved in planning and development within their jurisdiction, to identify the likely location and sequential timing of developments. This process involved first holding a workshop on February 28, 2018, which established the major growth areas and projected development timing by tier for the study area.

The workshop was an opportunity to identify the locations of future growth by type and timing. The major elements of the workshop involved:

- **Verifying 2016-2017 Development Areas**: The model is a 2015 baseline, so the future year data needed to incorporate any development that had occurred since Jan 2016. Much of this work was completed prior to the workshop, including reviewing updated building permit data in GIS, reviewing recent aerial photography to verify, and discussing reasonable jobs and housing assumptions for each recent development.
- **Reviewing On-going and Near-Term Developments**: The workshop participants identified ongoing and newly-platted commercial and residential developments. These developments were associated with Tier 1, as they were the most likely to occur next.
- **Reviewing GIS data to identify Mid-Term and Long-Term Developments**: The workshop participants discussed next likely parcels and groups of parcels for development, with an understanding of the development environment and constraints.

- **Discussing Infill Opportunities**: Planning staff identified opportunities for infill development in the downtown areas. In Bismarck, staff identified areas for potential commercial and residential development, based on an assessment of underutilized parcels in the downtown area. In Mandan, the *Mandan Downtown Subarea Study* was used as the guide for identifying the location and amount of development to assume. That study's "Hybrid Scenario" was viewed as the most reasonable infill redevelopment scenario, and was used as the basis for infill development for Mandan.
- **Discussing Development Details:** As the workshop went through individual parcels and groups of parcels for developments, comments were recorded on development timing, unique features on development density or type. These discussions informed how many jobs and how many housing units could fit within the identified development areas, and which Tier those areas would fall into.

Following the allocation workshop a first draft of the resulting development types and development timing was developed in GIS, with additional time spent refining development areas and jobs and housing calculations by area. This first draft was distributed to the steering committee for review and comment in March 2018.

Several iterations of follow-on small-group and individual conversations about refinement of the draft development allocation occurred in March and April 2018. The revised development allocation was incorporated into the TAZ structure, and submitted to the steering committee for review on May 2, 2018. Based on final comments received, the development allocation was finalized in May 2018. The final development allocation was presented to the TAC and Policy Boards at the June 2018 meetings. **Figure 13** shows the resulting allocation of households by TAZ. **Figure 14** shows the allocation of jobs by TAZ.

Figure 13. 2015-2045 Household Growth by TAZ, "Continue Past Trends" Development Scenario

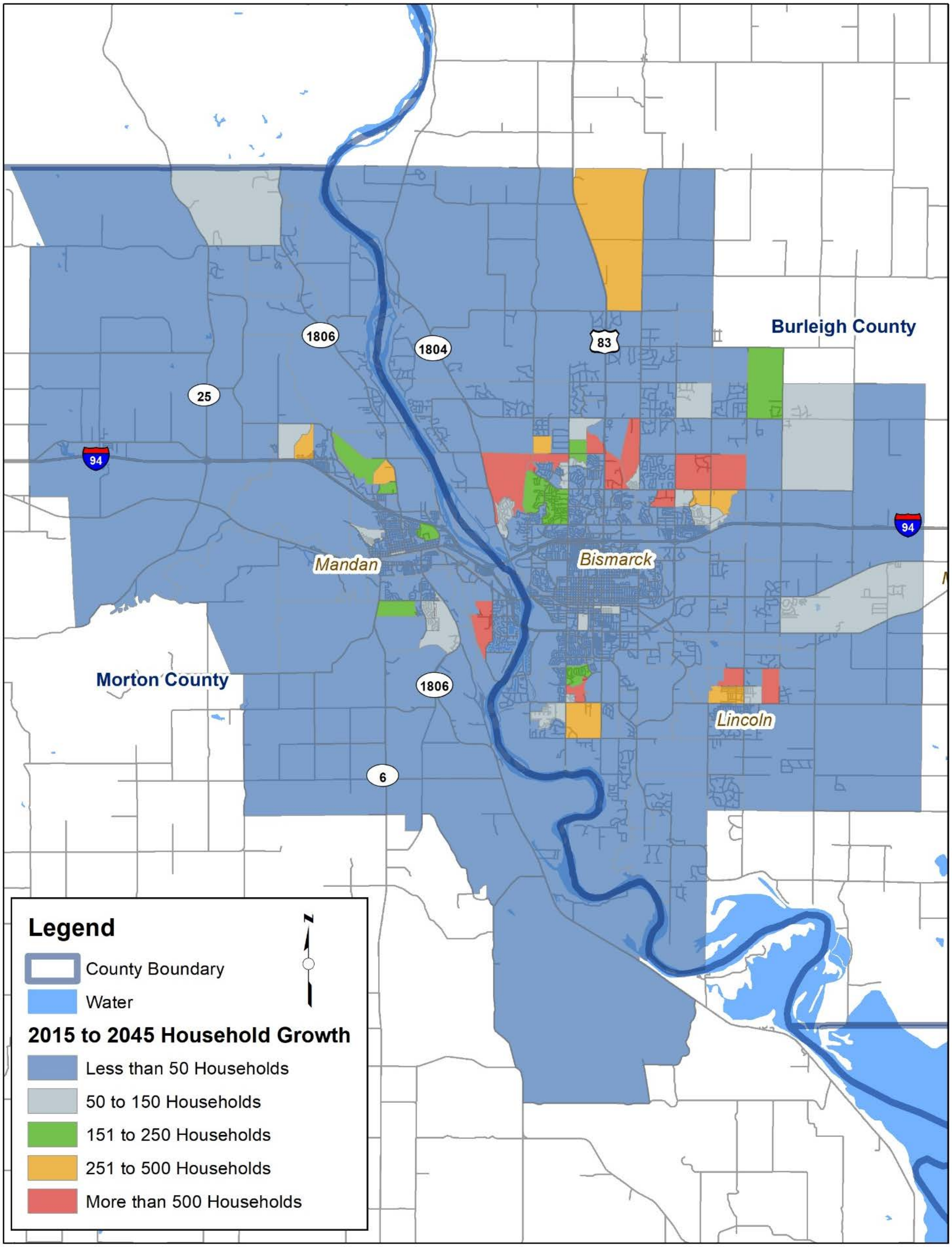
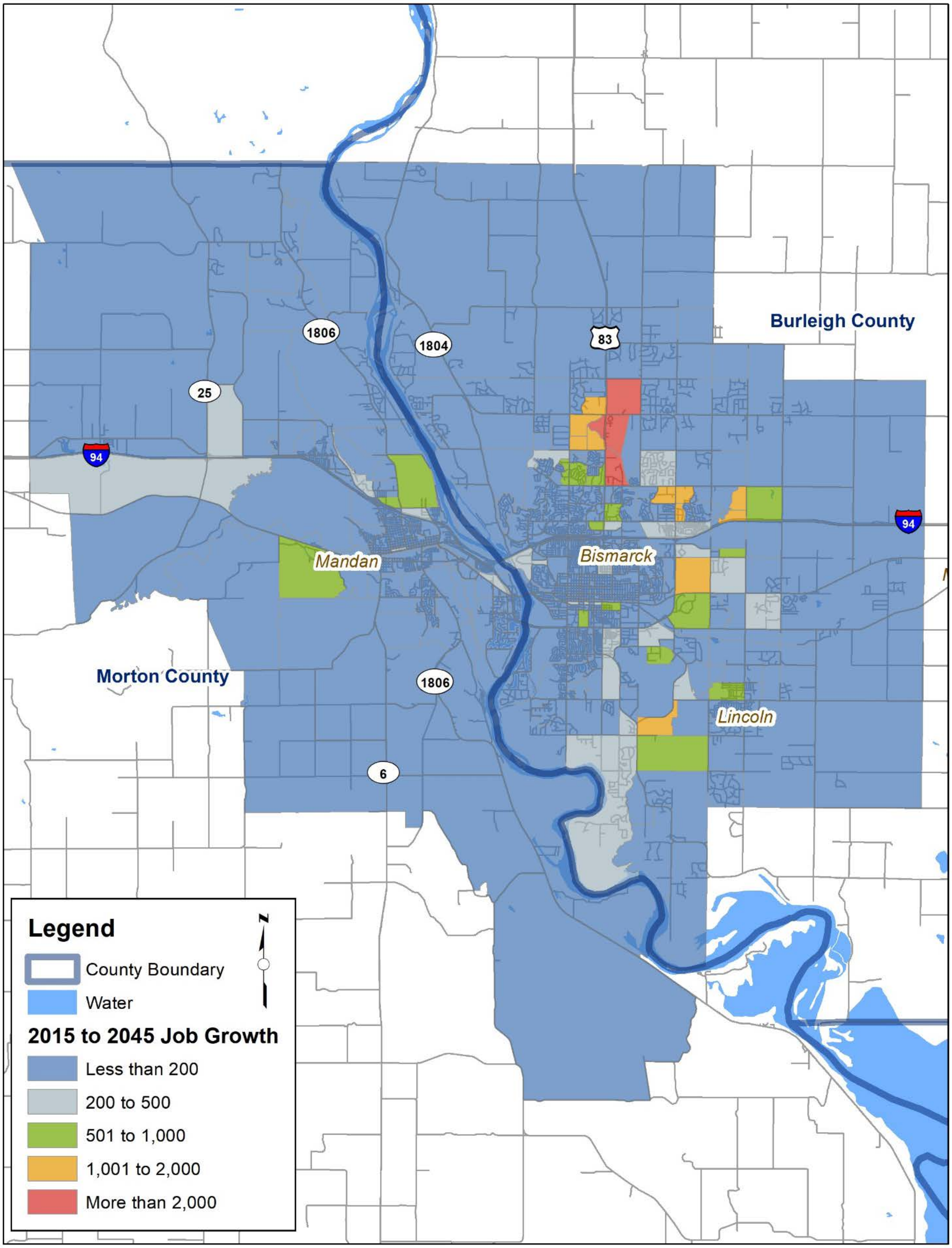


Figure 14. 2015-2045 Employment Growth by TAZ, "Continue Past Trends" Development Scenario



Travel Model Review

The overall goals of the travel model review were to:

- Identify how the MPO and its partner members use the travel model.
- Review model elements for consistency with local needs.
- Review the model for best practices.

Model User Interviews

Individual interviews were conducted with staff members from partner agencies, to get an understanding of how they use the travel model and its products. The interviews were conducted with individual staff members one-at-a-time, and a general set of questions was developed to facilitate the discussions. The questions asked included:

- What level of understanding does the staff member have on how the travel model works? Follow up discussions provided the staff member with more background information on the model and how it might be used by their agency, if desired.
- If the staff member had used output from the travel model to support decision-making on a project. If so, what types of projects? Did they use the model output directly, and if so how and what adjustments did they make to the model outputs?
- If sufficient documentation, context, assumptions, etc. were provided when model output was turned over for their project purposes.
- How did the staff member interpret the accuracy of model output for project development needs?
- Does the model provide the staff member the types of data they need to make project decisions?

In addition to discussing the model with MPO staff, the jurisdictional partners who were interviewed included:

- Mark Berg, City of Bismarck
- Justin Froseth, City of Mandan
- Marcus Hall, Burleigh County
- Michael Johnson, North Dakota Department of Transportation
- Ken Nysether, contracted by City of Lincoln
- Natalie Pierce, Morton County
- Roy Rickert, Bis-Man Transit
- Gabe Shell, City of Bismarck

Model Themes from Interviews

Several themes were identified through the responses received during the interviews. Based on those discussions, general model themes were:

Most Staff Have Some TDM Familiarity. Many staff at partner agencies understand how the model works. In general, staff that used model output understood that it was best used in a relative sense to inform understanding of traffic growth patterns.

The TDM is Mostly Used for Corridor Planning. By far the most frequent use of the model for the partner agencies is development of corridor-level traffic forecasts. Most partner agencies use model output to evaluate traffic volumes in corridors. Guidance on applying the TDM for use on corridor studies is provided in a later section.

Model Performance is Generally Sufficient, with Opportunities for Improvement. Staff generally seemed to think the model worked well, but that there were sometimes network coding errors and that could be updated. Most seemed to view the model as a constantly evolving tool.

Potential Model Enhancements Identified by Users. Some other notes from staff interviews included two potential enhancements compared to the previous 2010-2040 TDM.

- **Freight Model Integration**: Some of the staff noted that a truck-based freight model might be a good addition to the Bismarck-Mandan TDM if it provided reasonable outputs. ATAC staff have developed a commodity flow and truck forecasting element for the Bismarck-Mandan area as a part of the 2015 model update. This module is included in trip generation, but does not provide standard model outputs that can be easily reviewed. More discussion about future enhancements for a freight model is provided in the "Future Model Enhancements" section of this document.
- **"Mid-Cycle" Model Updates**: Some staff noted that as major new developments come on line and major roadway projects are completed, there might be some benefit to occasional updates to the future year existing-plus-committed (E+C) scenario model. TDM updates are usually made on a 5-year cycle, prior to the Metropolitan Transportation Plan being update. This approach might trigger a "mid-cycle" update to the model, to incorporate the latest information in the MPO's Transportation Improvement Program, and revisiting any land use updates that have occurred in the interim.

Support Traffic Forecasting Needs through Appropriate Model Application. Most staff understood that the TDM is a tool requiring interpretation, and not intended to be a perfect travel representation. Based on the interviews, the consultant recommends that staff have assistance interpreting TDM outputs when required. A detailed description of recommended practice for interpreting and applying TDM outputs is provided later in the "Model Application for Traffic Forecasting" section.

Model Technical Review

When developing a travel forecasting model for transportation planning applications, it is preferred for the TDM to be both:

1. A good representation of existing travel patterns, and
2. A flexible model that responds to transportation and socio-economic inputs.

When constructing the model, there can often be trade-offs between having good calibration accuracy, where the model is a good representation of observed travel characteristics; while also desiring a model that is not overly constrained, so that it can be primarily driven by the input transportation and socio-economic scenarios and responsive to future conditions.

The model technical review was intended to bring an independent review of all phases of the TDM. Thus, much of the technical review saw the consultant team focused on identifying best practices and an in-depth review of model processes and parameters. The goal was to inspect model adjustments and consider if they allowed the input data and assumptions to guide the output model results as would be expected.

This section provides a summary of the elements reviewed. A more detailed summary and discussion of the findings of the model review was provided to MPO and ATAC staff for model updates, and notes of the items discussed are included in the Appendix.

Model Input Data

The model input data are the items the modeler controls to test a scenario. The input data include socio-economic data (number and location of jobs and households) and roadway network data (travel speeds, number of lanes, and how intersections are controlled). The following data elements were reviewed.

Reasonableness checks of base year 2015 socio-economic data. The consultant worked with MPO staff on the development of 2015 socio-economic data, including methodologies for:

- **Developing Base Year 2015 Household Data**. The basis for the development of 2015 household data was to start with 2010 US Census data, and use building permit data for the years 2011 to 2015 to estimate where new households were formed. Recent US Census data on vacancy rates were used to convert housing units into households, and summarized by TAZ for 2015. Households were sub-allocated into estimates of household size and number of vehicles available to meet model requirements.
- **Developing Base Year 2015 Employment Data**. Infogroup employment data was the starting point for MPO staff to develop base year estimates of employment for 2015 by TAZ. MPO and consultant staff reviewed aerial photography and applied local knowledge of employers to verify and adjust employment by TAZ.

Review of base year 2015 roadway network coding. The consultant reviewed the TDM roadway network developed by ATAC staff that reflected 2015 conditions. This included reviews of:

- **Input network speeds**: The TDM uses posted roadway speeds as the starting point for estimating travel time across roadway links. The model review evaluated the TDM's input speeds compared to posted speeds.
- **Intersection control**: The TDM uses intersection control type (stop sign, traffic signal, yield sign, etc.) to estimate travel delays that occur for each approach to an intersection. The model review evaluated intersections in the model compared

Network Review

The TDM network is the model's representation of the functionally-classified street and roadway system, including Interstate, arterials, and collectors. The network includes details on travel speeds, segment length, number of travel lanes, and intersection control type.

to current real conditions, based on local knowledge and a desktop review (in Google Earth) of intersections.

- **Through lanes**: reviewing the number of roadway lanes in the model against the number of continuous lanes (non-turn lanes, non-auxiliary lanes) in the field, again based on local knowledge and a desktop review.

The findings of these roadway coding checks were provided to ATAC staff for incorporation into the TDM network.

Best practices for developing TAZ boundaries. The consultant collaborated with MPO staff on their update to TAZ boundaries. The effort focused on adding appropriate levels of detail, having boundaries that fit with the surrounding roadway network, and ensuring that the TAZs are at a scale that allows easy socio-economic data maintenance – particularly consistency with US Census Block Group Geography. The final TAZ geography is shown for the entire region in **Figure 15** and at a more detailed scale for the urban area in **Figure 16**.

Trip Generation

Trip generation is the first of the three steps the Bismarck-Mandan TDM employs[4]. The trip generation step evaluates the amount of households and jobs in each TAZ, and estimates the amount of trip making that occurs in that TAZ as a result. Several elements of trip generation were evaluated.

Trip production and attraction rates

The trip rates determine the number of trips generated per household (production) or job (attraction). Trip production rates are based on two characteristics of each household: the number of people in the household and the number of vehicles available to the household.

> **Trip Generation**
>
> Trip generation is the model process that estimates the number of trip productions and trip attractions for all TAZs. Trip productions are based on the number and type of households and trip attractions are estimated based on the number and type of jobs (and students for zones with schools).

ATAC used a combination of travel survey results from other metropolitan areas and national data such as *National Cooperative Highway Research Program (NCHRP) Report 716: Travel Demand Forecasting: Parameters and Techniques* to develop trip rates. These rates were reviewed by the consultant, and several adjustments were recommended and implemented by ATAC.

[4] Many TDMs have four steps: trip generation, trip distribution, mode choice, and traffic assignment. The Bismarck-Mandan TDM does not include mode choice, the step some models use where trips are estimated by mode of travel; typically by personal vehicle or transit.

Figure 15. Bismarck-Mandan MPO TAZ Geography, Regional Scale

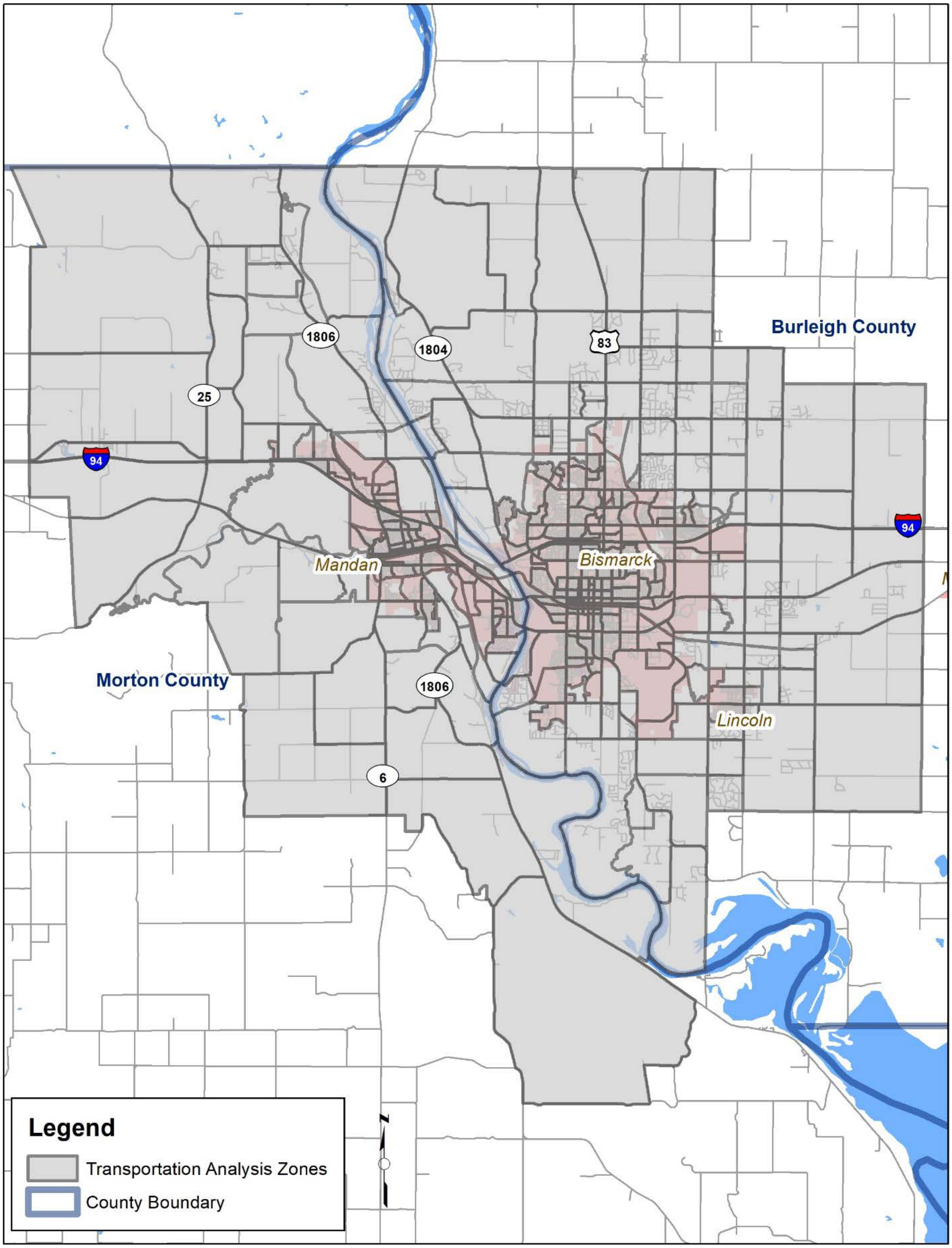
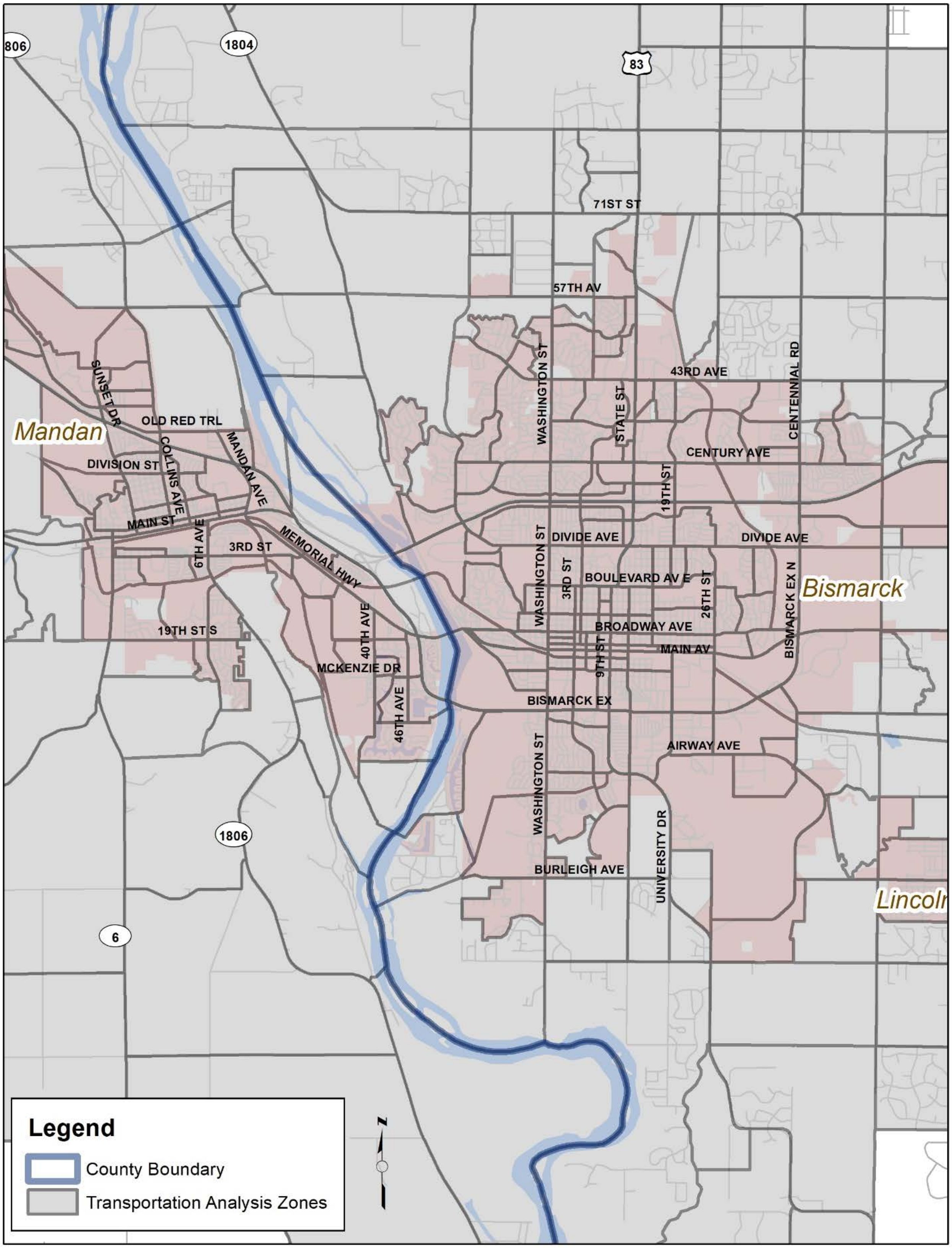


Figure 16. Bismarck-Mandan MPO TAZ Geography, Urban Scale



Trip productions and attractions balance

Travel models are estimates of travel, and not perfect representations. Since trip production rates and trip attraction rates are estimated based on two different data types (household data and employment data) they will yield different estimates. Productions and attractions need to be equal by trip purpose prior to trip distribution, and Bismarck-Mandan TDM includes a routine that balances trip attractions to productions. However, coming out of trip generation the goal is to have the ratio of unbalanced attractions be close to 1.0. Large differences might indicate issues with the underlying socio-economic data or trips rates. Initial versions of the TDM had large discrepancies between productions and attractions for several trip purposes. Trip rates and script calculations were reviewed and adjusted, and as a result the final model has unbalanced productions and attractions that are within +/- 10 percent of each other.

Best Practices for Trip Generation Rates

Trip production rates should increase as household size and vehicles available increase. The initial version of the Bismarck-Mandan trip production rates had some instances where larger households with more vehicles available had lower trip rates than smaller households with fewer vehicles available. This was a byproduct of survey data with a limited sample size in some household categories. This anomaly was flagged as an issue with the earlier version of the model, since this trend is inconsistent with national survey data, and would not have likely reflected actual experience in Bismarck-Mandan. Thus, the recommendation was to group survey categories together (e.g., households with 3 people and 3 cars added to households with 3 people and 4 cars) in larger sample clusters to get results that followed intuitive trends.

Trip Distribution

Trip distribution is the second of the three steps the Bismarck-Mandan TDM employs. The trip distribution step estimates the number of trips that are exchanged between all TAZs in the region. ATAC used AirSage origin-destination data for validation checks of how well the trip distribution model was performing. The distribution of home-based work trip lengths from the American Community Survey were also compared to model-derived trip lengths. After some initial adjustments through the review process, the data were generally comparable. More information on the trip length distribution comparison is provided in ATAC's *Bismarck-Mandan 2015 Travel Demand Model Update Report* (Appendix).

> **Trip Distribution**
>
> Trip distribution is the process of estimating the number of trips exchanged between all TAZs. The Bismarck-Mandan TDM uses the gravity model for trip distribution, which matches production to attraction zones by trip purpose based on the number of productions, attractions, and travel cost (a combination of distance and time).

Friction Factor Review

The trip distribution routine uses friction factors to specify the relative impact that travel cost (time and distance) have on the length of trip travelers are willing to make. Early versions of the Bismarck-Mandan model had relatively "flat" home-based work (HBW) friction factors with little cost variation between trip lengths; which made relatively long work trips attractive. The consultant pointed this out to ATAC staff, and alternative versions of the HBW friction factors were used that were more consistent with national practice.

Use of K-factors

K-factors are optional parameters that can be used in the gravity model. These factors are used when the quantifiable aspects of travel behavior that are not captured via productions, attractions, and travel cost / impedance. K-factors are sometimes referred to as "social" factors that cannot be explained by other model factors. While the use of K-factors can improve how well the model replicates survey trip patterns, they can also unnecessarily restrict the model's long-term forecasting capabilities. In order to maintain a flexible model for regional forecasting, it is recommended that K-Factors be used sparingly. State boundaries and major rivers are examples of applications that many consider appropriate for K-factors, as they are static, long-term sociological barriers that affect peoples' travel decisions that cannot be modeled with the available gravity model parameters.

Best Practices for Trip Distribution

The initial version of the model used several sets of K-factors. Consultant staff recommended eliminating all K-factors other than the Missouri River crossing if needed, and focusing on other modeling factors to address the underlying trip distribution issues. The final version of the TDM does not include any K-factors.

Traffic Assignment

Traffic assignment is the final of the three steps the Bismarck-Mandan TDM employs. Much of the traffic assignment verification goes back to the network reviews identified earlier in this section. The traffic assignment process and results were evaluated as part of the model review.

Traffic Assignment

Traffic assignment is the final step of the model, where each zone-to-zone trip exchange is loaded onto the network. Routes for each trip are selected so that costs (time and distance) are minimized. The traffic assignment process adjusts the travel time across a corridor as traffic volumes approach capacity to reflect the impacts that congestion has on travel time.

Traffic Assignment Performance

The primary check of traffic assignment performance is comparing model-estimated volumes to observed traffic counts, on segments where traffic count data are available. The traffic assignments are the primary product from the model that are used for planning purposes; thus, the traffic assignment performance and validation statistics often get the most attention. The model validation statistics look at statistics that compare the goodness of fit between model-estimated and observed traffic. In general, the 2015 TDM has traffic assignment validation statistics within acceptable guidelines. More details and these validation checks are provided in the ATAC *Travel Model Update Report* in the Appendix.

Feedback Loop Discussion

The Bismarck-Mandan TDM uses an equilibrium assignment approach, where estimated congested travel times are used, traffic is assigned to the network in multiple iterations, and travel times are recalculated. The equilibrium assignment iterations continue until convergence is achieved and no trips can have a shorter travel time by changing routes. The travel model includes a feedback loop, where congested times from the assignment module were fed back into the trip distribution step module, and distribution and assignment steps are run again with these congested travel times. The theory of the feedback loop is that travelers make trip destination decisions understanding congested travel times, and this step can add a level of realism to the model.

Best Practices for Traffic Assignment

It was noted that the initial version of the Bismarck-Mandan model did a single traffic assignment feedback loop, which did not include convergence for the loop. Consultant staff noted that this has the potential to add unwanted variability and instability in traffic assignment results between alternative model runs. As a result, ATAC tested feedback loops and convergence. ATAC added a second feedback loop to the model to add stability in between runs.

It is suggested that future versions of the model add convergence criteria to the existing loop structure, so that loops continue to run until convergence is achieved.

Sensitivity Testing

Sensitivity tests were run to see if the model responded reasonably to localized, yet significant changes to socio-economic data and roadway network additions. Two different sensitivity tests were completed.

Sensitivity Testing

The goal of the sensitivity tests was to evaluate the TDM's response to controlled changes to a model input variable. Socio-economic testing and network testing were completed.

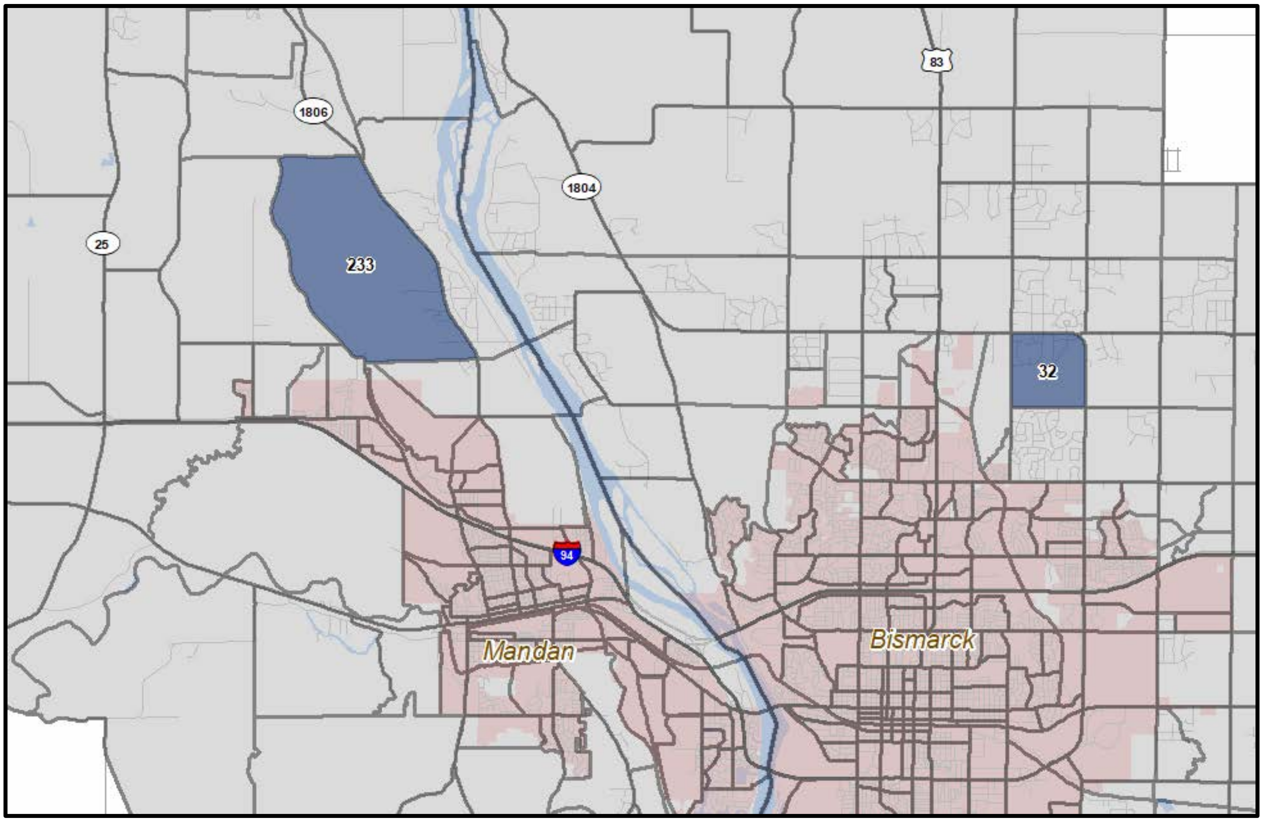
Socio-Economic Data Test

To test how the model would respond to changes in socio-economic data, jobs and households were added to two different TAZs on the fringe of the urbanized area in the 2015 model. The socio-economic data test made the following additions: TAZ 233 added 500 households and TAZ 32 added 200 retail jobs and 400 service jobs. The TAZs with added data for this model test are shown in **Figure 17.** In general, the results of this test were:

- TAZ 233 increased trip productions of 4,550.
- TAZ 32 increased trip attractions of 3,230.
- Vehicle Miles Traveled (VMT) increase of 24,600 daily, or 1.4%. This is approximately consistent with the growth in regional households, particularly with job and household growth placed on the edge of the current urban developed area.

In general, the results of the socio-economic data test were reasonable.

Figure 17. Socio-Economic Sensitivity Test Locations, TAZ 32 and TAZ 233



Roadway Network Data Test

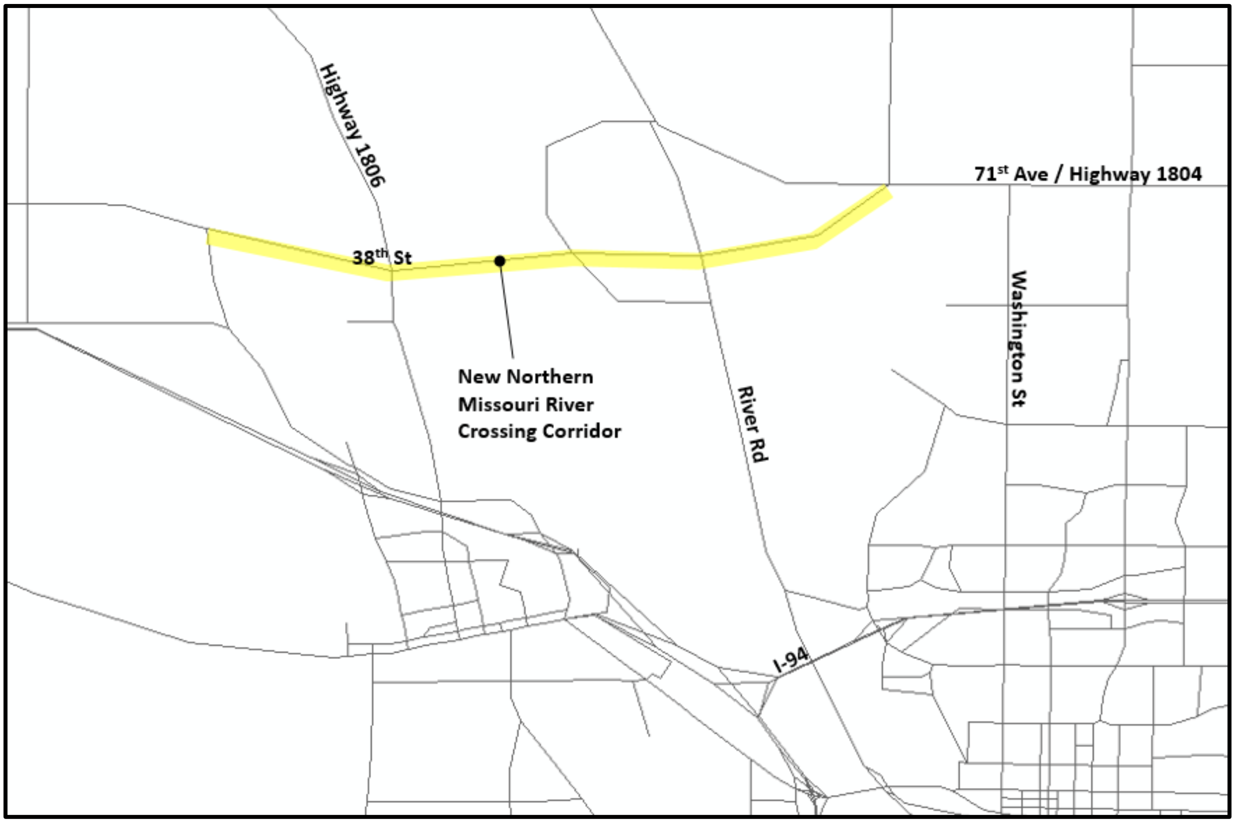
To test how the model would respond to changes in the roadway network, a northern Missouri River crossing was tested. The bridge was coded as a two-lane bridge with a corridor speed of 50 miles per hour, and connected from 71st Ave / Highway 1804 on the Burleigh County side to 38th Street at Highway 1806 on the Morton county side. The links added for this model test are shown in **Figure 18**. The general results of this sensitivity test were:

- The bridge attracted 5,850 vehicles per day in 2015.[5]
- The bridge diverted 3,800 vehicles from the I-94 river crossing and approximately 400 vehicles from the Liberty Memorial Bridge.
- The new bridge induced 1,600 new river crossings per day, or a 2% increase in daily river crossings.
- VMT decreased slightly, by 3,000 VMT daily (a change of 0.1%). This drop is reasonable for a major new regional connection like this, making some trips more direct while attracting new trips to cross the river.

As with the socio-economic data test, the results of the roadway network data test seemed reasonable.

[5] It should be noted that this was a test of the 2015 model, with moderate speed assumptions, and was not intended to reflect a preferred set of assumptions for any potential future Missouri River crossing corridor.

Figure 18. Roadway Network Sensitivity Test Location for Northern Missouri River Crossing



Model Application for Traffic Forecasting

As noted in the Model User Interviews section, the TDM is a regional-scale representation of land use and transportation, and not intended to be a perfect representation of reality. Minor roads are not included, traffic loading via centroid connectors or pseudo links are imperfect representations of actual side streets and driveway access, and not all jobs and households of the same type actually produce trips at the same rates. Thus, when applying the TDM to derive future traffic projections, some understanding and interpretation of model results are required. Three critical areas related to model application for travel forecasting are identified below.

Forecast Volume Post Processing

When comparing model-estimated traffic to observed traffic, there is always some level of corridor- or link-level error in the base year (2015) TDM volumes. The calibration and validation process attempts to limit this, but there is always some level of deviation between the two. "Post processing" traffic volumes is a practice that recognizes the imperfections of the model and attempts to address them. Post processing applies the level of deviation seen in the base year model and corrects for that error when model scenarios are run, typically for future year model scenarios. Thus, if the TDM is 1,000 vehicles per day low in Corridor A in 2015, a simplistic post processing approach would be to add 1,000 vehicles per day to Corridor A's future scenario model-estimated traffic volumes.

As noted in the 2012 Model Review Study[6], a typical post processing approach for the model user to employ could include:

1. **Comparing Model-Estimated Volumes and Observed Volumes**: In a GIS or within the model software, complete a link-by-link comparison of 2015 model-estimated daily traffic volumes ("assignment") to the observed 2015 daily traffic volumes ("count") where available. This comparison includes developing two different correction factors: an **absolute correction factor** and a **relative correction factor**.

2. **Calculating Correction Factors:** The two correction factors are calculated by:

- Absolute correction factor - calculated by subtracting the model traffic volume assignment from the observed traffic count. This absolute correction factor is calculated with the equation:

  Absolute Correction Factor = (2015 observed traffic count) – (2015 model traffic volume assignment)

- Relative correction factor - calculated by taking the observed count and dividing it by the model traffic volume assignment. This relative correction factor is calculated with the equation:

  Relative Correction Factor = (2015 observed traffic count) / (2015 model traffic volume assignment)

3. **Determining Which Correction Factor(s) to Apply**: For links with high levels of base year deviation and high growth rates, a relative correction could have unreasonably high impacts and skew post-processed volumes. Thus, it is important to select a deviation threshold. The deviation threshold is the point at which relative deviation is high enough that only an absolute correction will be applied. For links within the threshold (limited levels of relative

[6] *Bismarck-Mandan MPO Travel Demand Model Study*, URS Corporation, February 2012.

deviation), it is acceptable to post-process with both an absolute and relative correction factor.

The suggested threshold for this determination is a deviation within +/- 15% (a relative correction factor of between 0.85 and 1.15). These bullets illustrate how this correction factor would be applied:

- If the relative correction factor [(2015 observed count) / (2015 model assignment)] is between 0.85 and 1.15, both correction factors should be applied to the 2045 assignment and the results averaged.
- If the relative correction factor is less than 0.85 or greater than 1.15, apply only the absolute correction factor to the 2045 model traffic volume assignment.

Best Practices for Corridor-Level Forecasting

For project-level or corridor-level forecasting, it is recommended that traffic forecasts be smoothed according to detailed traffic counts available in the corridor. The level of detail in the TDM is not intended to represent every local road and driveway along a corridor. The following items should be considered for corridor-level forecasting:

- **Detailed hourly turning-movement traffic volume data should be collected in the corridor of interest**. These detailed turning movement volumes should represent existing conditions in the corridor. The TDM and forecasted traffic volumes (in daily terms) can be used to inform how much these base year turning movements are anticipated to grow or change. [7]
- **If critical design decisions are required for one of these local streets or driveways, a parcel-level traffic impact study is recommended** and would supersede site-level traffic forecasts from the TDM. Centroid connectors or pseudo-links are how the TDM gets traffic generated by the TAZ onto the TDM network. These connectors are rough approximations of the local street and driveway network. Typically, one centroid connector will represent multiple existing or future local roads and driveways. When doing corridor-level forecasts, it is recommended that centroid connector growth (comparing 2045 and 2030 models to the 2015 model) be assessed for the entire TAZ, and those growth rates be a general guide for how much total growth might be expected along all local streets and driveways for that TAZ**.**
- **For detailed corridor design projects, a simulation model might be warranted.** Decisions about the level of detail required for a corridor study vary from project-to-project, but in some cases a corridor micro-simulation model can be the best tool. The TDM can support development of this corridor-level simulation model, but several refinements in network detail, origin-destination table detail, and traffic characteristics might be applied to the TDM for use in the simulation model.

Best Practices for Regional-Level Forecasting

The TDM is well-suited for the regional-level forecasting required of the MPO. The model is the right tool for scenario planning, regional performance measures, and supporting development of the Metropolitan Transportation Plan. The model allows the user to manipulate input land use and roadway

[7] It should be noted that observed traffic volumes vary, sometimes significantly, from day-to-day. The TDM provides volumes representative of an average day. Thus, users should verify that the variation in traffic is accounted for and that it informs design decisions.

network characteristics, and see how travel patterns respond to those changes. When using the TDM for regional planning, some key items to keep in mind include:

- **Code Appropriate Future Intersection Control**. When testing potential future roadway projects, users typically will add lanes and change network connections. As rural areas transition to urban, and new roadway capacity projects are tested, it is important to also change intersection control coding to appropriate types. For instance, many current rural two-lane roads might need to be converted to urban 4-lane divided arterials between 2015 and 2045. Most of these rural intersections are currently coded as two-way or four-way stop controlled intersections. To get reasonable travel speeds on that corridor being tested, it is important to code an appropriate intersection control type for a four-lane arterial / urban treatment such as traffic signal.
- **Verify Future Travel Speeds**. As land develops adjacent to currently rural corridors in the 2030 and 2045 models, it is reasonable to adjust posted speeds for the urbanizing corridors. Currently rural corridors might be posted at 55 miles-per-hour, but when adjacent land is developed at urban densities and land use types, it would likely be posted at speeds consistent with suburban corridors (such as 40 or 45 miles-per-hour).
- **Provide Appropriate Centroid Connector Access to Future Roadways**. As new roadways are tested in the future model, the user should consider how adjacent land might access that roadway. It is important to make reasonable centroid connector / pseudo link connections to these new corridors to reflect reasonable levels of expected traffic loading.

Future Model Enhancements

Based on the model user interviews and the model review process, two primary future model enhancements were identified for implementation.

Freight Model Enhancement

A freight model was implemented for the 2015 Bismarck-Mandan model for the first time by ATAC. This element should be viewed as the first step towards implementation of a freight model for the Bismarck-Mandan TDM. Eventually it will allow the MPO and member jurisdictions to test the impacts that land use and network changes might have on truck flows. ATAC developed the regression-based truck model by using the Freight Analysis Framework (FAF) data from the Federal Highway Administration (FHWA). The freight element has not been calibrated and does not produce truck flows in the model output for users to review. Next steps for enhancement of this freight model might include:

- Use “big data” sources or a local travel survey to estimate Bismarck-Mandan-specific trip rates.
- Use Origin-Destination matrix estimation (ODME) techniques to get a better fit between truck flows and observed truck volumes.
- Adding a freight assignment element so users can review truck flows.

Time-of-Day Model Calibration

A time-of-day model was also implemented for the 2015 model for the first time. This addition is an improvement compared to the 2010 model, in that it now better reflects the impacts that peak period congestion can have on route choice, while allowing off-peak travel routing to occur with a representation of off-peak, uncongested travel. The previous 2010 model used only a daily model assignment and had some level of congestion assumed for all daily traffic routing.

ATAC developed the time-of-day factors that convert daily traffic into peak period traffic based on the AirSage data discussed earlier in this document. This is a reasonable data source to use as a starting point for developing a regional time-of-day dataset. During model review, the consultant noted that overall peak period delay areas seemed reasonable, but identified a few areas where congested speeds differed from expectations and provided these areas to ATAC for their review.

A next step would be a more rigorous calibration of the time-of-day element, using available peak hour traffic counts. This peak period calibration would provide an opportunity to refine the time-of-day factors.

Appendix

Bismarck-Mandan Model Review
Consultant Review of Model Script and Parameters

These notes reflect the consultant's review of the original set of model files received in July 2018, and ATAC's response and adjustments. The notes walk through each of the model steps and comments / responses. Some of the notes were direct questions about errors or potential areas to improve model performance or practice, while other notes were just discussion items for ATAC to consider and investigate. Many of the comments were made, understanding that making an adjustment in one step would likely have an impact on the issues identified in another step.

Build Network Process

- HDR comment: In the skim process, the calculated intrazonal distances in the matrix diagonal use the same "nearest neighbor" function as time, but a comment in the script says to set intrazonal distance to 0. Reconcile.
    - ATAC Response: Fixed this.
- HDR staff provided detail check reviews of input link speeds, lanes and traffic signal control (stop sign versus signal control)
    - Submitted to ATAC in August, 2018.

Trip Generation Rates

- Special Generators
    - HDR Noted that some special generator rates changed between base model and future model rates. Is this intended?
        - ATAC response: this part of the script is not active, but are testing it for potential future use. Might be used for scenario testing and Connected / Autonomous Vehicle scenarios.
    - HDR noted that there is a script typo maybe with the statement "TAZ_2015=6244" in the special generator routine – 6244 is not a TAZ.
        - ATAC response: not using this part of the script for now. He did fix it in case the script ever got activated for scenario testing.
- HDR noted that the balance of productions and attractions is very unbalanced coming out of trip generation for HBSH, HBO, and NHB.
    - ATAC response: after other suggested changes with trip rates, the percentage difference between trip productions and attractions for HBSH, HBO and NHB is 4%, 4% and 9% respectively.
- HDR noted that attraction rates were quite high for HBSH, HBO, and NHB? Might relate to retail attraction rate noted below.
    - ATAC response: the attraction rates for the three categories were adjusted.
- HDR noted some issues were observed in production cross-class rates:
    - Use caution basing trip generation rates on very small samples.
        - Many of the cross-class rates are likely based on a handful of observations.
        - While the numbers may reflect survey observations, but they may not be statistically significant.

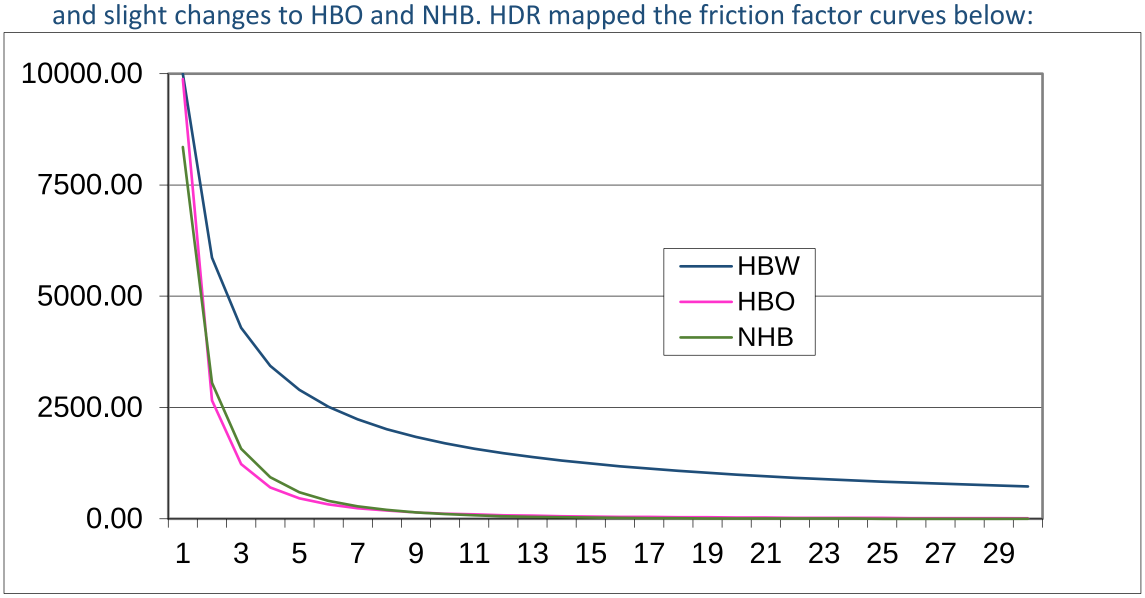
        - When using survey results (especially for smaller communities), consider aggregating rates across a few major categories.
    - Example in the data: we noticed instances where lower car ownership households have higher trip rates than higher car ownership households (e.g., 3 person / 1 car HH = 3.99 trips, 3 person / 2 car HH = 1.88 trips).
        - Access to cars is the only explanatory / independent variable being exerted here, so this does not make sense.
        - Many zero car households have NO trips (this is not reasonable)
        - HDR provided options to address this issue:
            - Factor according to NHTS / NCHRP 716 rates
            - Group rates together – essentially apply weighted average of 0 car – 2 car households for 3 person households, and apply to all three cells.
        - ATAC adjusted the trip rates by combining categories and using average trip rates.
- HDR noted that trip Generation adjustment factors were applied for 2 subareas (Bismarck along I-94, Bismarck along Divide). Observations on this issue:
    - Make sure the underlying issue is not more structural before applying these trip rate adjustments – which seem arbitrary on the surface.
    - Is the I-94 trip adjustment reflecting a trip length issue? or a trip rate issue?
    - Divide area – does it include State Capitol? If so, are trip rates for state employees too high / low? Or does state employment need to get distributed elsewhere? (check 2010 model for SE data consistency).
    - Goal is to eliminate these special subarea trip generation factors, addressing some of the other issues noted in this review.
        - ATAC eliminated these subarea adjustment factors in the trip generation – other suggested changes addressed the underlying issues.
- HDR noted that retail-based jobs have trip rates that are unexpected:
    - Total attraction rates were high (~18 trips / job – 2x more than other documented sources)
    - Retail rate generates more for HBO than for HBSH – this is non-intuitive.
    - Reducing retail attraction rates might address the attraction – production misbalance coming out of trip generation.
        - ATAC reduced total trip attraction rates for retail based jobs are reduced from 19.084 trips/job to 9.484 trips/job. ATAC noted that the retail attraction rate for HBO is 1.1 now compared to 5 for HBSH which is intuitive, and that the reduction in retail trip attraction rates addressed the production and attraction imbalance issue.
- HDR noticed that PM NHB trips had an erroneous coefficient in the step where it summarizes Trip Distribution: MW [7] = (MI.3.6 + MI.4.6 + MI.6.6)*.5 + (MI.3.6 + MI.4.6 + MI.6.6)***5**
    - ATAC confirmed that this was an error and it was corrected - the coefficient should be "0.5" instead of "5". This fix improved the overall model results.

Time-of-Day Factors

- HDR inquired where the TOD factors come from.
  - ATAC responded that the AM, PM and Off Peak percentage factors were estimated from airsage data. The directional distribution factors were taken from literature.
- HDR noted that some of them seem asserted, rather than based on data. For instance, HBW AM peak is 99% Productions, 1% Attractions. Agree that majority of AM work trips are productions, but this seemed synthetic. Suggested ATAC review this.
  - ATAC noted the percentages are from NCHRP 716 (based on the National Household Travel Survey), but that there was a calculation mistake. They recalculated and addressed the issue with a new proportion that is now 96% P and 04% A.
- HDR noted that the18% of daily traffic during the AM peak seems high compared to typical.
  - ATAC noted that 18% daily traffic during the AM peak does seem high but came from the Airsage data.
- HDR asked if the peak hour modules been validated against peak hour traffic volumes?
  - ATAC noted that they were not, as they did not have the peak hour traffic volumes.
- HDR noted that simple peak hour model checks (such as screenlines) against observed peak counts might be beneficial, if available.

Trip Distribution

- HDR noted that a doubly-constrained gravity model tends to be best practice to conserve productions and attractions out of trip distribution.
  - ATAC noted that the gravity model used in the trip distribution is doubly constrained.
- HDR noted that the friction factor curves were very flat for HBW (longer trips encouraged), and VERY steep for HBO and NHB.
  - HBW might be fine, as HBW trips are longer
  - HBO and NHB might be leading to some of the other issues identified in this discussion (need to increase trip rates, etc).
- HBO trip friction factor curve is virtually vertical between 1 and 4 minutes.
  - ATAC made updates to friction factors that addressed HBW trips with a steeper curve, and slight changes to HBO and NHB. HDR mapped the friction factor curves below:



- HDR noted that in the original model files, there were several k-factor matrices observed, including crossing I-94, Missouri River, and AirSage-based K-factors
    - HDR noted that the Missouri River K-factor was non-intuitive to have a K-factor >1 to use bridge. Usually the interchange across a barrier like a river requires <1 k-factor.
        - Is it a bridge access / network issue?
        - Is it a trip length issue?
        - Goal is to have no k-factors or very small values in isolated applications.
        - We like that the only K-factor applied is between counties / across Missouri River.
    - ATAC's original adjustments were to scale back to only the Missouri River K-factors were applied, with AirSage used to validate Burleigh-to-Morton flows. The final version of the model had no K-factors.
- School trip distribution:
    - Any sort of varying friction factors / Trip Length distribution implemented to keep public school trips within community schools? (at least making K-6 trips shorter than 9-12 trips?)

Feedback Loop of Congested Feeds:

- HDR noted only 1 feedback loop iteration with no convergence criteria.
    - Panelists noted that a lack of feedback convergence can add unwanted noise and instability between alternatives runs
    - Suggest adding a convergence criterion to the existing loop structure to limit volatility between alternative runs.
    - ATAC noted that they tested it with multiple feedback iterations with similar results, and were concerned with long run times with several iterations. For now, model will have two feedback loops anticipating that it will converge with most scenarios.

Traffic Assignment / Cost function:

- HDR noted two different sets of BPR functions for link delay, but there was also node-based coding of intersection control types for delay.
    - ATAC noted that the link and node-based a hybrid approach that incorporates both. They also noted that they were testing two different BPR formulations and settled on one. One used a table and one was incorporated directly into the network. At no time were the two BPR parameters being used at the same time.
- HDR noted that in the assignment cost function, uncongested speeds (T0) appeared to be used for the link costs, not congested speeds (TC)
    - ATAC checked with the software developer (Citilabs), and confirmed that the model needed to feed congested speeds (TC), not T0. This error was fixed in the final model.
- HDR noted that distance has a substantial weight on it (44%), almost as much as time (56%). This was not flagged as an error, but something that could be tested to see if maybe time should be weighted more highly.
    - HDR asked if this weight on distance potentially impact interstate traffic levels (high or low)? Or bridge crossings?
    - While some MPOs have a distance component in assignment, first calibrate and validate each of the models before using band aids to fix potential upstream problems.
    - If Interstate volumes are an issue (low or high), look at ramp speeds, Interstate alpha and betas for BPR function, node delays at ramp terminal intersections, etc.
    - ATAC adjusted the distance weight down to 24% and time up to 76% weight.
- HDR noted that the node delays are a little bit of a "black box" to review, and that ATAC should use validation checks below to verify corridor travel speeds are appropriate.

- ATAC noted that the model uses intersection data in the model instead of true node delay. They believed that this would treat intersections more neutrally, and provide a better way to calculate node delays.

Recommended Validation checks

HDR provided some recommended validation checks to ATAC:

- Trip length distribution checks:
  - Compare HBW modeled trip length distribution vs CTPP/ACS trip length distribution
  - Compare other trip purposes vs. AirSage data for internal-internal trips
    - ATAC completed this, and it is in the document. (shown below)

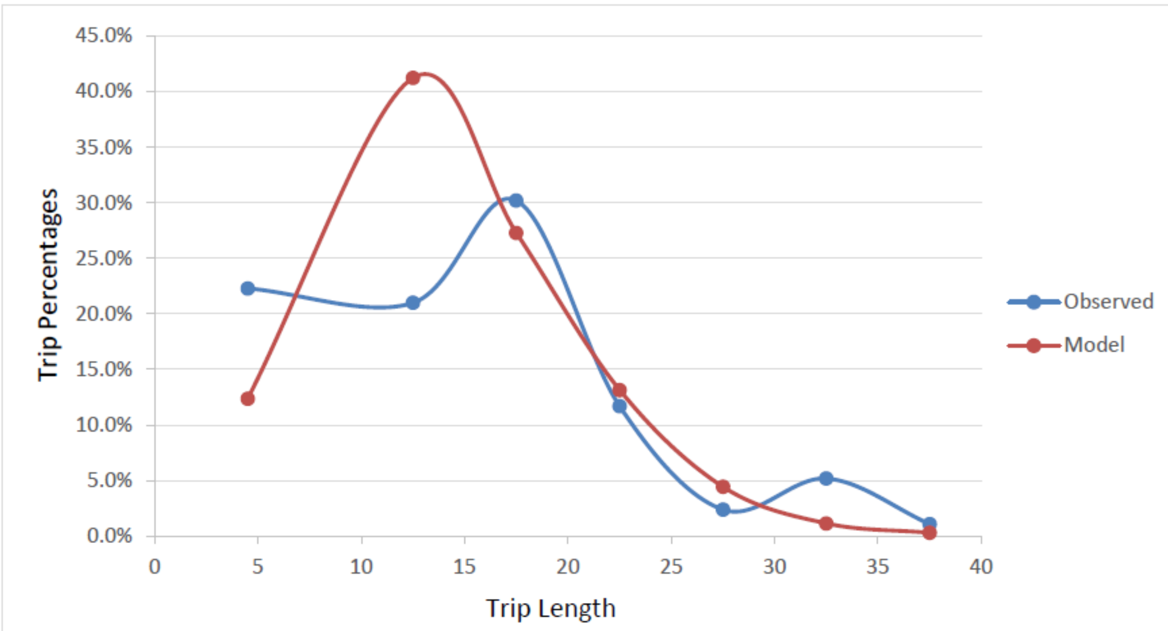


Figure 8 Comparison of Observed to Model Trip Length Frequency

- Travel times - are traffic skims consistent with observed corridor travel times?
  - Check congested travel time between multiple origins-destinations with available sources (even Google maps peak travel times)
- Performed appropriate network checks (QA/QC) been performed for discontinuity, erroneous link assumptions, or other problems. Recommend assign a matrix of ones to see if there are any issues.
  - HDR reviewed input speed codings and node control
  - ATAC noted that they performed internal reviews for appropriate network checks. Note that the model is for 2015 base year network. Some of the updates recommended were done after 2015 which may show up on google maps.
- Report traffic assignment goodness-of-fit checks in a range of ways:
  - RMSE by functional class and volume category
  - Over-under by functional class and volume category (ATAC standard practice)
  - Flows of model and counts along screenlines
  - VMT by functional class and volume class

- Potentially others in *Travel Model Validation and Reasonability Checking Manual, 2nd Edition*
    - ATAC completed a range of validation checks in the document.
- HDR selected several of the key validation / calibration reports from the ATAC document provided in September 2018, and provided below. Overall model statistics after the model adjustments were made are acceptable.

Table 18 Modeled VMTs compared to Observed VMTs by Functional Class

Functional Class	Observed VMT	Modeled VMT	% Diff
Interstate	161,586	164,118	1.5%
Major	477,944	475,752	-0.5%
Minors	279,917	288,078	2.8%
Collectors	133,668	130,090	-2.8%
Locals	-	-	0.0%
Total	1,053,116	1,058,037	0.5%

Table 19 Modeled VMTs compared to Observed VMTs by Volume Range

ADT Range	Observed VMT	Modeled VMT	% Diff
ADT >25,000	65,493	65,661	0.3%
25,000 TO 10,000	482,717	460,271	-4.9%
10,000 TO 5,000	296,125	295,139	-0.3%
5,000 TO 1,000	198,740	217,764	8.7%
ADT<1000	10,041	19,203	47.7%
	1,053,116	1,058,037	0.5%

Table 20 Comparison of Modeled and Observed ADTS by Functional Classification

Functional Classification	Below Criteria	Within Criteria	Above Criteria	Total	%age Within	RMSE %
Interstates	0	10	0	10	100%	7%
Major Arterials	22	135	21	178	76%	26%
Minor Arterial	29	131	30	190	69%	26%
Collectors	23	138	13	174	79%	70%
Locals	0	0	0	0	100%	0%
Total	74	414	64	552	75%	
Percent	13%	75%	12%			

Table 21 Comparison of Modeled and Observed ADT by Volume Range

ADT Range	#Above	#Within	#Below	%Within	RMSE
ADT >25,000	0	13	1	93%	8%
25,000 TO 10,000	9	96	33	70%	20%
10,000 TO 5,000	24	101	29	66%	31%
5,000 TO 2,500	13	92	11	79%	38%
2,500 TO 1,000	11	90	0	89%	72%
ADT<1000	9	33	0	79%	217%
Total	69	427	68	75%	

Table 22 RMSE Comparison by Volume Range

Volume Range	RMSE (%)	Typical Limits (%)
AADT>25,000	8%	15-20 %
25,000 to 10,000	21%	25-30 %
10,000 to 5,000	33%	35-45 %
5,000 to 2,500	38%	45-100 %
2,500 to 1,000	72%	45-100 %
AADT<1000	217%	>100 %

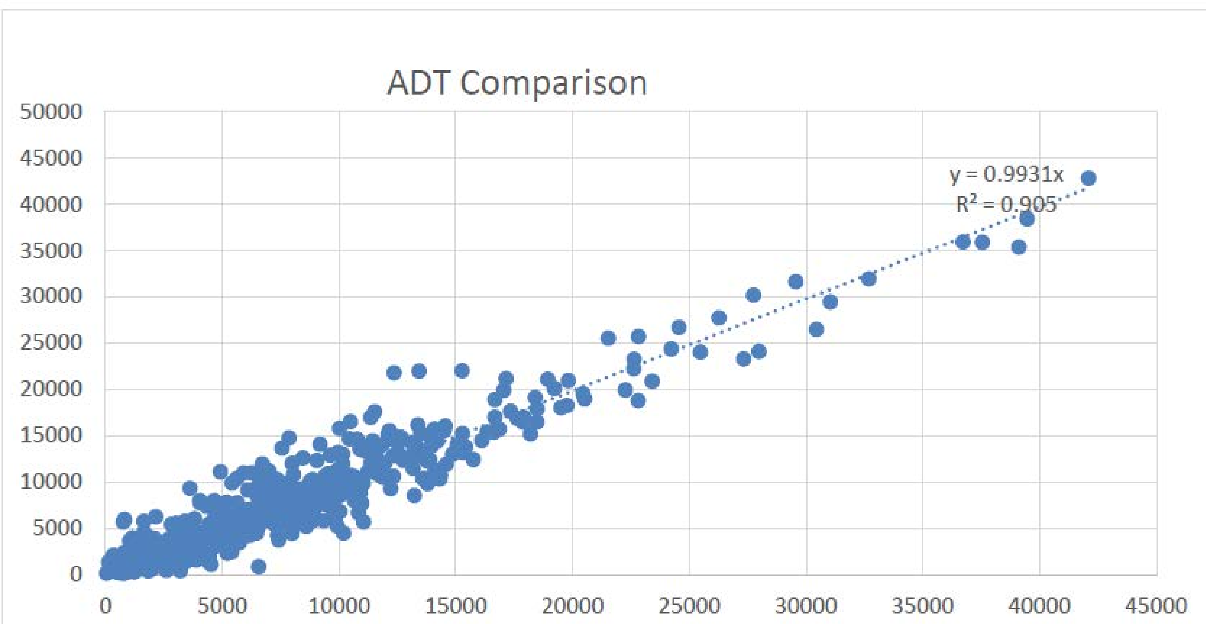


Table 23 Travel Time Validation

Link Type/Location	Distance (Miles)	Observed Travel Time (Min)			Modeled Travel Time (Min)		
		AM	PM	OFF	AM	PM	OFF
Principal Arterials							
State St - Century Ave to East Divide	1	3	3	3	2.92	2.65	2.36
Washington St - 43rd Ave N to Boulevard	3.3	5 to 8	5 to 8	5 to 7	9.98	6.83	5.09
Bismarck Expressway - Washington St to 5th Ave	3.6	6 to 10	6 to 12	6 to 12	7.08	7.54	6.69
W Main St - 6th Ave NW to Memorial Hwy	1.3	4 to 6	4 to 6	4 to 6	5.31	3.58	3.55
Minor Arterials							
Divide Ave - Washington St N to 19th St N	1.5	4 to 6	4 to 7	5	4.6	4.63	3.62
Broadway - Washington St to 16th St N	1.3	5 to 6	5 to 7	5 to 7	4.46	3.78	3.45
Highway 1804 - US Highway 83 to 80th St NE	5	7	7	7	5.53	5.61	5.47
1st St - Sunset Dr to Mandan Ave	1.3	4 to 6	4 to 6	4 to 6	5.13	4	3.73
Collectors							
C Ave - Griffin St to 16th St N	1.5	6 to 8	5 to 6	6 to 7	5.35	4.97	4.06
Interstate Ave - Century Ave W to State St	1.8	4 to 7	5 to 7	5 to 7	4.74	4.16	3.7
3rd Ave - Division St to W Main St	0.6	3	3	3	2.39	2.19	2.18

Table 24 Screen Line Comparison

Screen line	Modeled	ADT	% Difference	Difference
Railroad	86,858	88,309	1.6%	1,451
I-94	141,512	141,200	-0.20%	(312)
Missouri River	75,766	72,645	-4.30%	(3,121)

Bismarck Mandan 2015 TRAVEL DEMAND MODEL UPDATE

DRAFT REPORT

To the Bismarck Mandan MPO

September, 2018

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Advanced Traffic Analysis Center

Upper Great Plains Transportation Institute

North Dakota State University

Fargo, North Dakota 58102

TABLE OF CONTENTS

1. INTRODUCTION

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

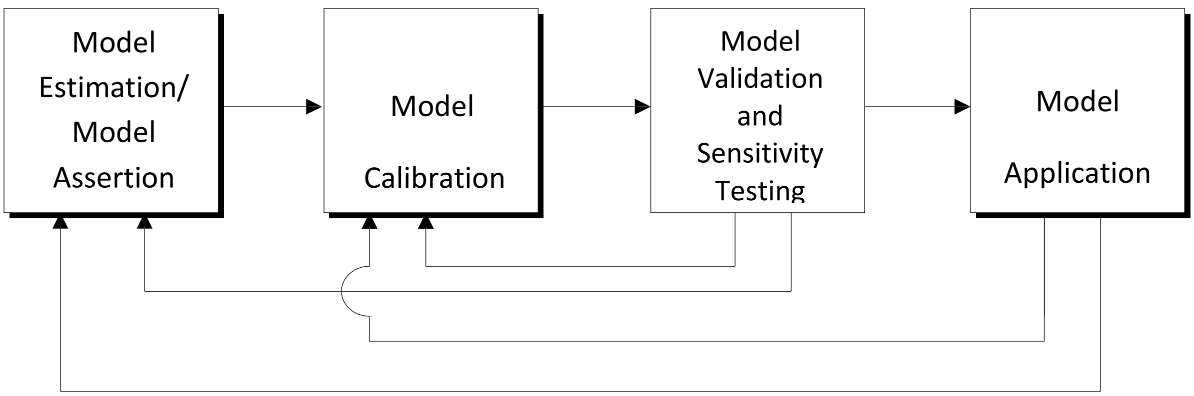


Figure 1 B-M TDM Calibration Flow Chart

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 2015 TDM; Chapter 3 discusses the capacity calculation methodology; Chapter 4 discusses the input data used in the model; Chapter 5 summarizes the trip generation models and methods; Chapter 6 discusses the trip distribution step; Chapter 7 discusses the trip assignment step; Chapter 8 discusses the model calibration, validation and output.

2. IMPROVEMENTS TO THE 2015 TDM

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

2.1. Origin Destination Data Obtained from Airsage

Origin-destination (OD) data were obtained from a commercial vendor Airsage. Airsage is a company that aggregates cell phone cellular-signal data points anonymously in partnership with the nation's largest wireless carriers. Origin Destination data were collected for the entire North Dakota and external locations rather than for the B-M MPO area only. Overall, a total of 301 OD TAZs were used. OD TAZs are defined as TAZS that were used in the OD survey data collection. Of the 301 OD TAZs, 52 were TAZs internal to the B-M MPO area. The internal OD TAZs were an aggregation of the TAZs in the B-M TDM which had a total of 406 TAZs. Figure 2 shows the overall OD TAZs and the B-M MPO TAZs geographies.

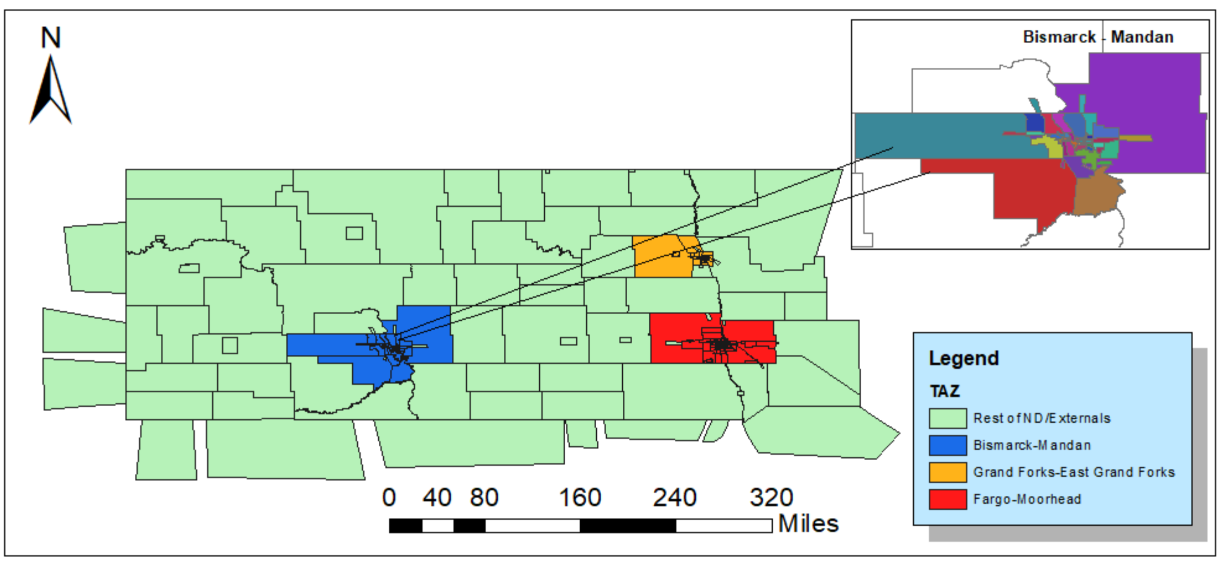


Figure 2 OD TAZs

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

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

2. Average Weekday Peak Hour matrices (7:00AM-10:00AM, 10:00AM-4:00PM, 4:00PM-7:00PM) by trip purposes. Four Matrices were provided for different socioeconomic variables including age (5 year cohorts), income ($10,000 increments), and vehicle attributes (0->5 for rent/owner households).
3. Weekend matrices for each of the weekends of October 2015 by trip purposes (HBW, HBO, NHB). Four Matrices were provided for different socioeconomic variables including age (5 year cohorts), income ($10,000 increments), and vehicle attributes (0->5 for rent/owner households) for each weekend.
4. Long Distance ODs, showing external-external trips for the full day for both weekday averages and each weekend for HBW, HBO and NBH trips. No socioeconomic data were provided for these matrices.

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

2.1.1. Internal-Internal OD Trip Summary

The data shows the trip purposes by time of day, Peak AM, Peak Afternoon, Peak PM and Night trips. For HBW trips for the B-M MPO TAZs, night period had the highest proportion of trips (29%) followed by the late-morning to early-evening period (28%), AM peak (25%) and the PM Peak period (17%). The late-morning to early-evening period had the highest proportion of HBO trips (32%), followed by the PM peak (20%) and AM Peak 16%. This is expected and possibly because fewer non-work trips originate from homes during the morning peak period. Trip activity locations such as malls, schools, walk-in hospitals, banks, typically open after 8:00AM. For NHB trips, the late-morning to early-evening period again has the highest proportion of trips (42%), followed by the PM Peak (22%), night period (20%) and the AM peak (16%).The % overall column reflects the percentage of trips that had at least one end in the Bismarck Mandan MPO area with respect to the entire dataset. 11% of HBW, 15 % of HBO, and 15% of NHB, of total trips in the overall North Dakota data had trip ends in the B-M MPO area.

Table 1 Summary of Internal-Internal OD Data from Airsage

Bismarck-Mandan MPO TAZ OD Trips						
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**	**% of Overall**
HBW	5,099	5,842	3,531	6,054	20,526	11%
HBO	18,973	37,378	23,376	36,762	116,489	15%
NHB	26,000	69,064	37,108	33,969	166,141	15%
Total	50,072	112,284	64,015	76,785	303,156	15%
Proportions by Trip Purpose and Time of Day, B-M MPO TAZs Only						
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**	**% of Overall**
HBW	25%	28%	17%	29%	100%	11%
HBO	16%	32%	20%	32%	100%	15%
NHB	16%	42%	22%	20%	100%	15%
NHCRP 718 Time-of-day Distributions by Purpose						
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**	
HBW	25%	22%	26%	27%	100%	
HBO	15%	38%	26%	21%	100%	
NHB	15%	53%	21%	11%	100%	

The data were further disaggregated to reflect the different proportions of trips by purpose and type for different external locations. The external locations were distinguished as North, South, East and West with Interstate 94 and U.S. Highway 83 the main highways trips used for entry/exit to the B-M MPO area.

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 9% of the total trips for the B-M MPO OD study area. For HBW trip purposes, the proportions of EI/IE 7% of the total trips and ranged from 6% to 9% for the different time periods. For HBO trips, the IE/EI made up 8% of total trips and ranged from 7% to 9% for the different time periods. The NHB trips were for IE/EI where 11% of the total B-M NHB trips and ranged from 9% to 12% for the different time periods.

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

Total IE Trips					
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**
HBW	684	748	567	1,252	3,251
HBO	3,458	5,559	3,429	7,316	19,762
NHB	7,351	15,513	7,706	8,560	39,130
Total	11,493	21,820	11,702	17,128	62,143
Percentage of IE Trips to Total Trips for B-M Data					
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**
HBW	6%	6%	7%	9%	7%
HBO	8%	7%	7%	9%	8%
NHB	12%	10%	9%	11%	11%
Total	10%	9%	8%	10%	9%

2.1.3. External-External OD Data

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

1. Select all OD pairs that are not part of the internal B-M MPO OD TAZs i.e. not part of the 52 B-M OD TAZs. 249 OD TAZs fit this category.
2. Calculate average shortest travel path between all OD pairs using API algorithm developed for online mapping application for each time period.
3. Evaluate whether any portion of the route between each OD pair included a spatial location point within the B-M MPO area (longitude/latitude).
4. If yes to 3, trips between those OD pairs were considered as EE trips for the B-M MPO area.

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

The percentage of EE only trips ranged from 18% for the AM Peak period to 37% for the night period. For HBW, the majority of trips occurred during the Night period (46%) with the least amount of trips occurring during the AM Peak period. This could be because this time period includes the early morning (6:00AM to 7:00 AM) and late evening (7:00PM to 9:00PM). Trips passing through the B-M MPO area for work may typically leave early and arrive later due to comparatively longer travel times. For HBO trips, 49% 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 (35%) followed by the night period (31%), Peak AM (19%) and PM peak (14%).

Table 3 EE Trips from OD Data

EE Trips passing through B-M MPO					
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**
HBW	129	147	140	356	772
HBO	1016	1296	835	3031	6178
NHB	2384	4,315	1780	3811	12290
Total	3,529	5,758	2,755	7,198	19,240
Percentage of EE Trips passing through B-M MPO					
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**
HBW	17%	19%	18%	46%	100%
HBO	16%	21%	14%	49%	100%
NHB	19%	35%	14%	31%	100%
Total	18%	30%	14%	37%	100%
Percentage of EE Trips to Total EE/EI Trips					
	7-10AM	**10AM-4PM**	**4-7PM**	**Night**	**Total**
HBW	1%	1%	2%	3%	2%
HBO	2%	2%	2%	4%	2%
NHB	4%	3%	2%	5%	3%
Total	3%	2%	2%	4%	3%

2.1.4. Use of Airsage OD Data in the TDM

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

2.1.4.1. Trip Generation

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

2.1.4.2. Trip Distribution

Trip distribution assigns trips generated in the trip generation step between origin and destination pairs. The typical output of the trip distribution step in TDMs is a matrix showing the origins and destination of each trip. For the B-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") variables as input. The K-factor is used to account for the effects of variables other than travel impedance in the model. The OD data were used to develop K-factor matrices imputed in the trip gravity model that were used for distributing trips for each time period and purpose.

2.1.5. Shortcomings of the OD Data

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

1. The data did not show transient locations only Origins and Destinations. Paths between OD pairs can be estimated using network data.
2. The data does not include all cell phone networks and could suffer from cell phone provide biases. For example, low income earners might use different networks from the major networks for cost savings.
3. The raw data collected is anonymous and does not contain the demographic data that is provided with the dataset. The provider uses an algorithm to create the profile for average users (age, gender etc) based on their socioeconomic data. We cannot verify the veracity of the algorithm or the socioeconomic data that was used for this process.
4. Truck Data is not included in the dataset.

2.2. Freight Analysis Framework Data

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

The FAF data for North Dakota is aggregated for the entire state. A methodology was necessary to disaggregate the data to the MPO level. Data for Bismarck Mandan came from the North Dakota FAF aggregate data. A regression model was developed to disaggregate the statewide data to the MPO level. The model used the employments as the explanatory variable. Overall, the model had very good fit with R-square ranges from 65-95 %.

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

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 examine 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 type of MPO 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 are 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

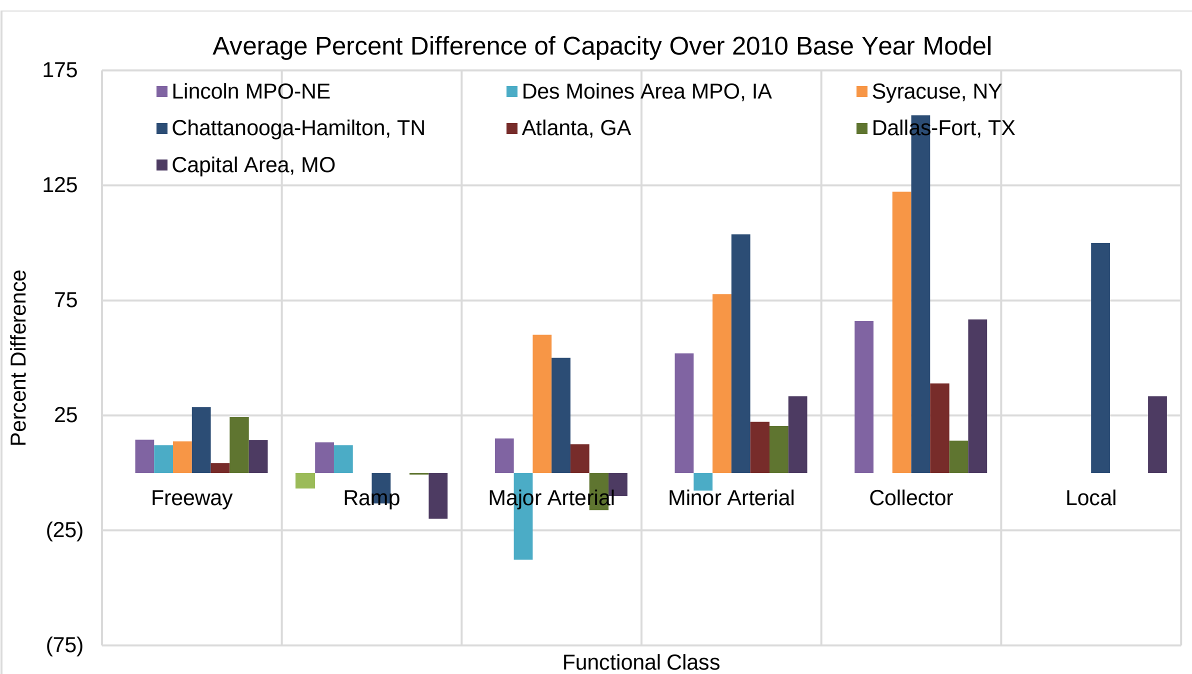
Lincoln MPO-NE, 2006	For the Lincoln MPO model, capacity at Level of Service (LOS) C was used as the threshold capacity. Highway Capacity Manual (HCM) 2000 procedures were used for estimating the capacity for each combination of functional class and area type. First, peak hour lane capacity was calculated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

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

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

Figure 3 shows the comparison of the base 2010 B-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 2010 B-M model. For ramps, the capacities for other MPO areas were typically lower in comparison to the 2010 B-M model. For major arterials, minor arterials, collectors and locals, the capacity calculations were typically for the MPOs compared. Most of these MPOs used a Level of Service E for capacity calculations, reason why their capacities were higher.

Figure 3 Capacity Comparisons to Bismarck Mandan MPO 2010 Base Year Model



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

3.1. Capacity Calculations for Signalized intersections

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

3.1.1. Step 1: Develop Lane Groups for each Link

The first step defined the lane groups for each link. For the 2015 network, lane groups are defined by the Attribute Linkgrp1. Table 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 that link had two through lanes with no turn lanes. Similarly, if the Linkgroup1 code was 35, it means the link had three through lanes, with two right turn lanes.

Table 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 single exclusive right turn lane
N9	N through lanes, two exclusive right turn lanes and single exclusive left turn lane

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

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

Equation 1

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

Where:

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

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

1. *Base Saturation Flow Rate, So*

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

2. *Adjustment Factor for Lane Width, f_W*

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

Equation 2

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

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

5. *Adjustment for Parking, f_p*

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

Equation 4

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

Where:

f_p = Parking adjustment factor

N = Number of lanes in group

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

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

6. Adjustment for Bus Blockage, f_{bb}

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

7. Type of Area Adjustment, f_a

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

8. Lane Utilization Adjustment, f_{LU}

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

9. Adjustment for Left Turns, f_{LT}

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

10. Adjustment for Right Turns, f_{RT}

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

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

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

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

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

13. Peak Hour Factor (PHF)

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

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

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

3.1.3. Step 3: Approach Capacity Calculation

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

Equation 5

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

Where C_{SI} is signalized intersection approach capacity,

S_i represents saturation flow rate for lane group i and

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

3.2. Capacities for Stop Control Intersections

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

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

The potential capacity for each turning movement uses the conflicting flow rate, the critical gap, the number of lanes, follow up time for each movement, and percent heavy vehicles as input parameters. Equation 6 shows the equation used to calculate the potential capacity for stop controlled intersections in 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 and Table 7 show the default values that were used for calculating the potential capacities for stop-controlled intersections in the model. 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,

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

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

Table 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
$C_{p,SH}$	=	Potential capacity of shared lane (vph)
$C_{p,T}$	=	Potential capacity for through movement (vph)
$C_{p,RT}$	=	Potential capacity for right turn movement (vph)
$C_{p,LT}$	=	Potential capacity for left turn movement (vph)

3.3. Freeway Capacity

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

3.3.1. Step 1: Calculate Free Flow Speed

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

Equation 8

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

Where:

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

Table 9 shows the adjustment factors for lane width. This value was set as zero since it was assumes 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 6Ft. Adjustments should be made accordingly if these are different. For studies used to evaluate the construction/reconstruction impacts on freeways, this parameter will be critical in determining the reduced capacity if shoulders are closed or reduced.

Table 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

Area Size	Interchange Density	Interchange Adj. Factor, (f_{ID})
Small Urban	0.70	1.0
Small Urbanized	0.76	1.3
Large Urbanized	0.83	1.7
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 70mph and freeways with speeds greater than 70mph.

Equation 9

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

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

3.4. Ramp Capacity Calculations

The following steps were used to calculate ramp capacities:

3.4.1. Step 1: Calculate Free flow Speed

Using Equation 1Equation 10, the free flow speed for ramps were calculated as follows

Equation 10: Ramp Capacity Equation

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

Where S_{fo} = base free-flow speed (BFSS); 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-maximum service flow rate;

C ideal capacity based on S_{fo};

N lumber of lanes;

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

PHF peak hour factor.

Table 25 and Table 26 Appendix 1 shows sample Capacity calculations that are used in the model for signalized intersections.

4. MODEL INPUT DATA

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

4.1. Transportation Network Data

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

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

4.1.1. Distribution of Modeled Network by Functional Classifications

Table 13 shows the percentage of centerline miles by functional class.

Table 13 Centerline Miles Distribution by Functional Classification

Functional Class	Centerline Miles	Percentage
Interstate	35.32261	9.6%
Major	76.7199	21.0%
Minors	131.20811	35.8%
Collectors	121.0004	33.1%
Locals	1.80722	0.5%

Figure 4 B-M 2015 Model Network

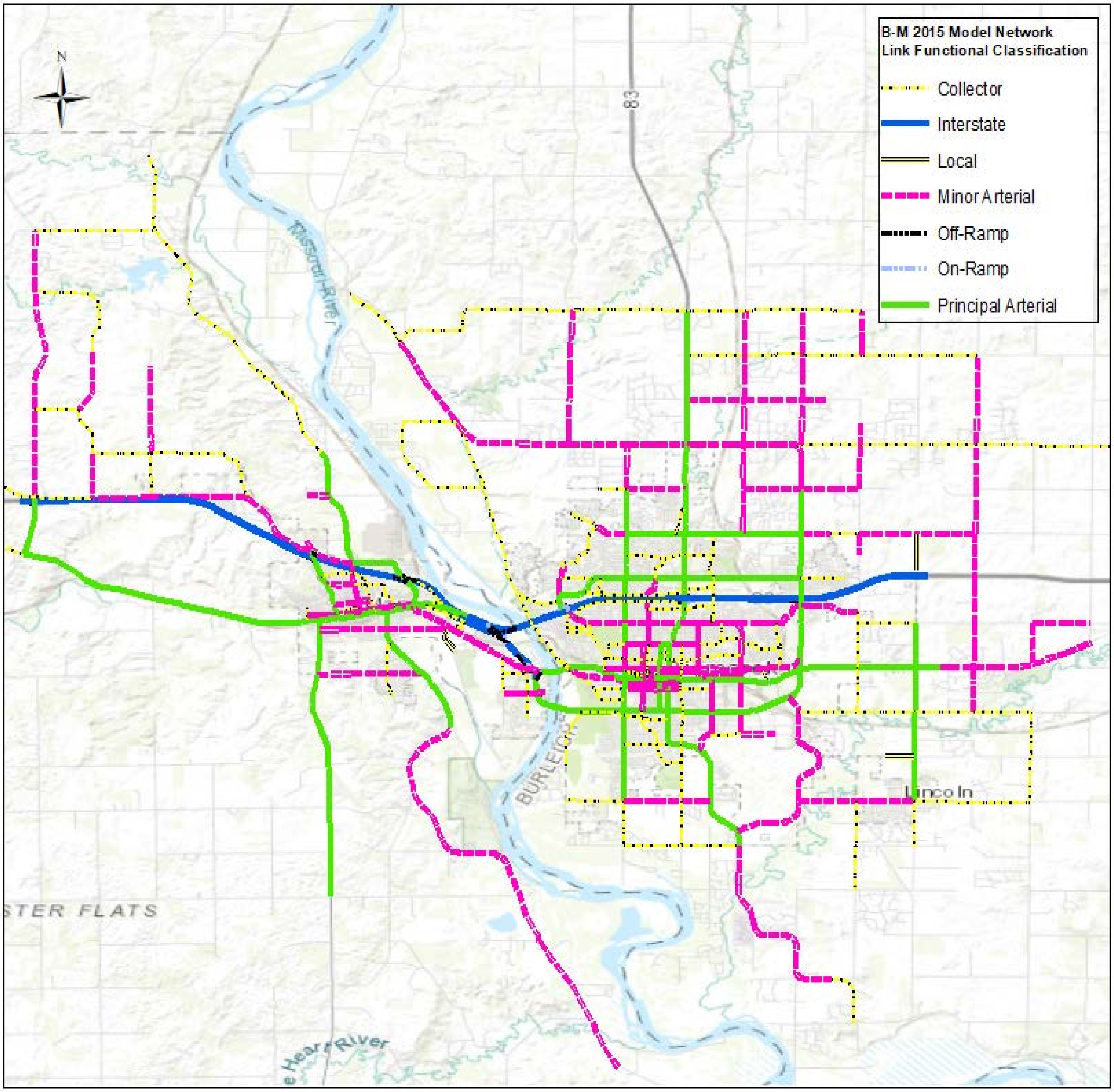


Figure 4 shows the modeled network distribution by functional class. The network does not show the centroid connectors.

Intersection controls were added to the model to incorporate delay experienced by road users. CUBE software uses a built in algorithm to calculate the delays that each intersection type contributes to the model. Two way stop controls; four way stop controls; Signals; Roundabouts and Yield controls were added as inputs to the model and are shown in Figure 5.

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

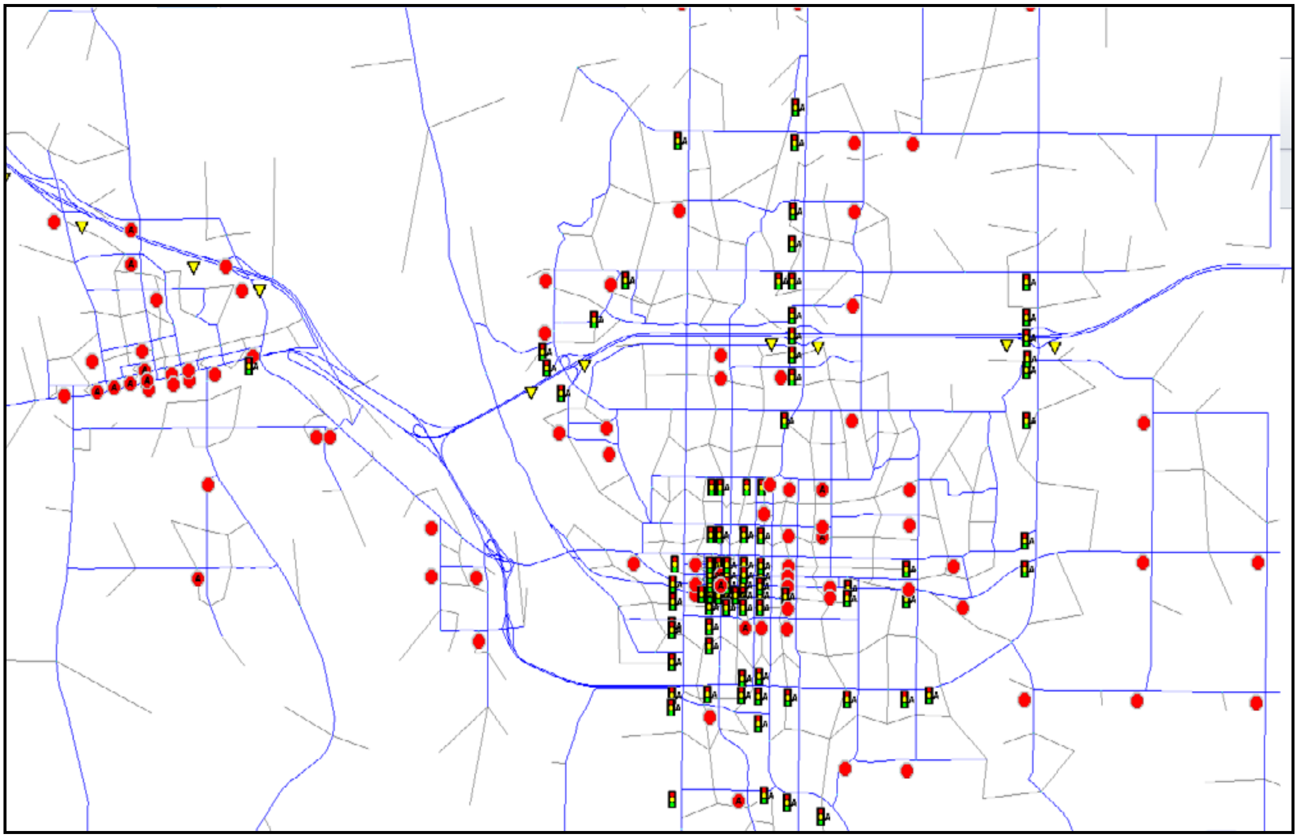


Figure 5 Intersection Data Used in Mode

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:

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

4.2.2. Socioeconomic Data TAZ Attributes

The socioeconomic data within the TAZ contained the following fields

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

1. # of one person households
2. # of two person households

   # of three person households
3. # of four person households
4. # of five person households
5. > # five person households
6. Total number of households

4.2.2.2. Vehicles per household in each TAZ[1]

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

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

1. # of Grade school age children
2. # of Middle age school children
3. # of High school age children
4. # of College age (18-23)

---

[1] Data was not in the 2010 model

[2] Data was not in the 2010 model

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

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

4.2.2.5. Enplanements

7. Yearly enplanements for the Bismarck Airport for 2015 (259,734)

4.2.2.6. Special generators

8. Special generator TAZS (wholesale distributors (Walmart and Super Target, large retail stores, and Malls).

4.2.2.7. ADT at external locations

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

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

5. TRIP GENERATION

Trip generation is the initial step of the TDM and 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 for 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 14 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 14 Internal-Internal Passenger Trip Generation Equations

	1-		2-		3-		4+Person/		All	
	Average of	Average	Average of	Average	Average of	Average	Average of	Average	Average of	Average
HBW	*0.914*	*13.32*	*1.422*	*16.34*	*2.327*	*12.37*	*2.240*	*15.54*	*1.547*	*26.97*
No Vehicles	0.00	.	0.00	.					0.00	.
1 vehicle Available	1.07	12.65	1.15	5.26	3.42	5.40	0.82	2.00	1.24	13.49
2 Vehicles Available	0.87	7.41	1.71	14.49	1.64	6.05	2.25	10.90	1.72	19.86
3+ Vehicles	0.33	1.73	1.76	10.67	2.74	10.59	2.42	11.67	2.08	17.54
HB-Shop	*0.19*	*4.85*	*0.41*	*9.12*	*0.71*	*5.70*	*0.71*	*6.99*	*0.44*	*13.30*
No Vehicles	0.00	.	0.33	0.50					0.23	0.58
1 vehicle Available	0.24	4.51	0.31	3.55	0.00	.	0.00	.	0.23	5.40
2 Vehicles Available	0.07	1.38	0.37	7.26	0.94	4.15	0.57	4.86	0.48	9.87
3+ Vehicles	0.24	1.36	0.68	5.56	0.70	4.40	1.02	5.55	0.75	8.95
HBO	*0.58*	*8.15*	*1.06*	*14.25*	*1.05*	*6.34*	*2.01*	*11.56*	*1.08*	*19.63*
No Vehicles	0.00	.	0.11	0.50					0.08	0.58
1 vehicle Available	0.51	5.70	0.86	4.73	0.34	0.76	1.75	2.23	0.60	7.42
2 Vehicles Available	0.78	6.62	1.33	12.94	0.99	3.59	2.01	7.92	1.38	15.65
3+ Vehicles	1.26	5.39	1.07	7.35	1.37	5.99	2.03	8.21	1.47	13.22
HBSchool (K-12)	*0.00*	*0.80*	*0.00*	*0.76*	*0.47*	*4.49*	*0.42*	*4.92*	*0.15*	*6.85*
No Vehicles	0.00	.	0.00	.					0.00	.
1 vehicle Available	0.01	0.81	0.00	.	0.00	.	0.93	1.61	0.03	1.72
2 Vehicles Available	0.00	.	0.01	0.81	0.33	2.70	0.31	3.17	0.14	4.98
3+ Vehicles	0.00	.	0.00	.	0.79	4.35	0.54	3.46	0.38	5.65
NHB	*1.43*	*11.06*	*1.55*	*13.61*	*2.03*	*6.07*	*2.34*	*8.06*	*1.73*	*19.21*
No Vehicles	0.00	.	0.11	0.50					0.08	0.58
1 vehicle Available	1.54	9.91	1.45	4.16	0.25	0.52	0.46	1.61	1.40	10.26
2 Vehicles Available	1.62	5.71	1.91	12.33	1.48	6.11	2.68	5.85	2.00	14.52
3+ Vehicles	1.10	2.23	1.57	7.51	3.29	5.28	2.03	5.97	2.13	10.27
Internal-External	*0.05*	*2.25*	*0.18*	*5.90*	*0.16*	*2.55*	*0.21*	*2.84*	*0.14*	*6.74*
No Vehicles	0.00	.	0.00	.					0.00	.
1 vehicle Available	0.03	1.41	0.09	1.20	0.00	.	0.36	0.82	0.05	1.94
2 Vehicles Available	0.19	2.09	0.22	5.52	0.15	1.70	0.05	1.31	0.16	5.89
3+ Vehicles	0.00	.	0.22	3.24	0.21	2.10	0.45	2.70	0.27	4.35
All Trips (Include	*3.18*	*21.51*	*4.73*	*24.19*	*6.84*	*14.12*	*8.00*	*19.23*	*5.16*	*34.98*
No Vehicles	0.00	.	0.56	0.50					0.38	0.58
1 vehicle Available	3.39	21.10	4.18	9.30	4.01	4.17	4.32	2.71	3.60	22.66
2 Vehicles Available	3.54	10.94	5.61	23.51	5.54	10.25	7.88	12.94	5.91	28.24
3+ Vehicles	2.93	5.09	5.42	13.45	9.39	12.43	8.68	15.27	7.26	21.93

5.1.2. Trip Attractions

Trip attractions represent the number of trips attracted to each zone based typically based on employment the size of the school for school trips. Table 15 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 aggregated to represent the categories shown in Table 15.

Table 15 Trip Attraction Rates

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

Table 16 shows the school trip attraction rates that were used for the model. These trip rates were obtained from the ITE Trip Generation Manual.

Table 16 School Trip Attraction Rates

School	Rate
Elementary	1.85
Middle	1.85
High	1.96

5.2. Freight Data

Freight movements have been an issue for previous models as they have not accounted for freight movements. Long haul freight movements for the 2015 model. A commodity-based model will be developed using the Commodity Flow Survey Data. This data is publicly available for the 2015 base year. Commodity Flow Survey Data exists only for the largest metropolitan areas and for the rest of the states. The implication is that for the B-M MPO, the commodity flow survey data had to be disaggregated from statewide totals to local data. Data on the employment for the North Dakota state was used to disaggregate freight data to B-M MPO and for the rest of the state.

Ordinary Least Square Models were used to develop model parameters that were applied to the number of jobs for each freight generation industry for productions and attractions. The model used data for the metropolitan areas that had disaggregate commodity flow survey data to develop the parameter estimates. This parameter estimates were then applied to the commodity flow survey data for both North Dakota and Minnesota to obtain the total tonnage of freight produced and attracted to the MPO. The total tonnage was assigned to the TAZ level based on the number of jobs for each commodity group in the TAZ. Table 17 shows the results of the freight model.

Table 17 Freight Trip Productions and Attractions (IE/EI)

Productions	
NAICS Category	**Freight Productions**
Manufacturing Jobs	328
Industrial Jobs	263
Total	591
Attractions	
NAICS Category	**Freight Attractions**
Manufacturing Jobs	229
Industrial Jobs	2242
Retail Jobs	706
Service Jobs	0.15
Other Jobs	594
Total	3771.15

6. TRIP DISTRIBUTION

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

Equation 12 Gravity Model Used for Trip Distribution

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

T_{ij} = Number of trips assigned between Zones i and j;

P_i = Number of Productions in Zone i;

A_j = Number of Attractions in Zone j;

F_{ij} = Friction Factor; and

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

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

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

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

For K-12 school trip distribution, school zones were used to assign trips for Bismarck Mandan Public Schools
K-12 school trips. The K-factor matrix used ensured that no Public school trips between the cities

7. 1. TRIP ASSIGNMENT

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 three origin destination matrixes; AM peak, PM peak and 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 equation Equation 13. It takes into account the link travel time, the value of travel time and the link distance.

Equation 13 Trip Assignment Cost Equation

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

Where:

TC = Link Travel Cost

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

L_t = Link Travel Time, and

L_d = Link Length.

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

8. VALIDATION AND CALIBRATION

Model calibration refers to the adjustment of model input parameters in order to replicate observed real world data for a base year to otherwise produce reasonable results. It involves adjusting model input parameters such as trip generation rates, node delays, free flow speeds, K factors and friction factors. Figure 6 shows the calibration and validation flow chart that was used for the model. It was an iterative process that involved adjusting the model parameters until a certain level of confidence of the model's replication of real world data was achieved.

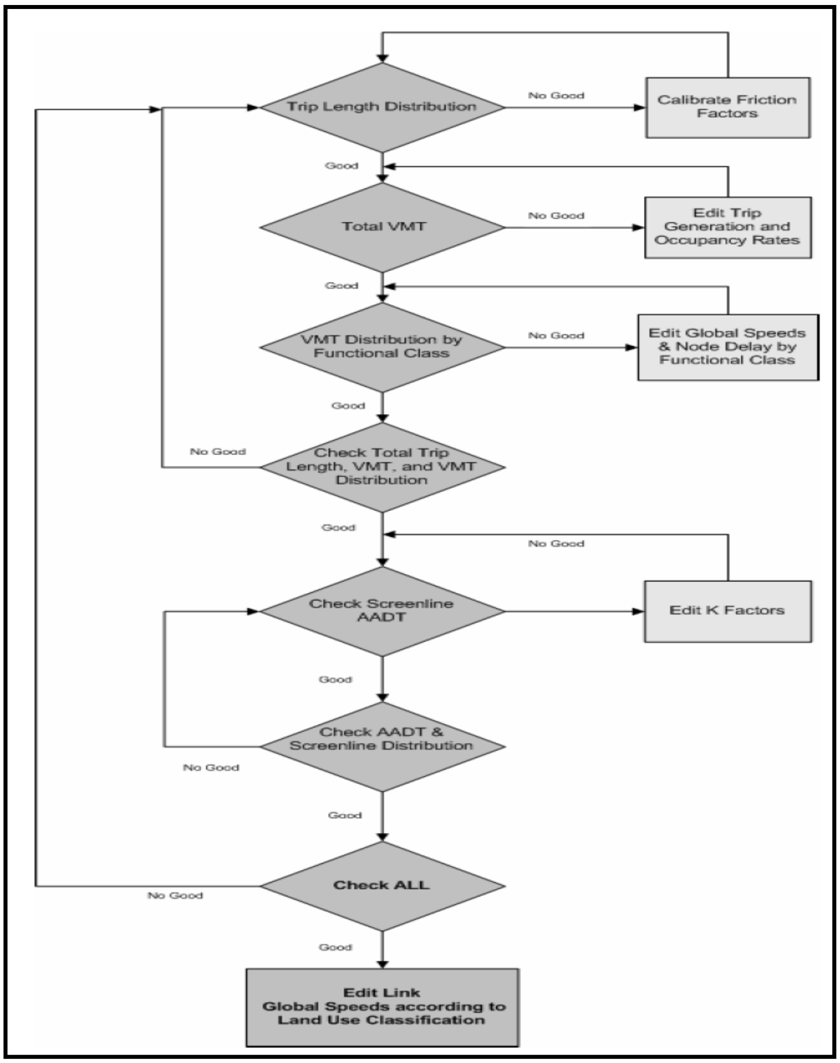


Figure 6 Calibration Flow Chart

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 travelers sensitivity to travel time by trip purpose. Steeper curves mean more sensitive travel times. Friction factors are calibrated until a desired trip length frequency is validated against observed data. The friction factors are the main dependent variable in the gravity model. The gamma function was used to develop the friction factor for this model and are shown in Figure 7.

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 zone 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 were reached. Observed trip length frequency data for the home-based work trips were obtained from the census journey to work database for the metropolitan area. Only trips lower than 35 minutes were considered with the assumption that 35 minutes was the highest possible travel time between any two points within the metro area.

The average trip length for the observed data was calculated as 14.31 compared to the average trip length of 15.11 produced by the model for HBW trips. The desired average trip lengths for HBO and NHB trips were 84% and 73% of the average trip length for HBW trips. The average trip length for the models HBO and NHB trips were 12.70 and 11.01 minutes respectively.

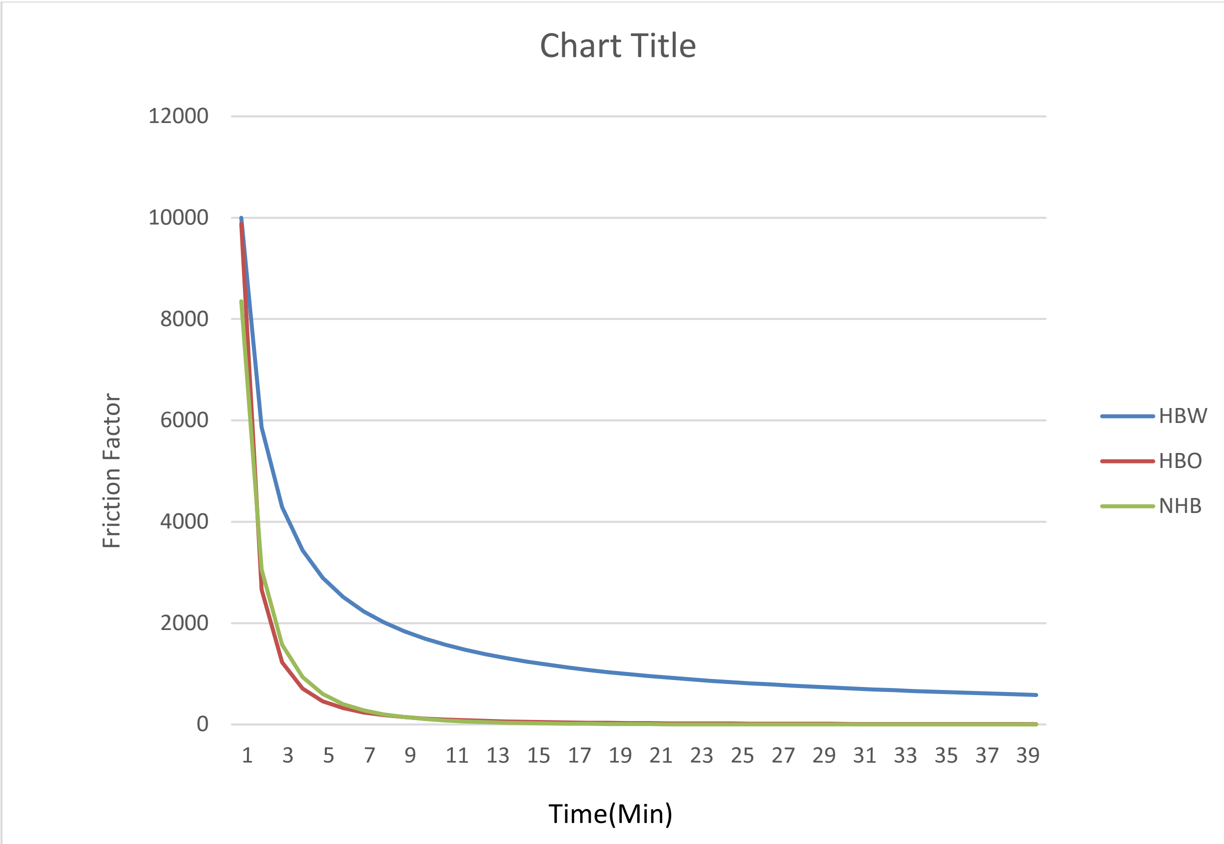


Figure 7 Friction Factors

Figure 8 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.

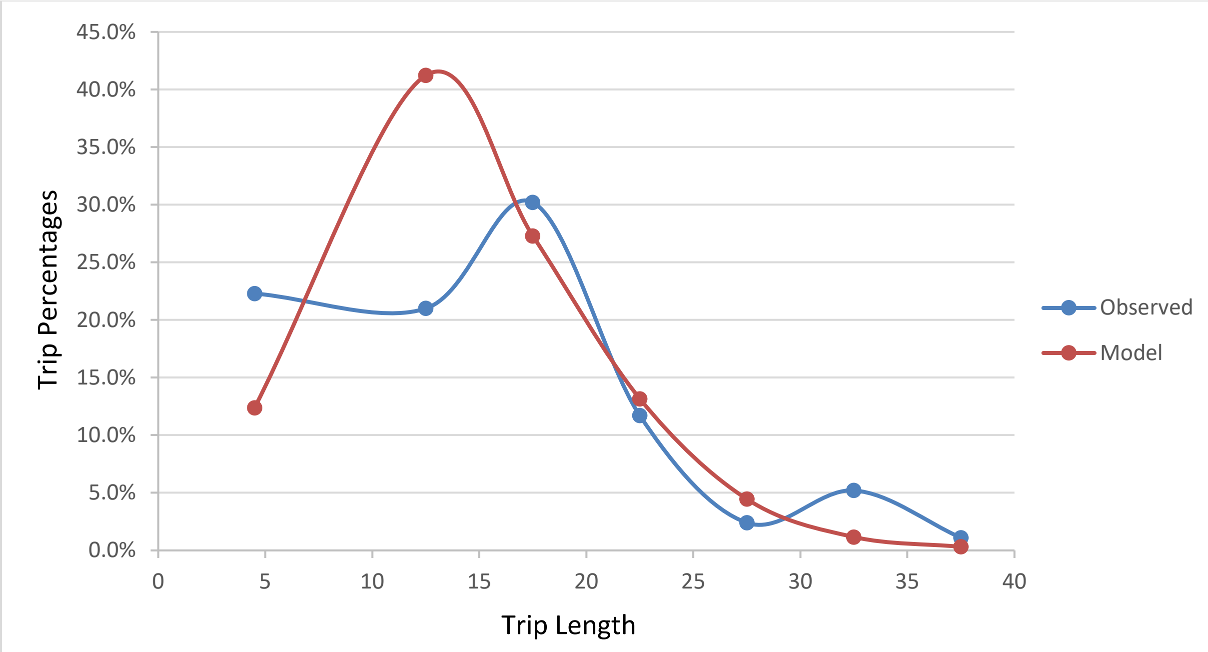


Figure 8 Comparison of Observed to Model Trip Length Frequency

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

Table 18 shows the VMT comparison between modeled and observed VMTs and their various distributions as a percentage of total VMT by functional class. The model performs very well in replicating the VMTs for Interstates and Major arterials with VMT differences of less than 2% and had similar distributions to the observed VMTs. Overall, the model performs within reasonable deviations in replicating VMTS by functional class with overall 0.5% deviation.

Table 18 Modeled VMTs compared to Observed VMTs by Functional Class

Functional Class	Observed VMT	Modeled VMT	% Diff
Interstate	161,586	164,118	1.5%
Major	477,944	475,752	-0.5%
Minors	279,917	288,078	2.8%
Collectors	133,668	130,090	-2.8%
Locals	-	-	0.0%
Total	1,053,116	1,058,037	0.5%

Table 19 shows the observed and modeled VMT comparison by volume range. The model performs well for replicating VMTs for higher volume ranges with VMT differences of less than 5%. The VMT difference is highest for ADT range less than 1000 i.e. 47.7%.

Table 19 Modeled VMTs compared to Observed VMTs by Volume Range

ADT Range	Observed VMT	Modeled VMT	% Diff
ADT >25,000	65,493	65,661	0.3%
25,000 TO 10,000	482,717	460,271	-4.9%
10,000 TO 5,000	296,125	295,139	-0.3%
5,000 TO 1,000	198,740	217,764	8.7%
ADT<1000	10,041	19,203	47.7%
	1,053,116	1,058,037	0.5%

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

Table 20 shows the comparison of the modeled and observed ADTs by functional classification. Overall, the model performs reasonably replicating over 75% of observed counts. Minor arterials have the lowest replication of observed counts at 69%.

Table 20 Comparison of Modeled and Observed ADTS by Functional Classification

Functional Classification	Below Criteria	Within Criteria	Above Criteria	Total	%age Within	RMSE %
Interstates	0	10	0	10	100%	7%
Major Arterials	22	135	21	178	76%	26%
Minor Arterial	29	131	30	190	69%	26%
Collectors	23	138	13	174	79%	70%
Locals	0	0	0	0	100%	0%
Total	74	414	64	552	75%	
Percent	13%	75%	12%			

Table 21 shows the comparison of modeled and Observed ADTs by volume range. The FHWA criterion sets limits to the deviations between observed and modeled ADTs. Overall the model meets all deviation criterion for all the volume ranges and replicates 75% of the observed traffic.

Table 21 Comparison of Modeled and Observed ADT by Volume Range

ADT Range	#Above	#Within	#Below	%Within	RMSE
ADT >25,000	0	13	1	93%	8%
25,000 TO 10,000	9	96	33	70%	20%
10,000 TO 5,000	24	101	29	66%	31%
5,000 TO 2,500	13	92	11	79%	38%
2,500 TO 1,000	11	90	0	89%	72%
ADT<1000	9	33	0	79%	217%
Total	69	427	68	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 including link *i, (number of links with counts)*

Table 22 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 27.26.

Table 22 RMSE Comparison by Volume Range

Volume Range	RMSE (%)	Typical Limits (%)
AADT>25,000	8%	15-20 %
25,000 to 10,000	21%	25-30 %
10,000 to 5,000	33%	35-45 %
5,000 to 2,500	38%	45-100 %
2,500 to 1,000	72%	45-100 %
AADT<1000	217%	>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 9 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 0.91 shows a strong linear relationship between modeled and observed traffic counts.

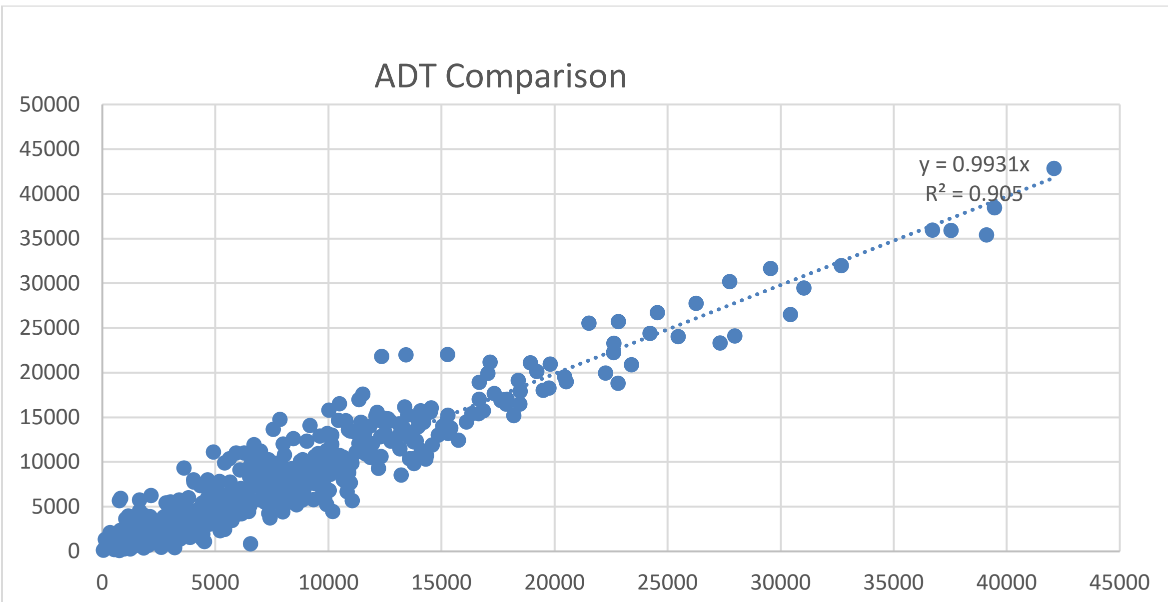


Figure 9 Scatter Plot of Modeled and Observed ADTS

8.6. Link Travel Time Validation

To evaluate how well the assignment algorithms and the intersection control data performed in the model assignment, sample travel times from the model were compared to average travel times that were obtained using online mapping tools. An online API was developed to collect the data for AM, PM and Offpeak travel times for the average weekdays. Table 23 shows the comparison of the modeled travel times and the average travel times collected. The modeled travel times are within plus or minus one minute for the different peak periods for the group of selected roadways. This is an indication that the model's assignment algorithms are performing very well in terms of replicating real time travel time data.

Table 23 Travel Time Validation

Link Type/Location	Distance (Miles)	Observed Travel Time (Min)			Modeled Travel Time (Min)		
		AM	PM	OFF	AM	PM	OFF
Principal Arterials							
State St - Century Ave to East Divide	1	3	3	3	2.92	2.65	2.36
Washington St - 43rd Ave N to Boulevard	3.3	5 to 8	5 to 8	5 to 7	9.98	6.83	5.09
Bismarck Expressway - Washington St to 5th Ave	3.6	6 to 10	6 to 12	6 to 12	7.08	7.54	6.69
W Main St - 6th Ave NW to Memorial Hwy	1.3	4 to 6	4 to 6	4 to 6	5.31	3.58	3.55
Minor Arterials							
Divide Ave - Washington St N to 19th St N	1.5	4 to 6	4 to 7	5	4.6	4.63	3.62
Broadway - Washington St to 16th St N	1.3	5 to 6	5 to 7	5 to 7	4.46	3.78	3.45
Highway 1804 - US Highway 83 to 80th St NE	5	7	7	7	5.53	5.61	5.47
1st St - Sunset Dr to Mandan Ave	1.3	4 to 6	4 to 6	4 to 6	5.13	4	3.73
Collectors							
C Ave - Griffin St to 16th St N	1.5	6 to 8	5 to 6	6 to 7	5.35	4.97	4.06
Interstate Ave - Century Ave W to State St	1.8	4 to 7	5 to 7	5 to 7	4.74	4.16	3.7
3rd Ave - Division St to W Main St	0.6	3	3	3	2.39	2.19	2.18

8.7. Screen Line Comparisons

Table 24 shows the screen line comparisons in order to validate the observed vs modeled ADT on major corridor locations. The screen line comparison has been done across railroad crossings, I-94 and Missouri river. The comparison results reveal that the difference between modeled and observed ADT is below +/-5%. This indicates model perform well across major corridor screen lines.

Table 24 Screen Line Comparison

Screen line	Modeled	ADT	% Difference	Difference
Railroad	86,858	88,309	1.6%	1,451
I-94	141,512	141,200	-0.20%	(312)
Missouri River	75,766	72,645	-4.30%	(3,121)

9. CONCLUSIONS

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

10. APPENDIX

Table 25 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**

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	0			**Rural**	**1**	**1900**	0.99	4718	4718	**0.4**	1887	**18,870**
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**

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		Minor	Urban	0.9	1900	0.90	1416	2265	0.45	1019	**10,194**
	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**

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	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**
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**

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		Minor	Urban	0.9	1900	0.90	2832	2973	0.45	1338	**13,380**
	2	0	1			Rural	1	1900	0.90	3010	3160	0.45	1422	**14,220**
	2	0	1		**Collector**	**Urban**	**0.9**	**1900**	0.99	2959	3107	**0.4**	1243	**12,429**
	2	0	1			**Rural**	**1**	**1900**	0.99	3145	3302	**0.4**	1321	**13,209**
	3	0	1	4	Principal	Urban	0.9	1900	0.90	4248	4389	0.55	2414	**24,141**
	3	0	1			Rural	1	1900	0.90	4514	4665	0.55	2566	**25,657**
	3	0	1		Minor	Urban	0.9	1900	0.90	4248	4389	0.45	1975	**19,752**
	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**
	3	0	1			Rural	1	1900	0.90	4514	4665	0.55	2566	**25,657**

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		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**
	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**

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**	0.99	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**
	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**

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	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 26 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