430 IACC Building – Fargo, ND 58105

Tel 701-231-8058 – Fax 701-231-1945

www.ugpti.org – www.atacenter.org

Grand Forks/East Grand Forks MPO 2010 Regional Travel Model Update

Technical Report

April 2013

Prepared for the:

Grand Forks/East Grand Forks Metropolitan Council of Governments

Prepared by: Diomo Motuba, PhD

Advanced Traffic Analysis Center

Upper Great Plains Transportation Institute

North Dakota State University

Fargo, North Dakota

TABLE OF CONTENTS

LIST OF TABLES .... **II**

LIST OF FIGURES .... **III**

1.0 INTRODUCTION **1**

1.1 BACKGROUND 1
1.2 REPORT ORGANIZATION 2

2.0 MODEL ENHANCEMENTS AND IMPROVEMENTS **3**

2.1.1 Trip Production Input 3
2.1.2 Trip Production Rates from the Fargo-Moorhead Area 3
2.1.3 UND Student Trip Generation Rates 3
2.1.4 Junction Constrained Assignment 3

3.0 INPUT DATA **4**

3.1 TRANSPORTATION NETWORK DATA 4
3.1.1 Node Centroid, and External Centroid Feature Classes 4
3.1.2 Link Feature Class 4
3.2 LINK CAPACITY CALCULATIONS 7
3.2.1 Signalized Intersections 7
3.2.2 Unsignalized Intersections 8
3.2.3 2005 Base Year TDM Capacities Vs 2010 Base Year TDM Capacities 8
3.3 TAZ GEOGRAPHIC DATABASE: 12

4.0 TRIP GENERATION **13**

4.1 INTRODUCTION 13
4.1.1 Trip Purposes 13
4.2 TRIP PRODUCTIONS 13
4.2.1 Internal production trips 13
4.2.2 School trip productions (K-12) 14
4.2.3 University Trips- University of North Dakota(UND) 14
4.2.4 External-External and External-Internal trips 15
4.2.5 Trip Production Summary 16
4.3 TRIP ATTRACTIONS 16
4.3.1 Internal Trip Attraction rates 17
4.3.2 External attraction trips 17
4.3.3 University of North Dakota Student trip attractions 18
4.3.4 Trip Attraction Summary 18
4.4 SPECIAL GENERATORS 18
4.5 BALANCING TRIP PRODUCTIONS AND ATTRACTIONS 19

5.0 TRIP DISTRIBUTION **20**

5.1 FRICTION FACTOR COMPUTATION 20
5.2 K (SOCIOECONOMIC) FACTOR ADJUSTMENTS 21
5.3 HOURLY ORIGIN-DESTINATION CALCULATION 22

6.0 TRIP ASSIGNMENT **23**

7.0 MODEL CALIBRATION AND VALIDATION **25**

7.1 TRIP LENGTH DISTRIBUTION 26
7.2 TOTAL VEHICLE MILES TRAVELED (VMT) 28
7.3 SCREENLINES 29

7.4 COMPARISON OF MODELED ADTS WITH COUNTED ADTS....29
7.5 ROOT MEAN SQUARED ERROR AND PERCENT ROOT MEAN SQUARED ERROR....30
7.6 SCATTER PLOTS AND R SQUARE OF MODELED VERSUS OBSERVED VOLUMES....31

8.0 BIBLIOGRAPHY....33

LIST OF TABLES

TABEL 3.1 NODE AND CENTROID ATTRIBUTE 1....4

TABEL 3.2 LINK ATTRIBUTE TABLE....6

TABLE 3.3 SUBURBAN/URBANIZING ARTERIAL TOTAL DIALY TRAFFIC CAPACITY....9

TABLE 3.4 URBAN/URBAN CORE ARTERIAL TOTAL DAILY TRAFFIC CAPACITY....9

TABLE 3.5 CAPACITY LOOKUP TABLE....11

TABLE 4.1 PERSON TRIP PRODUCTION RATES FARGO MOORHEAD....14

TABLE 4.2. SCHOOL TRIP PRODUCTION RATES- NCHRP 716 (2)....14

TABLE 4.3. EXTERNAL-INTERNAL PRODUCTION RATES....16

TABLE 4.4. TRIP PRODUCTION SUMMARY....16

TABLE 4.5. TRIP ATTRACTION RATES (FROM NCHRP 716 TABLE 4.4 AND ITE TRIP GENERATION MANUAL)....17

TABLE 4.6. EXTERNAL-INTERNAL ATTRACTION RATES....18

TABLE 4.7. TRIP ATTRACTION TOTALS....18

TABLE 4.8. BALANCED TRIP PRODUCTIONS AND ATTRACTION TOTALS....19

TABLE 7.1 VMT VALIDATION SUMMARY BY FUNCTIONAL CLASS....29

TABLE 7.1 SCREENLINE COMPARISONS....29

TABLE 7.3 MODEL VOLUMES BY TRAFFIC VOLUME RANGE....30

TABLE 7.4 MODEL ASSIGNMENT BY MODELED TRAFFIC VOLUME RANGE....31

LIST OF FIGURES

FIGURE 3-1 NETWORK-GF-EGF 2010 TDM 5
FIGURE 3-2 TRANSPORTATION ANALYSIS ZONES-GF-EGF 2010 TDM 12
FIGURE 4-1 SURVEY RESPONDENTS PREFERRED WALKING DISTANCE RELATIVE TO TEMPERATURE 15
FIG 5.1 FRICTION FACTORS FOR HBW, HBO AND NHB TRIPS 21
FIGURE 6.1 MODELED INTERSECTIONS 24
FIGURE 7.1 CALIBRATION FLOW CHART 25
FIGURE 7.2 CALIBRATION FLOW CHART 26
FIGURE 7.3 MODELED TRIP LENGTH DISTRIBUTIONS BY TRIP PURPOSE 27
FIGURE 7.4 MODELED HBW TRIP LENGTH FREQUENCY DISTRIBUTIONS VS OBSERVED HBW TRIP LENGTH 27
FIGURE 7.5 SCATTERPLOT OF MODELED VERSUS OBSERVED TRAFFIC COUNTS 32

1.0 INTRODUCTION

The calibration and validation of travel demand models (TDM) is an important part in transportation planning as it is used for modeling current and future travel patterns in a planning region. TDM quantifies future transportation demand and the impacts of improvements to the transportation system, thereby providing policy and decision makers with an important tool to make these decisions. This report documents the model, methods and data used to update, calibrate and validate the Grand Forks-East Grand Forks MPOs (GF-EGF MPO) regional travel demand model (TDM) to 2010 base year conditions. The update consisted of three major components, including:

1. Updating the network and socioeconomic data to 2010 base year conditions
2. Developing the model and applying it in CUBE voyager software
3. Calibrating and validating of the 2010 base year model to base year 2010 data.

This report is intended to serve as a technical reference which describes each of these components in great detail.

The model update was performed by the Advanced Traffic Analysis Center (ATAC) at North Dakota State University under a contract with the Grand Forks-East Grand Forks Metropolitan Planning Organization (GF/EGF MPO). The GF/EGF MPO provided ATAC with most of the necessary input data, guided the development of the model structure, and reviewed the model calibration.

1.1 Background

The main objective of this project was to update the GF-EGF MPO TDM model to 2010 base year conditions. This update is undertaken every five years with the previous model update done for 2005 base year. Secondary objectives of the model update were to incorporate the most recent improvements in travel demand modeling techniques and software in order to improve the models' ability to correctly replicate local travel patterns.

The model was upgraded to use Citilabs CUBE Voyager software in contrast to Citilabs TP+ modeling script that was used for the 2005 base year model update. Cube voyager offers more advanced modeling capabilities than TP+ and allows for seamless integration of future model enhancements such as activity base models and dynamic traffic assignment methods. The model used for the 2010 model update was based on the Urban Transportation Modeling Systems (UTMS) procedures. The UTMS involves specifying the characteristics of the activities generating vehicle traffic on the transportation system, and estimating vehicle traffic flows on the system generated by those activities.

The UTMS consists of four steps that are related to the user's trip decision-making process: Trip Generation, Trip Distribution, Modal Split, and Trip Assignment. The first two steps are related to the nature and intensity of the land-use patterns, while the last two steps are dependent on the attributes of the modeled transportation network and supply. The model does not incorporate a modal split step since vehicle trips are the overwhelming mode choice used in the GF-EGF region.

1.2 Report Organization

In addition to the introduction chapter, the remainder of the document is divided into the following chapters:

Chapter 2, *Model enhancements and Improvements:* provides a summary of the enhancements improvements implemented in 2010 base year model.

Chapter 3, Data preparation: data that was used to build the transportation network in GIS format, assign the necessary parameters to the links and update and prepare the socioeconomic data are discussed here.

Chapter 4, Trip Generation: socio-economic data are used to predict the number of trips produced by and attracted to each zone within the study area. The output is a trip generation table.

Chapter 5, Trip Distribution: trip ends are connected between productions and attractions and trips flow from production zones to attraction zones are established. The output from this step is an origin-destination (O-D) matrix representing the production and attractions between TAZs.

Chapter 6, Trip Assignment: assigns trips between OD pairs to the traffic network and an OD matrix is the main output for the travel demand model.

Chapter 7, Model calibration and validation: Model calibration refers to the adjustment of model input parameters in order to replicate observed real world data for a base year or otherwise produce more reasonable results. Model Validation applies base year calibrated models by comparing the results to observed data.

2.0 MODEL ENHANCEMENTS AND IMPROVEMENTS

This chapter describes the model enhancements and improvements that were done for the GF-EGF 2010 TDM in comparison to the 2005 model.

2.1.1 Trip Production Input

A significant improvement for the 2010 model was the use of household size (persons per house hold) rather than household type (single or multi-family) to develop zonal trip productions. The number of persons per household is a better predictor of the number of trips that each household makes than housing size. This change significantly improved the models replication of travel in the region.

2.1.2 Trip Production Rates from the Fargo-Moorhead Area

One of the limitations of the previous 2005 model was the use of national data that were not necessarily representative of travel in the area. This weakness was improved in the GF-EGF 2010 TDM by use of trip generation rates from the Fargo-Moorhead OD survey (1). Although, trip generation data from the GF-EGF area is not available, trip making behavior in the Fargo-Moorhead (FM) are expected to match those of GF-EGF area more closely than national averages. Trip rates from Fargo-Moorhead were compared to national rates from *NCHRP Report 716* (2) and were found to be about 10% lower. The trip generation rates are discussed in more detail in chapter four of this document.

2.1.3 UND Student Trip Generation Rates

UND trip generation rates were revised using several different sources. The UND trip generation rates takes into account the number of on campus students, the number of off campus students and the number of 18-24 year olds in each TAZ and are discussed in more detailed in Chapter 4.

2.1.4 Junction Constrained Assignment

The GF-EGF 2010 TDM took advantage of improvements in Citilabs software by using Cube Voyager's junction-constrained assignment process. This process improves the models ability to correctly model intersections in the network since it uses the actual intersection control data. The signal intersection data were obtained from the MPO as Synchro files and were converted into CUBE format. For intersections where no Synchro data were available, assumptions about network link capacities were made based on the functional classification of the link, the link geometry, and the control type. This is discussed in more detail in Chapter 3.2.

3.0 INPUT DATA

Several initial steps were carried out to model the study area in order to build the transportation network and the Transportation Analysis Zones (TAZ) before the actual model was implemented. The data used in the model fall under two main categories: Network data and socioeconomic data.

3.1 Transportation Network Data

The transportation network is an abstract representation of the real world transportation system. It consists of the functionally classified roadway links with the rest of the actual links in the network represented as centroid connectors. Figure 3-1 shows the functionally classified links that were used for the 2010 base year model. The network contains attributes data that describe the available transportation supply and 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.

3.1.1 Node Centroid, and External Centroid Feature Classes

The node feature class has two main attributes, the node number (ID) used to determine the to and from nodes on the link, and the control type which describes the control of the node according to whether it is a yield, stop (North South/East West), signal, or no control. The centroid and external centroid connectors have an identification field (ID) which is the external TAZ number. Table 3.1 shows the node and centroid attributes.

Tabel 3.1 Node and Centroid Attribute 1

Node Feature Class	
Attribute Field Name	**Attribute Description**
ID	Node ID
Control	Intersection control
Centroid/Eternal Centroid Feature Classes	
Attribute Field Name	**Attribute Description**
TAZ	Zone number corresponding to zone number in TAZ file

3.1.2 Link Feature Class

The link feature class contains the attributes of the network that the model uses to calculate travel time and distance skims used in the trip distribution step and to assign trips on the network. The links file uses shapes to accurately define the real geography and accurately calculate true distances in the network. Figure 3-1 shows the 2010 street network. Table 3.1 lists the attribute fields in the link file.

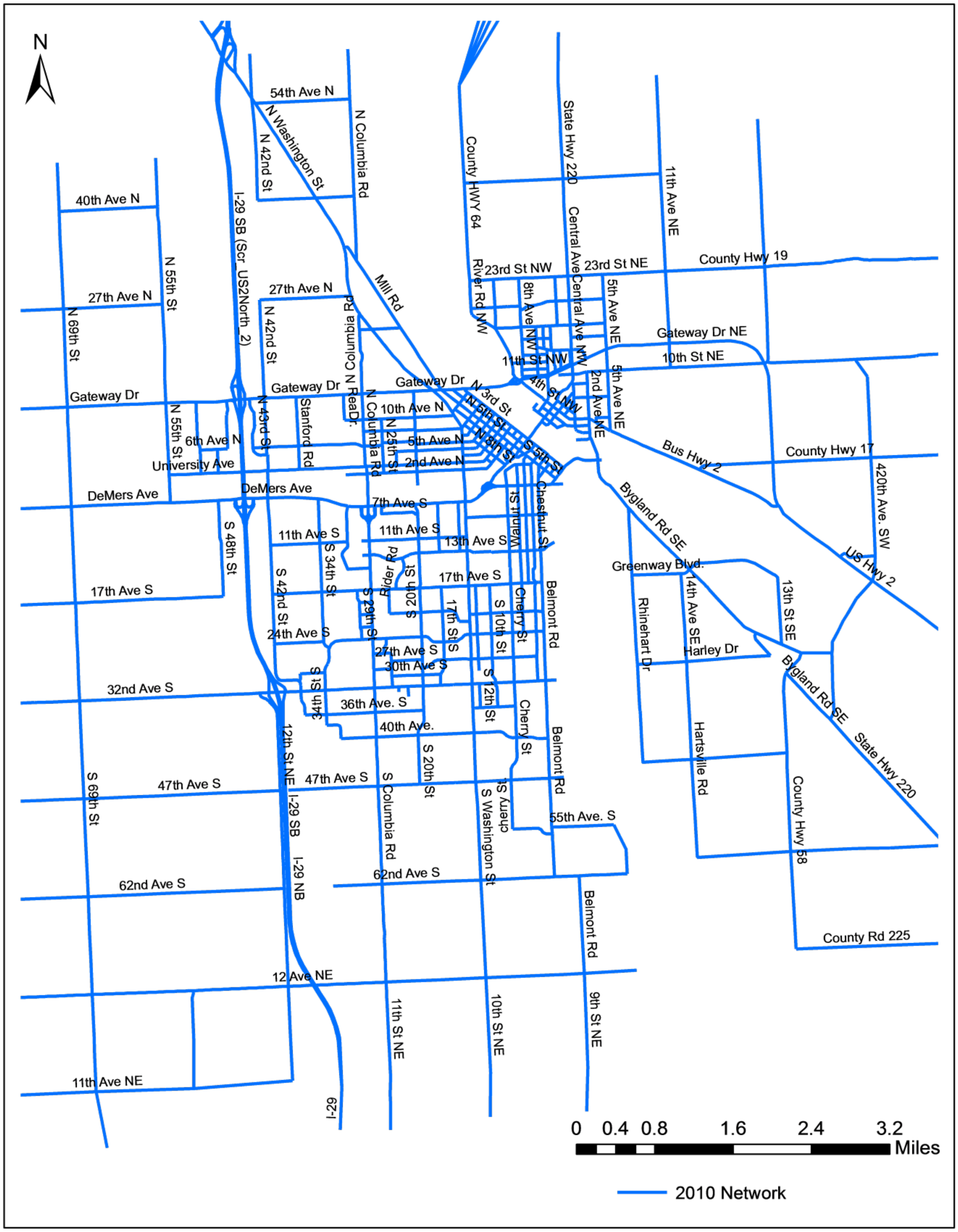

Figure 3-1 Network-GF-EGF 2010 TDM

Tabel 3.2 Link Attribute Table

Attribute Field Name	**Attribute Description**
A	Origin Node Number
B	Destination node number
ADT_2010	2010 Average Daily Traffic
Shape_Length	Length of Link
SPEED	Posted network speed
Oneway_twoway	Describes whether link is a one or two way
Numblanes/R_lanes	Number of through lanes going from A to B node / B to A node
LinkGroup 3	Intersection Control according to the following Code: 0= No intersection/surface street 11=Signalized intersection, low turn Volume, low Signal Priority 12= Signalized intersection, low turn Volume, medium Signal Priority 13= Signalized intersection, low turn Volume, high Signal Priority 21=Signalized intersection, medium turn Volume, low Signal Priority 22=Signalized intersection, medium turn Volume, medium Signal Priority 23=Signalized intersection, medium turn Volume, high Signal Priority 31=Signalized intersection, high turn Volume, low Signal Priority 32= Signalized intersection, high turn Volume, medium Signal Priority 33= Signalized intersection, high turn Volume, high Signal Priority 41=All way stop controlled intersection, one lane, low conflicting volume 42=All way stop controlled intersection, one lane, high conflicting volume 43=All way stop controlled intersection, two lane, low conflicting volume 43=All way stop controlled intersection, two lane, high conflicting volume 51=Two-way stop controlled intersection, one lane, stop on approach 52=Two-way stop controlled intersection, two lanes, stop on approach 53=Two-way stop controlled intersection, one lane, no stop on approach 54=Two-way stop controlled intersection, two lanes, no stop on approach 60=Roundabout 71= Interstate On-Ramp, one lane 81=Interstate, Two lanes 55mph speed 82=Interstate, two lanes 75 mph speed
Direction/R_Direction	Direction of travel from A to B/B to A node according to the following code: 2=Eastbound 4=Northbound 6=Westbound 8=Southbound
LinkGroup 1	Intersection geometries applied to B end of node [1]A0= No turn lanes A1= Single left turn lane A2=Dual left turn lanes A3=Single right turn lanes A4=Single right and single left turn lanes A5=Single right and dual left turn lanes A6=Dual right and dual left turn lanes
District	State in which road is found according to the following code: 1-MN 2-ND
Assgn	Functional classification of road according to the following code: 0=Rural unpaved

[1] Where A represents the number of through lanes

	1=Interstate 2=Major Arterial 3=Minor Arterial 4=Collector 5=Centroid connector 6=Ramp 7=External centroid connector 8=Local 9=Rural paved
Area_Type	Area type in which link is located according to the following code: 0-Rural 1-Urban 2-CBD

3.2 Link Capacity Calculations

Link capacities represent transportation supply and the amount of vehicle traffic that each link can physically accommodate per unit of time. These capacities physically constrain the assignment step of the model and are critical in determining the amount of traffic that each link will carry. The capacity determines the amount of congestion on a link, which is defined by the volume-to-capacity ratio, and the delay on the link caused by congestions. The Highway Capacity Manual (3) has standardized techniques for computing capacity calculations based on the network attributes. Link Attributes such as traffic signals, signal spacing, presence of on street parking, driveways, driver population complicate capacity calculations. Where all these variables are not available, assumptions that simplify these calculations are made and used to estimate link capacities.

For the GF-EGF 2010 model, capacities were calculated based on the links functional classification, the intersection control (Linkgroup 3), the link geometry (Linkgroup 1), signal timing data (for signalized intersections) and the area type. The functional classifications, intersection controls, signal timing data and link geometry information were provided by the GF-EGF MPO.

3.2.1 Signalized Intersections

For signalized intersections, the signal timing data was used to determine the Linkgroup 3 attribute for each intersection that had this data. The Linkgroup 3 attributes were assigned based on four criteria: priority of the approach with respect to cross street, the percentage of non through movements, the intersection geometry, and the functional classification of the link.

Three categories were used for the approach priority:

1. Low priority approach where the approach being evaluated has less green time than the cross street, (g/C=33%), with Linkgroup 3 values of x1 i.e. (11, 21, and 31).
2. Medium priority approaches, where the approach being evaluated has approximately the same green time as the cross street (g/C=50%), with Linkgroup 3 values of x2 (12, 22 and 32).
3. High priority approach, where the approach being evaluated had more green time than the cross street (g/C= 67%), with Linkgroup3 values of X3 (13, 23 and 33).

Intersection control data provided by the MPO was used to determine the percentage of non through movement. Three categories were used:

1. Percentage of non-through movements is approximately zero, with Linkgroup 3 values of 1x (11, 12, 13).
2. Percentage of non-through movements is approximately 12%, with Linkgroup 3 values of 2x (21,22, and 23).
3. Percentage of non-through movements is approximately 25%, with Linkgroup 3 values of 3x (31, 32 and 33).

Assignment groups (functional classification) were used when intersection data was not available to assign more capacity to arterials in comparison to collector and local roads.

3.2.2 Unsignalized Intersections

For unsignalized intersections, the Linkgroup 3 data was determined based on assumptions made from Highway Capacity Manual 2010 (3), MNDOT capacity calculations and comparisons to generally accepted capacity calculations. The variables used were the area type, control (stop on approach, all way stop control intersection, and roundabout), link geometry and the functional classification of the link.

3.2.3 2005 Base Year TDM Capacities Vs 2010 Base Year TDM Capacities

As part of the 2010 model update, capacities from the 2005 base year model were reviewed to reflect the additional intersection data that was made available for the base 2010 model. The 2005 base year capacities were based off of capacities from the 2000 base year model which ATAC had received a priori. The limitation of this data being that there was no intersection data to determine the accuracy of the Linkgroup 3 Values that were used to calculate them. This resulted in the mostly overestimation of capacities on several of the arterial links. Obvious examples were on Columbia road and Washington Street were four and five lane arterials were assigned with daily capacities ranging between 42,000 to 56,000 Vehicles per Day.

ATAC found these capacities to be considerably higher than what typically obtains for links of similar characteristics when compared to other travel demand models e.g. Duluth-Superior area travel demand model, HCM 2010 and MNDOT assumptions. Thus, an overall review of the capacities was performed with Linkgroup 3 assigned based on intersection data for signalized intersections and guidelines from MNDOT as shown in Table 3.3 and Table 3.4.

Table 3.3 Suburban/Urbanizing Arterial Total Daily Traffic Capacity[2]

Lanes	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Volume to Capacity	0.5	0.7		0.9	1	>1
2-Lane		<8,500	12,000	15,000	17,000	17,000
4-Lane		<17,000	24,000	30,000	34,000	34,000

With the following assumptions

• Signal Spacing: ¼ mile to ½ mile

• Free-flow speed: 35 mph to 40 mph

• Signal Cycle Length: 80s to 90s

• Portion of AADT in Peak Hour: 0.09

• Effective Green Ration (g/C): 0.50

• Left-turn lanes: Yes

Table 3.4 Urban/Urban Core Arterial Total Daily Traffic Capacity[3]

Lanes	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Volume to Capacity	0.5	0.7		0.9	1	>1
2-Lane		<8,000	11,000	14,500	16,000	16,000
4-Lane		<16,000	12,000	29,000	32,000	32,000

With the following assumptions

• Signal Spacing: 500 ft to 1/8 mile.

• Free-flow speed: 30 mph

• Signal Cycle Length: 70 seconds

• Portion of AADT in Peak Hour: 0.09

[2] Source: MNDOT/Duluth-Superior Metropolitan Interstate Council Travel Demand Model
[3] Source: MNDOT/Duluth-Superior Metropolitan Interstate Council Travel Demand Model

• Effective Green Ration (g/C): 0.50

• Left-turn lanes: Usually

The result of a capacity analysis from the 2010 base year model were compared to Table 3.3 and 3.4 respectively and were found to be close to the MNDOT suggested capacities. The capacities for the 2000 and 2010 base year models however were overestimated for several arterials links.

The consequence is that several links that were shown to have lower Volume to Capacity Ratios for the 2005 and 2010 models have higher V/C ratios due to the lower and more accurate capacity calculations for the base 2010 model. ATAC is very confident the 2010 capacities are a more accurate representation of the actual link capacities in comparison to the 2005 and 2000 base year models due to the availability of signal timing data for the 2010 base year.

A lookup table that was used to calculate each links capacity based on the attributes discussed earlier is show in Table 3.5. The capacity of a major arterial with two through lanes and one left turn lane (Linkgroup 1 = 21) with a Linkgroup 3 of 22 (Medium turns, medium priority approach) will have a capacity of 1,550 vehicles per hour as highlighted on the table.

Table 3.5 Capacity Lookup Table

		Link Group 1																
		10	**11**	**13**	**14**	**20**	**21**	**22**	**23**	**24**	**25**	**30**	**31**	**32**	**33**	**34**	**35**	**Unsignalized**
Linkgroup 3	**11**	550	550	550	550	1100	1100	1100	1100	1100	1100	1650	1650	1650	1650	1650	1650	0
	12	825	825	825	825	1650	1650	1650	1650	1650	1650	2475	2475	2475	2475	2475	2475	0
	13	1100	1100	1100	1100	2200	2200	2200	2200	2200	2200	3300	3300	3300	3300	3300	3300	0
	21	450	550	525	625	875	1050	1115	950	1125	1190	1300	1475	1540	1375	1550	1615	0
	22	685	825	760	900	1275	1550	1615	1350	1625	1690	1865	2200	2265	1940	2275	2340	0
	23	1000	1100	1075	1175	1800	2175	2240	1875	2250	2315	2600	3175	3240	2675	3250	3315	0
	31	350	550	500	700	650	1000	1130	800	1150	1280	950	1300	1430	1100	1450	1580	0
	32	550	825	700	975	900	1450	1580	1050	1600	1730	1250	1925	2055	1400	2075	2205	0
	33	900	1100	1050	1250	1400	2150	2280	1550	2300	2430	1900	3050	3180	2050	3200	3330	0
	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1000
	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	500
	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1600
	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	600
	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	400
	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	400
	53	0	850	1150	1000	0	0	0	0	0	0	0	0	0	0	0	0	800
	54	0	0	0	0	0	0	0	0	0	0	0	2800	2800	2800	2800	2800	1800
	60	1100	1100	1100	1100	1800	1800	1800	1800	1800	1800	2800	2800	2800	2800	2800	2800	2800
	71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1400
	81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3400
	82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3600

3.3 TAZ Geographic Database:

The -GF-EGF 2010 TDM has a total of 584 TAZs. TAZs 1-566 are internal TAZs, TAZs 566 to 571 are dummy TAZs for future use and TAZs 572 to 584 are for the external zones. The TAZ file is GIS shapefile that also contains the socioeconomic data attributes. TAZ were revised and updated with the addition of four new TAZs, while several TAZs were fused to form one based on input from the GF-EGF MPO staff. Figure 3-2 shows the TAZ data that was used for the model.

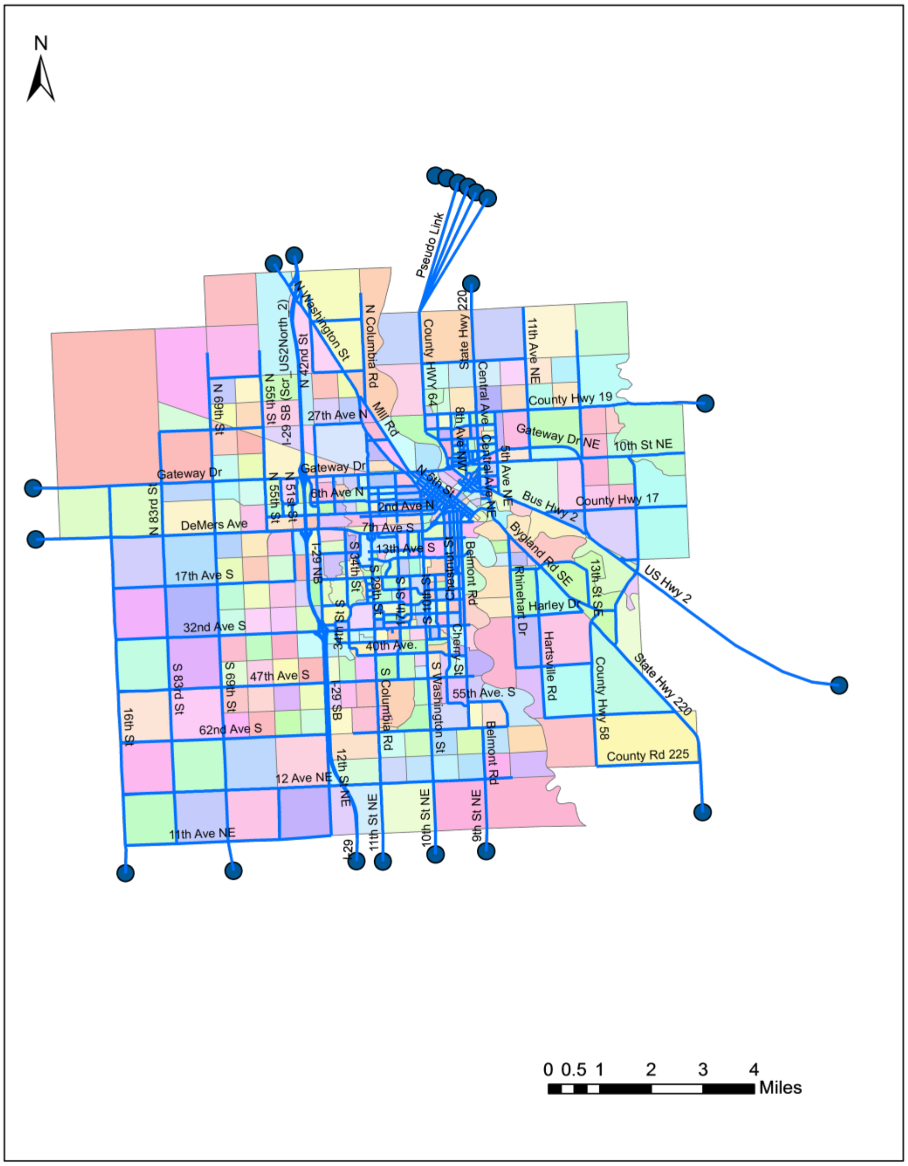

Figure 3-2 Transportation Analysis Zones-GF-EGF 2010 TDM

4.0 TRIP GENERATION

4.1 Introduction

Trip generation is the first computational step of travel demand models. It estimates the amount of trips produced by and attracted to each Transportation Analysis Zone (TAZ). These trips are a function of the socioeconomic and demographic data for each TAZ. The trip generation model had three components, trip production, trip attraction and trip balancing so that trip productions and attraction totals are equal.

4.1.1 Trip Purposes

Six trip purposes as described below were developed for the GF-EGF TDM.

1. Home based work (HBW) : Trips starting at home and ending at work
2. Home based other (HBO): Trips starting at home and ending at non-work locations (park, retail, restaurants etc.)
3. Non- home based (NHB): Trips neither starting nor ending at/from home.
4. School trips K12 HBSch: Trips starting/ending in school
5. University trips (UND) (HBU): Trips either ending or starting at University of North Dakota.
6. External-External, Internal-external, external –internal).

4.2 Trip Productions

Trip productions relate to the number of trips that originate from each TAZ for each purpose in the study area. Trip production equations were applied to Socioeconomic and demographic data to develop trip generation rates.

4.2.1 Internal production trips

Productions are more associated with home based trips. Socio-economic data was used to obtain household size for each TAZ. Trip production rates from the Fargo-Moorhead OD Survey (1) were used to develop trip production rates for the HBW, HBO, NHB and HBSch trip purposes. This is a major difference with previous models were national average rates were used. It is reasonable to assume that trip generation rates will not differ significantly from trip generation rates in Grand Forks-East Grand Forks. Trip Production rates are show in in Table 4.1. Zonal trip productions and attractions were converted into person trips by dividing them by a vehicle occupancy ratio of 1.30. Vehicle occupancy rations were obtained from the Grand Forks Bridge Origin Destination survey.

Table 4.1 Person Trip production rates Fargo Moorhead

	Household Size			
Purpose	**1**	**2**	**3**	**4+**
HBW	1.003	1.72	2.56	2.42
HBO	1.09	2.40	2.51	4.80
NHB	1.57	2.40	2.89	3.57

4.2.2 School trip productions (K-12)

School trip production (HBSch) were calculated based on NCHRP 716 (2). Table 4.3 shows the rates that were applied to household demographic data for the GF-EGF TDM.

Table 4.2. School Trip production rates- NCHRP 716 (2)

	Household size			
School	**1**	**2**	**3**	**4+**
Elementary	.000	.132	1.271	2.858
Middle	.000	.132	1.271	2.858
High	.000	.132	1.271	2.858

4.2.3 University Trips- University of North Dakota(UND)

Since Universities do not fall under normal trip patterns used by the model, a special trip generation was given to UND trips for UND students. In addition, the previous models have typically underestimate trips to UND; separate trip generation rates for UND were thus desirable. Trip productions for UND students were divided into two main components, trip productions for students who live on campus and trip productions for students who live off campus.

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

Figure 4-1 from the North Dakota Campus Shuttle Study (6) used to determine distances from campuses that students preferred to walk, bike or take the shuttle i.e. non-vehicle trips. For example, all TAZs that are within two blocks of campus will be assumed to be 100% walk, shuttle or bike i.e. non-vehicle trips, between 2 and four blocks, 80%, etc. It was assumed that there were eight blocks per mile.

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

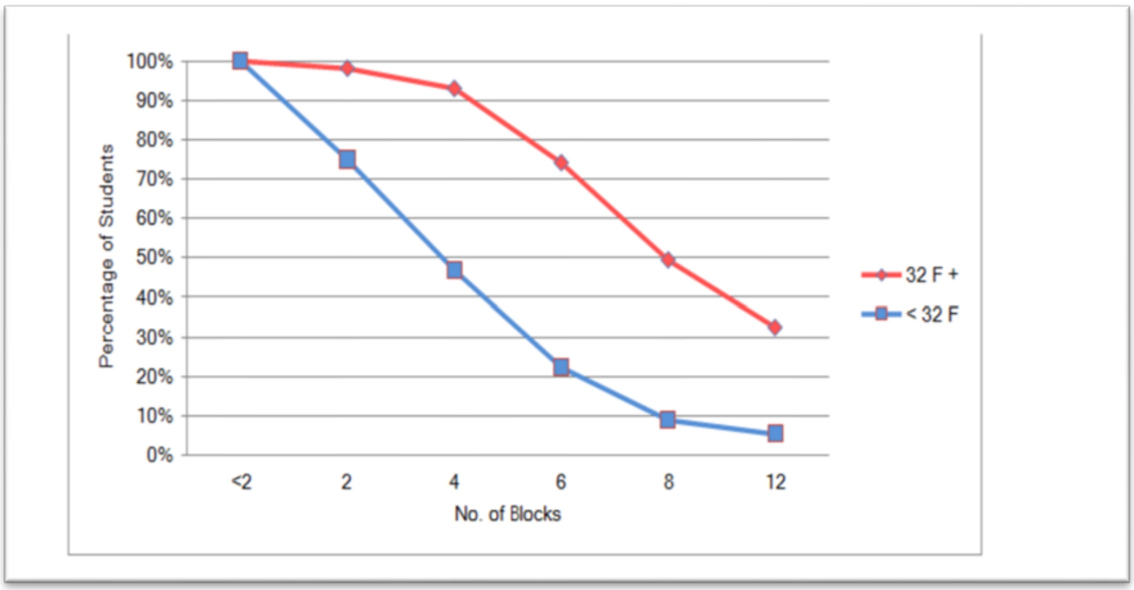

Figure 4-1 Survey Respondents Preferred Walking Distance Relative to Temperature

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

4.2.4 External-External and External-Internal trips

Any trip that has at least one trip end outside of the GF-EGF metropolitan planning area was considered an external trip. Internal-External (IE) trips are produced in the planning area and end in the exterior, External-Internal (EI) originate from outside of the planning area and terminate in the planning area and External-External (EE) are trips that do not stop in the planning area. Fourteen external stations were used for the model.

EI trip generations were calculated as a proportion of the counted Average daily traffic (ADT) at each external station. Table 4.2 shows the proportion of traffic at each external station that was considered to have been produced within the planning area. These proportions were average from the Grand Forks East Grand Forks MPO Bridge Survey and from the NCHRP 716 (2).

Table 4.3. External-Internal production rates

	Trip purpose		
IE	**HBW**	**HBO**	**NHB**
IE	24%	20%	1%

4.2.5 Trip Production Summary

After applying the various trip production rates to the demographic data, the total trip productions listed in table 4.3 were obtained.

Table 4.4. Trip Production Summary

	Production Totals	**2010 % Trips**
HBW	61,261	24%
HBO	95,584	38%
NHB	77,086	31%
HBGrdsch	6,401	3%
HBMid Sch	3,221	1%
HBHiSch	4,941	2%
EE	3,606	1%
Total	252,100	**100%**

4.3 Trip Attractions

Trip attractions are the number of trip attracted to each TAZ by based on the type of employment and the employment intensity for that TAZ. Trip attractions were developed for internal and external trip attractions.

4.3.1 Internal Trip Attraction rates

Trip attractions were adopted from NCHRP 716 for home-base work, home-base other, and non-home based trip purposes. These rates were applied to the number of households, and the employment by category (retail, service and other) as opposed to retail and other jobs that were used for the 2005 model.

K-12 school trip attraction rates were based on the Institute of transportation Engineers (ITE) Trip Generation manual 7th Edition. This was done to better reflect trip making behavior for K-12 schools. The rates used for the GF-EGF 2010 TDM are shown on Table 3.4 and were applied to the number of students enrolled for each school for each given TAZ.

Employment and enrollment data for the base 2010 year were provided by the GF-EGF MPO and the Grand Forks school district respectively.

Table 4.5. Trip Attraction rates (From NCHRP 716 Table 4.4 and ITE Trip Generation Manual)

Trip Purpose	Variable	Attraction Rate
Home-Base Work Attractions	Total Employment	1.2
Home-Base Other Attractions	Households	1.2
	Retail Employment	8.1
	Service Employment	1.5
	Other Employment	0.2
Non-Home-Based Attractions	Households	0.6
	Retail Employment	4.7
	Service Employment	1.4
	Other Employment	0.5
Home-Based School Attractions	Home Based Grade School	1.88
	Home Based Mid School	1.88
	Home Based High School	1.88

4.3.2 External attraction trips

Both EE and EI trip attractions were computed similar to EE ad IE production rates mentioned earlier. They were calculated as a function of the counted ADTs at each external location. Table 4.5 shows the trip proportions as a total of the external station counts each for home-base work, home-base other and no-home-base trips respectively. These proportions were average from the Grand Forks East Grand Forks MPO Bridge Survey and from the NCHRP 716 (2).

Table 4.6. External-Internal attraction rates

	Trip purpose		
	HBW	**HBO**	**NHB**
EI	27%	25%	3%

4.3.3 University of North Dakota Student trip attractions

The number of campus residence halls/dorms and their respective capacities per TAZ were used to compute trip attractions to campus. Data for parking lots (number of spots available), availability for off campus students and parking restrictions were used to compute the attraction intensity for each on campus TAZ. Home based university (HBU) trips were computed based on University of Lincoln Nebraska (5) rates. TAZs nearest to UND (less than 2 mile radius) were assumed to either walk or take campus shuttle and were not involved in developing UND trip attractions. Trip attractions for UND students were added to the Home-Base Other trip totals.

4.3.4 Trip Attraction Summary

Table 4.7 shows the total trips attracted after trip attraction rates are applied to the socioeconomic data by trip type.

Table 4.7. Trip attraction Totals

Trip Purpose	Attraction Totals	2010 % Trips
HBW	84,109	26%
HBO	137,012	43%
NHB	82,092	26%
HBGrdsch	6,401	2%
HBMid Sch	3,221	1%
HBHiSch	4,941	2%
EE	3,606	1%
Total	**321,382**	**100%**

4.4 Special Generators

During the validation process, several large trip generators were identified and reviewed to verify if the trip generation rates used were applicable for them. The Columbia mall, Grand Forks International Airport and the walmart just south of 32nd Ave S were found to be generating fewer than normal trips. Trips for the Columbia mall and walmart zones were increased by 30%. It was found that the model underestimated trips into these TAZs by 30%, based on traffic counts into these TAZs. In contrast to the 2010 model, a different model was used to calculate trip attractions to the Columbia Mall based on its size. It was however found that in the 2010 model, counts into the mall decreased by 68% in comparison to the 2005 base year model.

For the Grand Forks airport trip generation, 2010 yearly enplanement data was used to develop trip generation data for the base year. This data was divided by 365 (days in the year) to develop the daily number of trips attracted to the airport for air travel. These trips were added to trips that were previously calculated based on the airport employment.

4.5 Balancing Trip productions and attractions

Applying the methodology and equations described in the previous sections to the TAZ socio-economic data yields unbalanced production and attraction totals. In the travel demand mode each production must be matched to an attraction to form a round trip, the total productions must equal the total attractions for each trip type.

Trip attractions for HBW, and HBO were balanced to their productions while NHB and school trip productions were balanced to attractions to produce a balanced trip production as shown in Table 4.8.

Table 4.8. Balanced Trip Productions and Attraction Totals

Trip Purpose	Attraction Totals	Production Totals
HBW	61,261	61,261
HBO	95,584	95,584
NHB	82,092	82,092
HBGrdsch	6,401	6,401
HBMid Sch	3,221	3,221
HBHiSch	4,941	4,941
EE	3,606	3,606
Total	**257,106**	**257,106**

5.0 TRIP DISTRIBUTION

Trip distribution was the second computational step for the base 2010 TDM. Trip distribution links trip productions to trip attractions to create origin destination matrices (OD matrix). The most commonly used type of trip distribution model is the gravity model. This model is a modified version of Newton's law of gravitation between physical bodies in space. The number of trips between zones is assumed to be based on the relative attractiveness of zones, and the travel impedance between those zones which is measured by travel time or cost.

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 4.1 shows the gravity model formulation that was used for the model.

$$T_{ij} = P_i \frac{K_{ij} A_j F_{ij}}{\sum(K_j A_j F_j)}$$ Equation 5.1

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 key data input to the gravity model include:

1. Transportation network used to calculate link impedance values.
2. Travel survey data (6) used to calculate trip length frequency distributions and data from the Grand Forks/East Grand Forks MPO Bridge Survey for trip origin/destination patterns.

5.1 Friction Factor Computation

The friction factor in the Gravity model is the main independent variable that represents the magnitude of trip impedance between an OD pair. Friction factors were developed based on NCHRP Report 716 (2). Friction factors were calibrated to replicate trip length distributions (observed travel times) from the American community survey (6). Figure 4.1 shows the friction factors for home-based work, home-based other and non-home based trips which, expressed by the trip length in minutes.

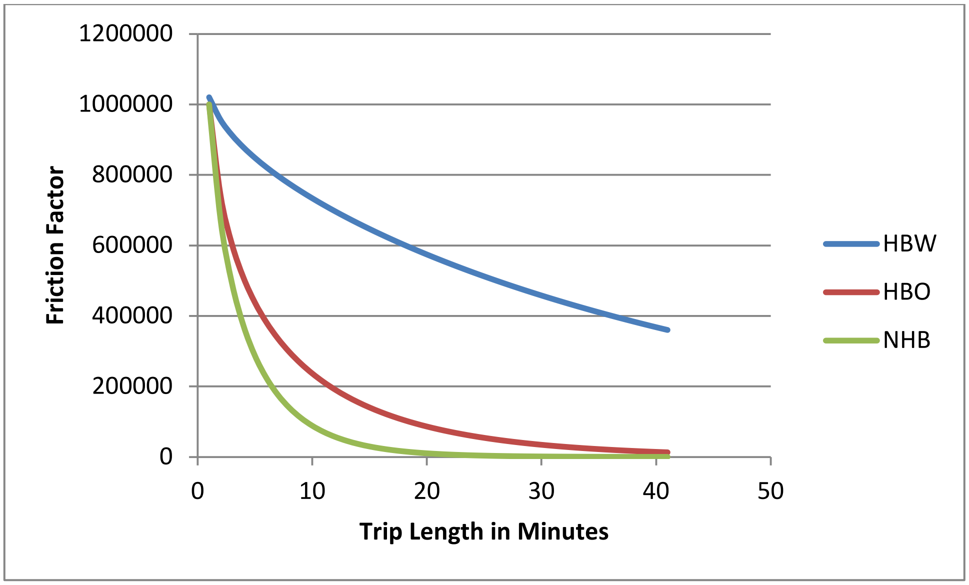

Fig 5.1 Friction Factors for HBW, HBO and NHB Trips

5.2 K (Socioeconomic) Factor Adjustments

K-factors are used in the trip distribution step to adjust origin and destination interchanges not well replicated by the gravity model. K-factors are often used where bridges and other travel barriers distort trip distribution of trips between specific areas in the modeling area. K factors were obtained from the Grand Forks-East Grand Forks Bridge OD survey (GF-EGF OD survey) and used to ensure that trips crossing between Grand Forks and East Grand Forks were distributed accordingly. To achieve this, the modeling area was divided into three super zones for GF and EGF respectively. This division was made based on the GF-EGF OD survey. The north super zone consisted of all TAZs north of Gateway drive, the Central super zone consisted of all TAZs between Gateway and Demers and the South super zone which consisted of all TAZs South of Demers.

K factors were also used in the school trip distribution for K-12 school trips which prevented trips between different school districts.

5.3 Hourly Origin-Destination Calculation

The OD table up to this point is daily vehicle trips which need to be converted into hourly trips for assignment purposes. NCHRP Report 716 (2) was used to develop peak hour factors which were used to create three matrices, AM, PM and Off-peak OD matrices according to the following:

1. AM peak, 7AM to 9 AM, 13.6%.
2. PM peak, 4PM to 6PM, 17.1%.
3. Off-peak, 5.0%/hr/14*hrs.=69.3 % ADT.

6.0 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.

For the peak AM and PM periods, CUBEs junction-based model was used. Junction based modeling is an improvement to the 2005 model. Junction-based assignment uses an intersection constrained assignment method. Junction-based modeling attempts to simulate congestion on a roadway network by modeling what happens at the intersections using the intersection control data like actual signal timing data. Figure 6.1 shows the different types of intersections that were coded in the junction file and used for AM and PM peak assignments.

For off-peak traffic assignment, the user equilibrium traffic assignment method was used. 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. User-equilibrium traffic assignment method is more realistic since drivers do not necessarily have knowledge of system-wide transportation supply; hence, it was used for this model. It was implemented using a cost function to evaluate the most desirable path.

Feedback loops are used in traditional four step planning models to achieve equilibrium. Feedback loops are sequential iterative modeling where the demand of regional travel patterns by trip purposes in no longer estimated independently, regardless of the network supply as a result of having link costs updated for each iteration of the feedback process (7). An iterative feedback loop was set up between the traffic assignment step and trip distribution steps of the model to use the congested travel time from the assignment step as input in the trip distribution process. Convergence was achieved after 10, 13 and 5 iterations for the AM, PM and off-peak periods.

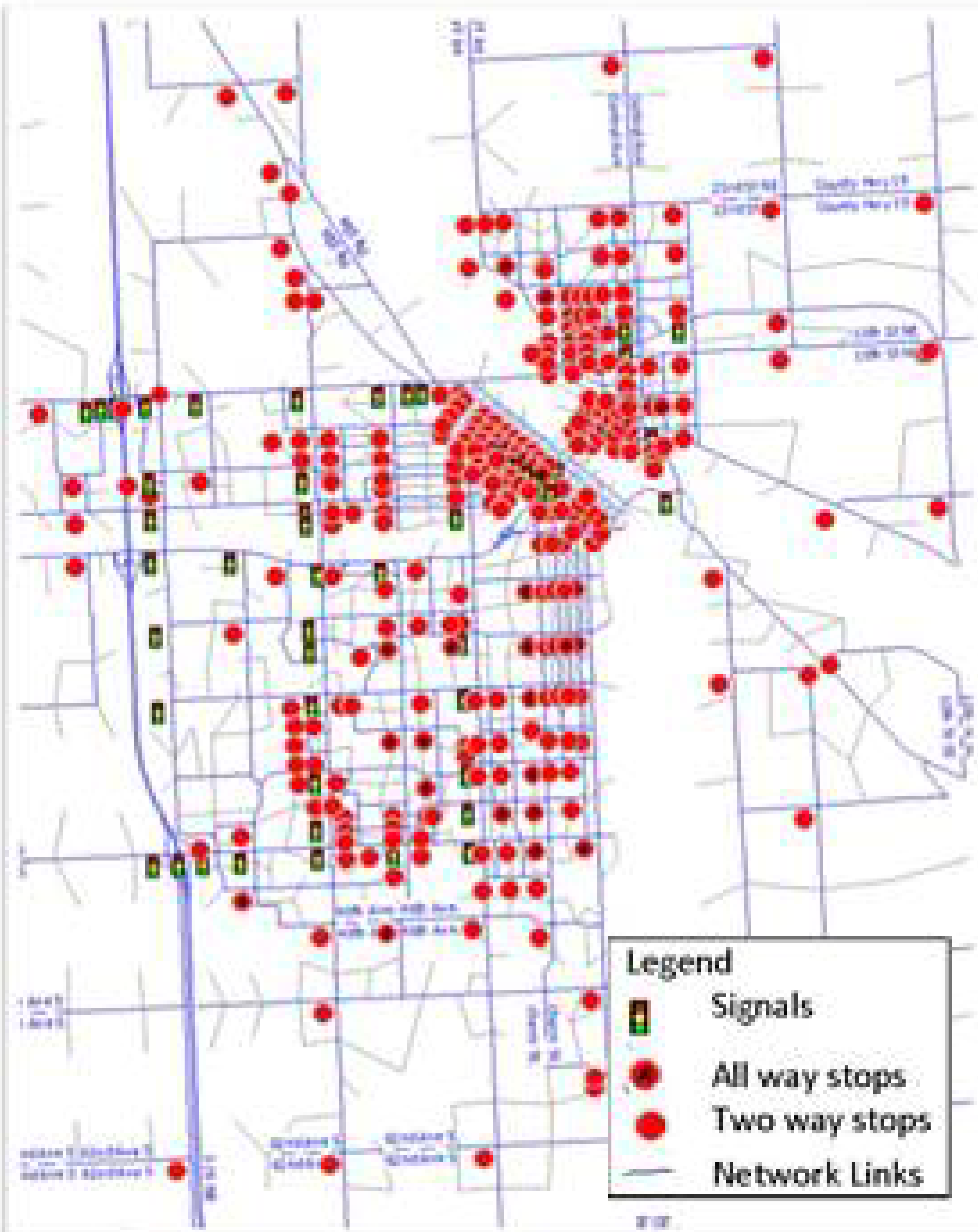

Figure 6.1 Modeled Intersections

7.0 MODEL CALIBRATION AND VALIDATION

Model calibration refers to the adjustment of model input parameters in order to replicate observed real world data for a base year to otherwise produce more reasonable results [6]. It involves adjusting model input parameters such as trip generation rates, node delays, free flow speeds, K factors and friction factors. Figure 7.1 shows the calibration flow chart that was used for the 2010 base year model.

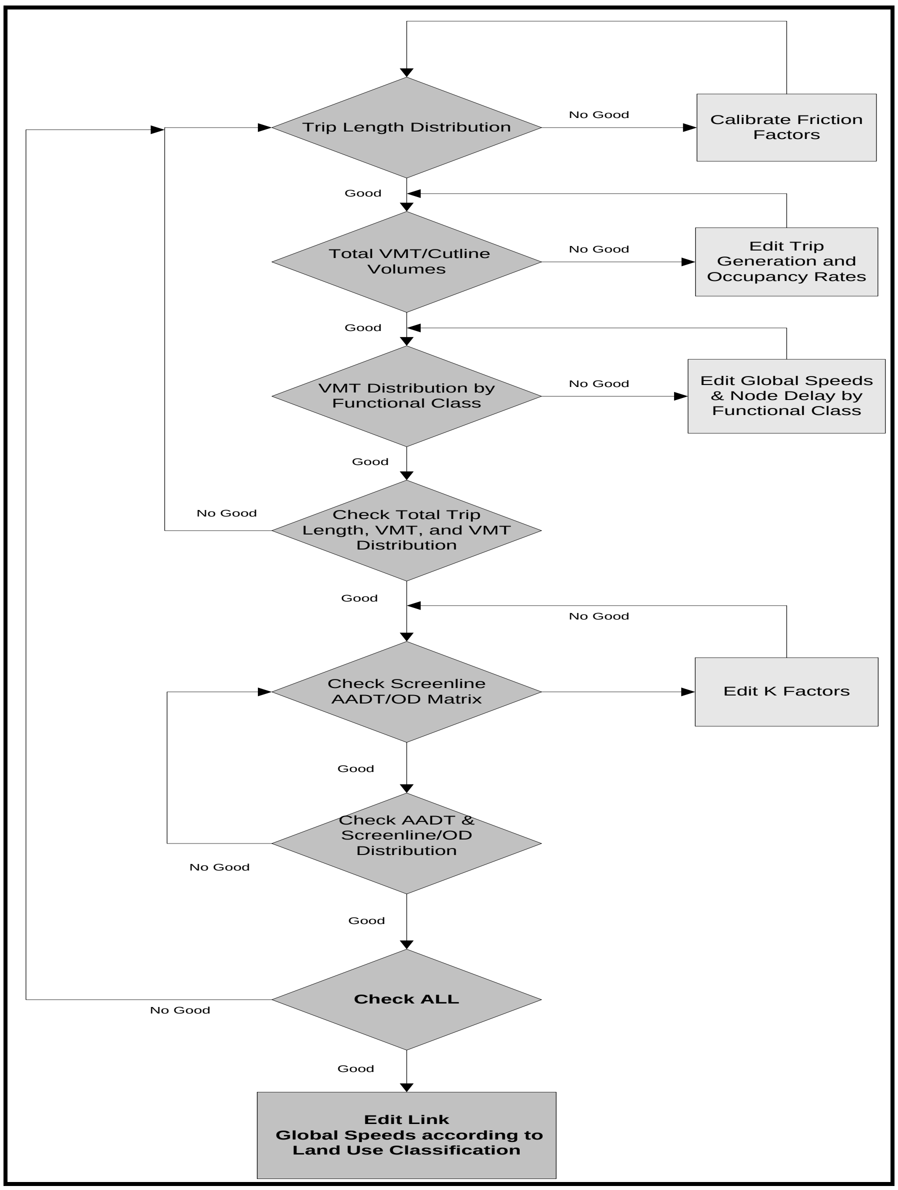

Figure 7.1 Calibration Flow Chart

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 as shown Figure 7.2 from [6]. The next sections describe the different model parameters that were used for model calibration and validation.

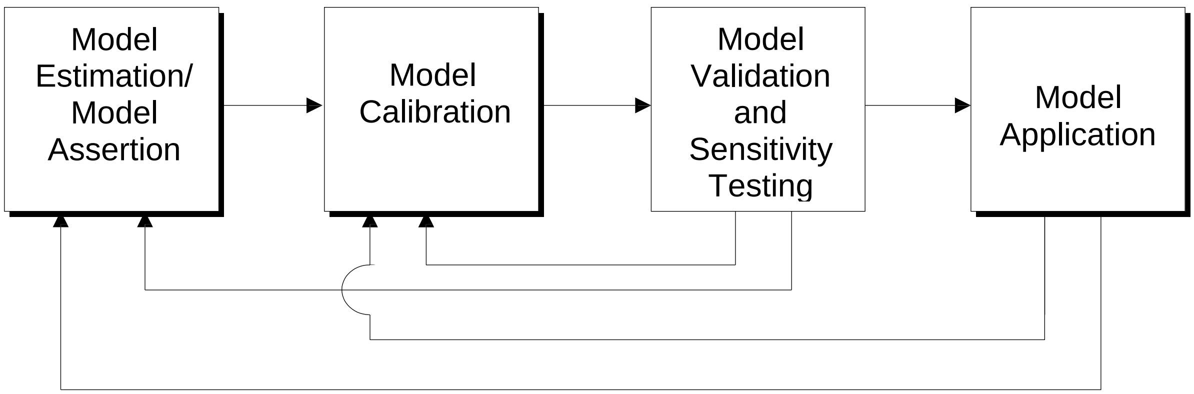

Figure 7.2 Calibration Flow Chart

7.1 Trip Length Distribution

The first step in the calibration process was to check if the modeled vehicle trips lengths were similar to observed trip lengths. Modeled trip lengths were compared to American Community Survey data for HBW trips since it was the only available data.

In general shorter trips tend to occur more frequently compared to longer trips and that was observed in the GF EGF model and can be seen in the figure 7.1. If the model did not represent observed trip length distribution data, friction factors were adjusted until the model replicated as closely as possible this data (Figure 7.3). Average trip lengths were 12.0 minutes, 11.1 minutes and 10.1 minutes for HBW, NHB and HBO trips respectively.

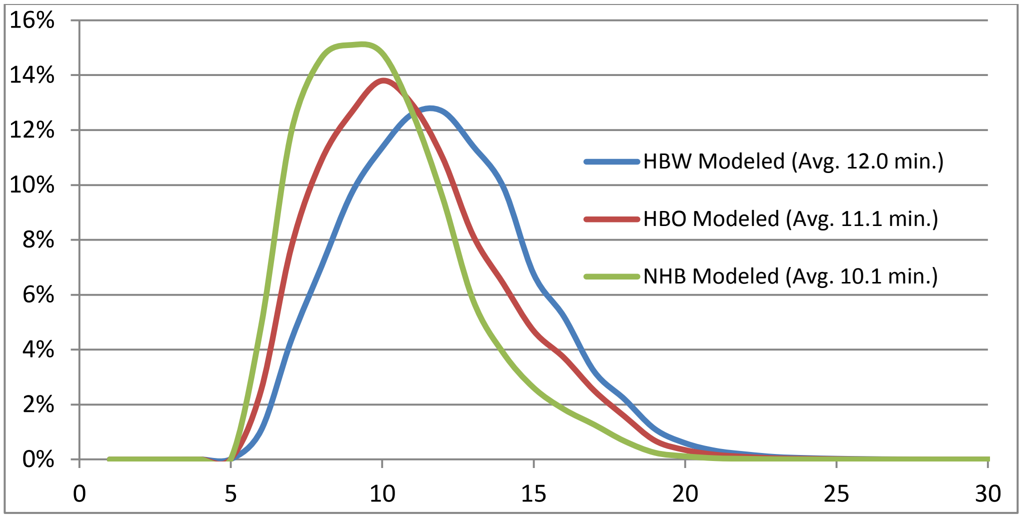

Figure 7.3 Modeled Trip Length Distributions by Trip Purpose

Figure 7.4 shows the comparison of the modeled trip lengths to the observed trip lengths for HBW trips with both having average trip lengths of 12.0 and 12.1 respectively.

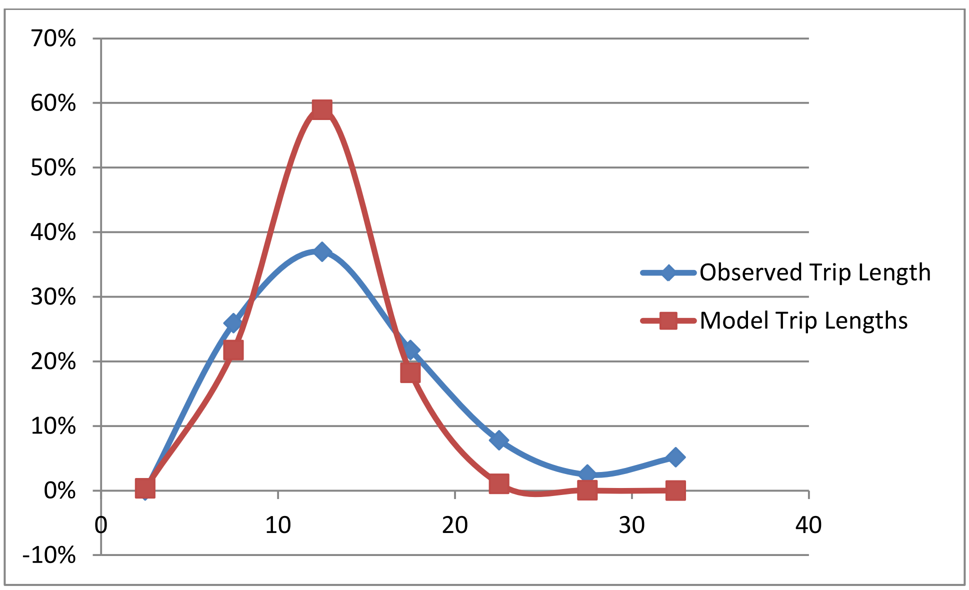

Figure 7.4 Modeled HBW Trip Length Frequency Distributions vs Observed HBW Trip Length

According to the Travel Model Validation and Reasonableness Checking Manual (8), a more rigorous check for validating trip length frequency distributions is calculating the coincidence ratio. Coincidence ratio measures the percent of the area that coincides for two curves i.e. between the observed trip lengths and the modeled trip lengths. Equation 7.1 (8) shows the mathematical formulation for calculating the coincidence ratio. A coincidence ratio of 1 indicates identical distributions and is desirable while coincidence ratios less than 0.5 are weak and undesirable. The coincidence ratio for the model was 0.68 which shows an acceptable coincidence between the modeled and observed trip length frequency distributions.

$$CR = \frac{\sum_T [min(PM_T, PO_T)]}{\sum_T [max(PM_T, PO_T)]} \quad \text{Equation 7.1}$$

Where:

CR = Coincidence Ratio;

PM_T = Proportion of modeled distribution in interval T;

PO_T = Proportion of observed distribution in interval T; and

T = Histogram interval for time, in 5 minutes time bins.

7.2 Total Vehicle miles Traveled (VMT)

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 value were different from the value calculated by multiplying the counted ADTs by length (observed VMTs), ATAC adjusted the trip generation and 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 7.1 provides a summary of the final modeled and reported VMT values by functional class. Collectors and locals roads had the biggest difference between observed and modeled VMTs. Overall, the difference between modeled and observed VMTs of -4 % is low and within the range of generally acceptable differences in VMTs of ±5%.

Table 7.1 VMT Validation Summary by Functional Class

	VMT		**Error**		**Distribution**	
Facility Type	Observed	Estimated	Difference	Percent	Observed	Estimated
INTERSTATE	74,342	70,587	(3,755)	-5%	17%	17%
MAJOR	207,483	198,989	(8,494)	-4%	49%	47%
MINOR	87,035	93,334	6,299	7%	20%	22%
COLLECTOR	44,378	42,755	(1,623)	-4%	10%	10%
LOCAL	13,560	13,780	220	2%	3%	3%
TOTAL	**426,798.00**	**419,445.00**	**(7,353.00)**	**-4%**	**100%**	**100%**

7.3 Screenlines

Screenlines are barriers to travel between two areas in a travel demand model including natural barriers such as rivers, mountains, etc. and man-made barriers such are interstates and major arterials, railroads etc. Five screenlines were used for the model: BNSF railroad, the Red River, 32nd Ave S., Columbia Rd and I-29. Table 7.2 lists the Screenlines that were used in the GF EGF model. Based on Travel Model Validation and Reasonableness Checking Manual the values fall within stated approved limits.

Table 7.1 Screenline Comparisons

Screenline	**Counted Volume**	**Modeled ADT**	**Difference**	**Percent Difference**
BNSF	81,195	78,630	2,565	3%
Red River	43,650	39,960	3,690	8%
S 32nd AVE	27,850	25,000	2,850	10%
Columbia Rd	70,820	66,220	4,600	6%
I-29	44,970	44,760	210	0%

7.4 Comparison of Modeled ADTs with Counted ADTs

A comparison of modeled traffic volumes to observed traffic counts was performed to verify how well the model represented these counts. Table 7.3 shows that 81% of the modeled links met the FHWA criteria for model validation.

Table 7.3 Model Volumes by Traffic Volume Range

Volume Range	Above Criteria	Meets Criteria	Below Criteria	Within Criteria	FHWA Criteria Deviation
AADT>25,000	0	4	0	100%	15%
25,000 to 10,000	2	53	9	83%	20%
10,000 to 5,000	10	47	20	61%	25%
5,000 to 2,500	9	94	3	89%	50%
2,500 to 1,000	13	88	0	87%	100%
AADT<1000	10	58	0	85%	200%
Total	**44**	**344**	**32**	**82%**	

Table 7.4 shows the comparison of the modeled volumes and observed traffic by functional class. The deviation ranged from 79% for local roads to 100% for the freeways.

Volume Range	Above Criteria	Meets Criteria	Below Criteria	Within Criteria
Freeway	0	8	0	100%
Major Arterials	5	69	11	81%
Minor Arterials	16	117	8	83%
Rural Paved	2	18	0	90%
Collector	13	98	12	80%
Local Roads	8	34	1	79%
Total	**44**	**344**	**32**	**82%**

7.5 Root Mean Squared Error and Percent Root Mean Squared Error

Although the comparison between modeled and counted ADTs gives a good indication of the performance of the model, they do not provide a goodness of fit test to the model. 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 7.2.

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

and Equation 7.2

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

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 7.4 shows the %RMSE by volume range. The %RMSE meet typical deviation limits for all the volume ranges shown indicating a good fit between the modeled and observed traffic.

Table 7.4 Model Assignment by Modeled Traffic Volume Range

Volume Range	**RMSE (%)**	**Typical Limits (%)**
AADT>25,000	8%	15-20 %
25,000 to 10,000	15%	25-30 %
10,000 to 5,000	26%	35-45 %
5,000 to 2,500	31%	45-100 %
2,500 to 1,000	78%	45-100 %
AADT<1000	151%	>100 %

7.6 Scatter Plots and R Square of Modeled Versus Observed Volumes

Scatter plots of the modeled traffic volumes against the observed traffic volumes are a good indicator of the model's fit. Figure 7.5 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.

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 0.92 shows a strong linear relationship between modeled and observed traffic counts.

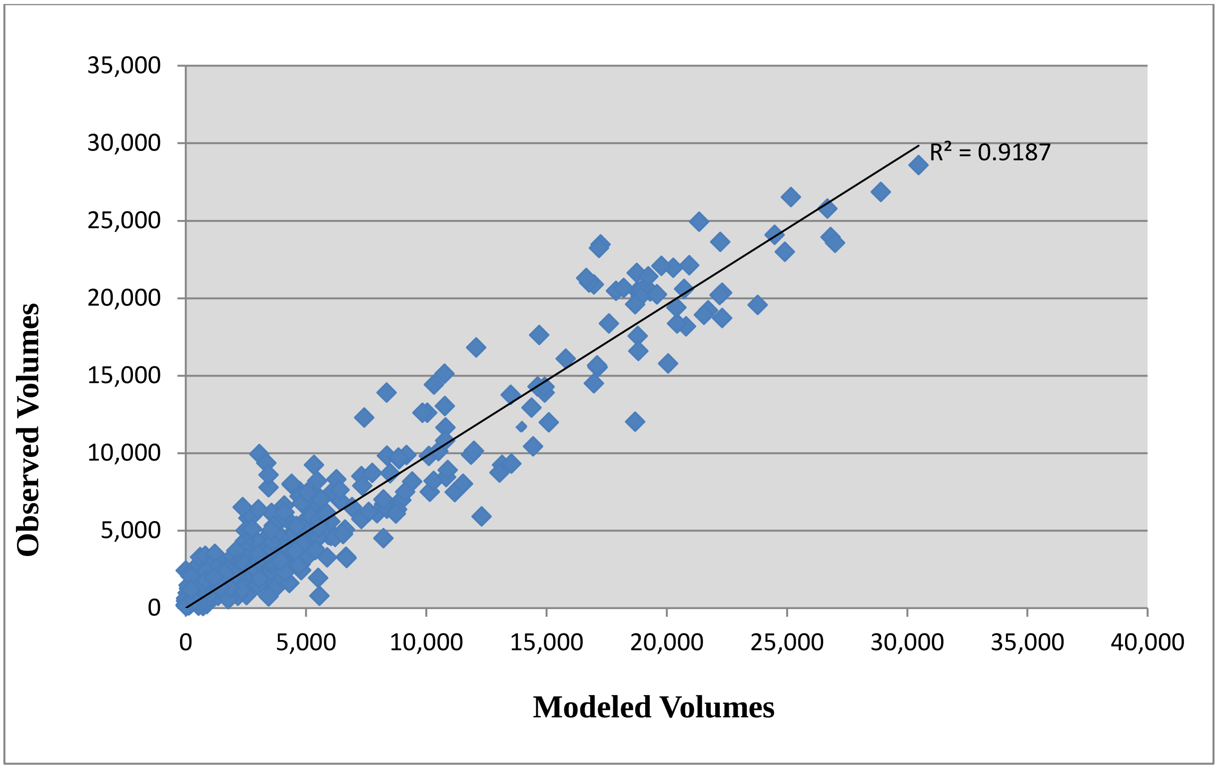

Figure 7.5 Scatterplot of Modeled Versus Observed Traffic Counts

8.0 BIBLIOGRAPHY

1. **SRF Consulting Group., Inc, Accorra Research, Inc.,ArceZmud Research, LLC.** *Fargo-Moorhead Origin-Destination Study.* Fargo : Fargo-Moorhead Metropolitan Council of Governments, 2012.
2. **Transportation Research Board of the National Academies.** *NCHRP Report 716 Travel Demand Forecasting: Parameters and Techniques.* Washington, D.C. : National Cooperative Highway Research Program, 2012.
3. **Adminstration, Federal Highway.** *Travel Model Validation and Resonableness Checking Manual .* September 2010.
4. **Transportation, North Dakota Department of.** *2010 Traffic Report.* s.l. : Planning and Asset Mangement Division, 2011.
5. **Cambridge Systematics, Inc.** *Travel Model Validation and Reasonableness Checking Manual Second Edition.* Cambridge, MA : Federal Highway Administration, 2010.
6. **Institute of Transportation Engineers.** *Trip Generation, 8th Edition, Users Guide.* Washington, D.C. : ITE, 2008.
7. **URS Transportatoin.** *Watertown, South Dakota Transportation Plan, Existing Conditions Report.* Watertown, SD : s.n., 2005.
8. **U.S Census Bureau.** Means of Transprotation to work by selected Charateristics, 2008-2010 American Community Survey 3-year estimates. [Online] 2010. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_3YR_S0802&prodType=table.
9. **University of Florida, Transportation Research Center,Transportation Research Center.** *Investigation of Freeway Capacity:a) Effect of Auxiliary Lanes on Freeway Segment Volume Throughput, and b) Freeway Segment Capacity Estimation for Florida Freeways.* s.l. : THE FLORIDA DEPARTMENT OF TRANSPORTATION , March 2010.
10. **Transportation Research Board.** *HCM 2010 Highway Capacity Manual.* Washington, DC : National Academy of Sciences, 2010.
12. **Heinz, Speiss.** *Conical Volume Delay Functions.* Transportation Research Center, University of Montreal. Montreal, Canada : Transportation Research Center, University of Montreal, 1989.
13. **Pedersen, N J and Samdahl, D R.** *NCHRP 255: HIGHWAY TRAFFIC DATA FOR URBANIZED AREA PROJECT PLANNING AND DESIGN.* Alexandria, VA : Transportaion Research Board, 1982.